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DEVELOPING CREATIVITY SKILLS FOR ENGINEERING PROBLEM-SOLVING AND DESIGN THROUGH PURPOSEFUL INSTRUCTION IN THE UNDERGRADUATE CURRICULUM: THEORY AND PRACTICE

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ABSTRACT

This research project demonstrates the feasibility of teaching creativity in an explicit fashion within a freshman-level engineering course. The results that can be achieved in developing students' creative abilities by using specific teaching methods are reported, along with suggestions for further research on creativity teaching. The course unit developed for this project was based on a theoretical framework that was derived from published literature. This paper describes the theoretical framework, the nature of the course unit, and the evaluation of the effect of the unit on the students' creativity in an engineering context. The data collected gives strong evidence that the students' creative abilities were positively affected as a result of their participation in the course unit. It also suggests that the critical need which currently exists for explicit treatment of creativity in the engineering curriculum could be addressed through activity-based course units. The results from this research indicate that more experimentation should be done to develop effective creativity teaching techniques that can be integrated into undergraduate engineering curricula.

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INTRODUCTION

In 1955, the Grinter report's recommendations concerning engineering education triggered a national effort to increase engineering students' exposure to basic science and engineering science coursework. The report's recommendation that steps also be taken to teach engineering design, "...to stimulate creative and imaginative thinking..." (Evans *et al.* 1990, 518) was largely ignored.

Creativity in engineering is something that is desired by professionals, but it is rarely explicitly encouraged in undergraduate engineering courses. Engineers agree that creativity plays an important role in engineering problem-solving, but few undergraduate engineering programs today teach specific problem-solving strategies that exploit creative talents. Engineering students are given many problems that reinforce their analytical skills, but few, if any, that demand the application of creative abilities. Many educators fail to realize that typical engineering problem exercises do not simultaneously encourage both types of skill.

Some creativity courses have been developed to reduce students' inhibitions and so promote creative behavior. These courses, however, fail to teach specific strategies that can be employed during problem-solving activities to generate creative ideas. The goal of the research project described here was to develop a course unit that would achieve three objectives: introduce a body of knowledge about creativity principles and factors that affect creative behavior, provide practice for students in exercising their creative skills through structured activities, and evaluate the development of students' creative abilities as result of their participation in the course unit.

Some of the earlier literature reviewed during the preparation for this research project described creativity courses developed for engineering curricula some 40 years ago. It seems that efforts to maintain and enhance such courses were not continued, for few courses of this type remain in existence today. Now, more is known about the factors that influence the development of individual creativity skills as well as organizational factors that promote or inhibit creative activity. Both bodies of new knowledge could be incorporated into a modern creativity course unit to build on the work that was discontinued.

In the past, efforts to develop creative skills in engineering have been restricted to isolated courses at a few institutions. It is now time for a concerted effort to integrate creativity teaching into engineering curricula in a broader sense. The research described here demonstrates how creativity could be taught explicitly. This work goes beyond pure research; it is prescriptive as well as descriptive. In that sense, it achieves the primary objective of engineering: to apply principles discovered through scientific research to meet the needs of society. It is hoped that this work will inspire other research efforts in the field of creativity for engineering.

Chapter 1
LITERATURE REVIEW

1.1. Overview

Engineering educators are becoming increasingly interested in encouraging creativity in their students, as creativity and technical innovation are perceived as essential to competing successfully in the global marketplace. Although they generally agree on the importance of creativity in engineering, many engineering professionals and educators consider creativity to be a mysterious human ability, a talent with which a person must be born -- not a skill that can be developed. It was this type of thinking that inhibited early efforts to develop a component of the engineering curriculum that would focus on deliberately developing engineering students' creative abilities. Creativity training courses were established during the late 1950's and early 1960's, but following this period of initial activity, efforts in the area died down. Recently there has been renewed interest in teaching students how to synthesize ideas. These new efforts have grown within a movement to teach design in the undergraduate curriculum. Innovative design and invention do require the use of creative skills, but explicit techniques for creativity are not being taught as part of this modern movement. Design exercises that are being created are more akin to "engineering" as defined by Olken: an analytical process of proportioning component elements of an idea to suit specification requirements (Olken 1964, 153). The time is ripe to resurrect, and build upon, the works from the early efforts to teach creativity skills within the engineering curriculum. Renewed efforts of this type would better prepare modern engineering graduates with the mental tools to synthesize innovative solutions to the engineering challenges of the present and the future. This chapter will examine works taken from a variety of sources. Individually, they represent many different perspectives on creativity, but together they constitute a foundation upon which the study and teaching of creativity in engineering problem-solving and design can be based.

1.2. Published Antecedents

Since creativity is such a broad, interdisciplinary topic, published literature plays an important role in facilitating the exchange of knowledge between professional groups who might otherwise not come in contact with one another to discuss key issues. In the case of creativity in engineering, not only disciplines, but generations, separate some of the leading figures from contemporary engineering educators.

1.2.1. Structure of the Literature

Many educators and professionals outside the engineering community are also interested in encouraging creativity in their students. As result, many discoveries and theories concerning creativity come from non-engineering sources. It is important to consider the input from these sources even though focusing specifically on creativity in engineering problem-solving and design. Of all people, those who are concerned with creative processes will best appreciate that ideas can come from many unusual and unexpected directions, and so no possible source should be left out as a potential source of inspiration.

There are three main categories in the literature reviewed for this paper:

1. Articles on Learning Theory
2. Articles on Creativity Theory
3. Articles on Engineering Education

The articles are written by education specialists, psychologists, engineering faculty and professional engineers. While creativity has maintained a fairly constant presence in the literature of the first two categories, it has had an interrupted history in articles related to Engineering Education. Creativity was a prevalent topic in the engineering education literature during the late 1950's and the 1960's when creative thinking strategies and training courses were widely discussed. Creativity then seemed to hibernate until the early 1980's. The reappearance came as design was proposed as a means of encouraging creativity -- gone was the talk, though, of explicitly teaching creativity techniques.

During the earlier period of creativity discussion, engineering educators were examining the undergraduate curriculum with an eye towards its reform. Many of the same concerns are again being expressed in the current reform movement in the U.S., although design has now replaced creativity as a focal topic. Because of this similarity between the two situations, many of the writings from the first period can be applied to a discussion of the current situation. For this reason, this paper uses literature from the 1960's period, without discrimination, alongside contemporary writings.

An additional distinction exists beyond the three categories. Some engineering education articles are taken from European journals. These articles tend to incorporate pedagogical aspects of learning theory with discussions of engineering education issues to a greater degree than U.S. publications. The European articles therefore help unify the discussion of educational and engineering issues.

1.2.2. Perspectives on Creativity

One significant issue that has gone unresolved is a problem of semantics. It appears that no universal set of definitions has been established by scholars writing on the topic of creativity. This may be in part due to the varied backgrounds of those contributing in this area. Terms like innovation, creative problem-solving, inventive thinking, and engineering design seem to be used interchangeably by different authors. Creativity itself seems to have multiple meanings. A small cross-section of definitions is presented in Table 1.

Authors have defined creativity using many different combinations of the following attributes:

1. Newness to the creator
2. Novelty and/or originality
3. Value and/or usefulness to society
4. Achievement of some goal
5. Improvement of a traditional idea

Some feel that creativity involves communicating an idea to an audience and implementing it successfully, while others contend that synthesis of the idea or concept is a sufficient end to constitute creativity. Bogue noted that the lack of a standard

Table 1. A Selection of Definitions for Creativity

Author	Definition for Creativity
Mathews & Bailey	...the achievement of a combination of elements that is new as far as the creator is concerned (Mathews and Bailey 1965, 85)
Koestler	The combination of previously unrelated structures in such a way that you get more out of the emergent whole than you put in (Adams 1976, 35)
Weisner	An activity that makes "contributions to the intellectual sphere of human experience that have novelty and value" (Whitman, 1983, 9)
Whiting	The process through which the mind produces new and useful ideas (Whiting 1958, 1)
Arnold	Mental process in which past experience is combined and recombined in such a fashion that one comes up with new arrangements, that better solve some need of mankind (Whiting 1958, 2)

set of definitions has hobbled efforts to develop creative problem-solving programs since investigation findings are not always transferable (Whitman 1983, 12). Definitions will have to be established and accepted by scholars if research advances are to be made and successfully implemented in an efficient manner.

1.3. Curriculum Development Considerations

In order to appreciate the role of creativity in the curriculum, it is important to develop an appreciation for the challenges currently facing engineering educators as they engage in curriculum reform. Such a perspective provides a basis for planning the integration of creativity training in engineering education.

1.3.1. The Nature of Student Problem-Solving

The engineering curriculum has a two-fold objective:

1. to teach students fundamental scientific principles and basic engineering analysis techniques
2. to teach a systematic approach to engineering problem-solving

Cowan pointed out the American Society for Engineering Education's stated commitment to these objectives in its report of 1968. He noted, however, that the report did not amplify what it called the "engineering method" (Cowan 1981, 744). This reference to the "engineering method" of problem-solving, and the subsequent avoidance of details about it, draws attention to a significant problem that has since continued to plague engineering education. Although the importance of teaching a systematic approach to problem-solving has been recognized, the traditional undergraduate engineering curriculum has evolved without provision for presenting optimal creative problem-solving strategies and techniques.

Scientific principles are easily identified and likewise taught within typical undergraduate engineering programs, but optimal strategies for approaching problems are usually not taught in an explicit manner. The problem presented by the need for creativity teaching and the simultaneous lack of provision for such teaching has gone unresolved for many years. Meanwhile, engineering educators have become accustomed to using textbook exercises to assign problems that apply to their course content. This practice has been perceived to prepare students to solve problems after graduation, but in reality the exercises do not reflect the challenges faced by engineering professionals when they engage in industrial problem-solving activities. The problems that engineering students face in their courses are not as open-ended as realistic industrial problems. Typical textbook problems give all necessary information without requiring the student to determine what information is necessary. These types of problems also emphasize numerical processing alone rather than qualitative decision-making and the synthesis of physical systems overcome technological challenges. Engineering curricula have evolved in such a way as to support the solving of the more narrowly-defined type of problem. As result, engineering students are often sent into the world of industry with incomplete preparation for realistic problem-solving activities.

1.3.2. Training Technicians vs. Engineers

With engineering advances increasing the amount of available technical knowledge on a daily basis, engineering educators have been continually faced with the formidable task of carefully selecting the limited amount of subject matter to present to students. This information is used to communicate fundamental principles that an engineer must understand and be able to apply. Unfortunately, the result of the rush to find room in the curriculum to accommodate increasing amounts of technical knowledge has resulted in the loss of courses that teach methods for applying technical knowledge to generate solutions to realistic engineering problems. Bugliarello warns against letting the nature of the curriculum be dictated by the "...need to give rapid coverage to increasingly extensive and analytical subject matter" (Bugliarello 1969, 880). Although technical knowledge is important, engineering professionals recognize that the learning of technical concepts usually extends into the engineer's professional career as technologies change, regardless of the amount of knowledge to which the engineer was exposed as a student. It has become accepted that a four-year degree in engineering will impart an incomplete amount of technical knowledge to students -- engineers typically must engage in a continual learning process as technologies change. As result, the law of diminishing returns will begin to apply if factual knowledge is taught increasingly at the expense of an emphasis on process. Even a small amount of additional time spent on teaching process approaches could yield significant advantages. Several authors have noted the danger of an overemphasis on teaching fundamentals of current technology to engineering students. While such an approach, they contend, could prepare engineers to address current technological problems, it could also inhibit the development of creative thought processes that could lead to new technologies for the future (Evans *et al.* 1990, 521; Mathews and Bailey 1965, 85; Whiting 1958, 21). Gardner felt that instead of serving as a knowledge base, the practice of exclusively reviewing previous innovations, without providing balance with fresh innovation activities for students, could discourage innovative thought (Mathews and Bailey 1965, 85). These arguments stress the importance of teaching generalized skills and thinking strategies to engineering students.

Some might feel that students are trained to solve engineering problems in the traditional undergraduate curriculum. These advocates base their views on the fact that engineering students engage in problem-solving in virtually all of their engineering courses. One must take a closer look, though, to consider whether the traditional problem-solving exercises prepare students for realistic engineering problem-solving. The typical problems assigned in undergraduate engineering courses require the student to use mathematics to correctly model a physical situation, and then work through calculations to arrive at either a final numerical answer or a single mathematical formula describing the behavior of the physical system. In either case, the student is presented with a well-defined problem for which there is one correct solution that the student must work towards. The one-problem/one-solution arrangement for problem exercises has been criticized as promoting convergent thinking -- the tendency to converge on a single answer, often without considering alternatives -- and thus inhibiting the development of creative thinking skills among students (Duck 1985, 131; Mathews and Bailey 1965, 85). The effect of this narrow type of problem-solving preparation was described by McMasters and Ford as training engineering science technicians rather than educating engineers (McMasters and Ford 1990, 528). This analogy makes a good point. Just as a technician uses a technical manual or personal experience to troubleshoot maintenance problems for an existing system, traditional engineering curricula prepare students to use current technological concepts to solve problems. An engineer needs to be able to step beyond the bounds of present technology, and the undergraduate engineering curriculum needs to be designed to prepare students for this type of challenge to their creative abilities.

1.3.3. Lack of Creativity Training in Engineering Curricula

In preparing students to meet the challenge of open-ended engineering problems, one of the key topics that must be addressed is that of creativity. The generation of multiple possible solutions is a crucial component of successful engineering problem-solving, and it requires creativity on the part of the engineer. Many engineering educators have noted the omission of creativity training in the engineering curriculum. Olken's observation, originally made in the 1960's, seems to still hold: engineering students often graduate with less creative ability than when they began their engineering studies, either because they have not been asked to exercise creativity, or because the skills have been "retarded by an overemphasis on the opposite faculty of analysis," (Olken 1964, 156). Berger echoed the sentiment in a more recent article, stating that there is not enough creativity training given in the traditional engineering curriculum (Berger 1989, 168). If one considers the hiatus between the publications of the articles, it is evident that the lack of creativity training has either been a persistent problem over the intervening years or it has reappeared in a cyclic fashion. The omission of such training in the undergraduate preparation of engineers has been viewed by many authors as a significant problem. They recognize that creative engineering is needed to maintain the pace of technological advancement, and thus a competitive technological edge in the world marketplace (Berger 1989, 169; Bugliarello 1969, 877).

1.3.4. Towards a Balanced Curriculum

Fordyce discussed a three-part model, illustrated in Figure 1, for an ideal engineering curriculum (Fordyce 1988, 289). This model can be used to discuss the overemphasis that has been placed on on area of the engineering curriculum at the expense of two other important components. Engineering curricula today focus primarily on the "subject knowledge and understanding" portion of the model. Although at first glance traditional problem-solving exercises might appear to satisfy the "engineering skills development" aspect of the curriculum,

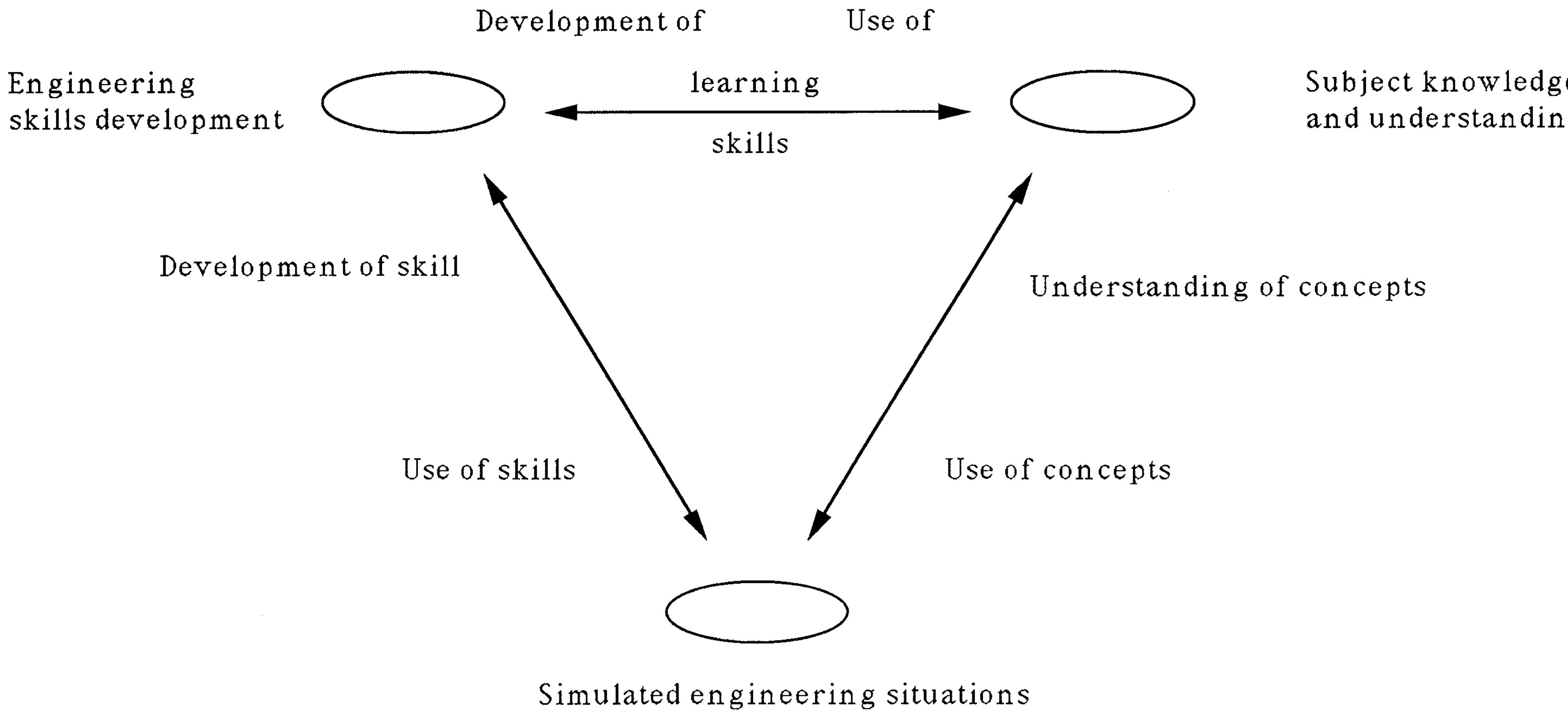

Figure 1. -- Fordyce's Three-Part Model for an Engineering Curriculum

the well-defined nature of typical problems has already been shown to limit their relevance to actual engineering problem-solving activities. Cowan showed that the quantitative nature of typical problem-solving exercises does not adequately develop engineering students' analytical skills (Cowan 1986, 71).

Whitman noted that problem solving can be used to achieve three distinct ends:

> 1. Help teach a subject,
> 2. Teach general skills,
> 3. Teach specific skills
>
> (Whitman 1983, 10)

The typical classroom problems examined by Cowan and prevalent in traditional curricula do address the first and third objectives to a certain degree, but do not fulfill the second objective. Problem-solving exercises common in the traditional curriculum can be designated as instructional tools for teaching engineering concepts and analysis techniques, for they require students to apply knowledge at a fundamental level, but do not teach advanced engineering skills such as creativity and judgement. Traditional problem-solving exercises therefore should be associated with the "subject knowledge and understanding" branch of the curriculum model, along with teaching of technical information.

Recently, engineering educators in the United States have begun introducing design projects as a vehicle for improving student's understanding of engineering science concepts while giving students experience engaging in realistic engineering activities in a supervised setting. This initiative came in response to a growing concern among engineering professionals and educators that was verbalized at a National Science Foundation (NSF) workshop on design. At that meeting, the general consensus of the participants was that design education in the United States is woefully inadequate for industrial needs. The movement to increase the amount of design experience that students receive is a beginning step towards strengthening the commitment to the "realistic engineering experience" element of Fordyce's curriculum model. As Cowan asserted, though, using projects in an existing class is not the same as executing a project-oriented class (Cowan 1980, 246). The context in which such design activities are introduced to students will affect the learning outcome that results from them. Design experiences will have to be integrated effectively into the overall curriculum structure to ensure their success.

Educators at the University of Strathclyde encountered evidence of the interdependence of two of the three branches in the curriculum model. They observed that their traditional course structure was producing "designers capable of working within a narrow, well-defined field with a set of limited constraints" (Ion and McCracken 1989, 195). The faculty recognized that students were inadequately equipped to deal with the realistic, open-ended type of design problem that is typical in actual engineering practice. The difficulty was that students had not been exposed to a cohesive design philosophy or a model describing the interaction of engineers from various disciplines during a design project. As result, the students did not have sufficient knowledge of design strategies or a repertoire of skills from which they could attack open-ended problems. The University of Strathclyde's situation highlights the importance of teaching principles of design to students before requiring them to practice design. In a broader sense, it illustrates the dependence of design activities on the "subject knowledge and understanding" element of the curriculum model. Subject knowledge portion of the curriculum must support design experiences, while it simultaneously benefits as a result of design project experience.

It is similarly true that the "subject knowledge and understanding" and "realistic engineering experience" branches of the model are interdependent on the "development of engineering skills" branch. Skills such as idea synthesis, design evaluation, and technical communication require technical knowledge; they also provide an application context for students that will motivate learning of technical concepts. Likewise, design experiences test students' engineering skills, and the skills supplement the design experience. The University of Strathclyde faculty recognized the need for the development of engineering skills relevant to design, and they responded by modifying their program's course structure so that students would develop relevant skills throughout their undergraduate program (Ion and McCracken 1989). The faculty's response is a part of the growing movement in the United Kingdom to actively develop students' skills in applying their engineering knowledge to professional tasks during their formal engineering experience, rather than leaving the students to acquire the skills haphazardly as result of industrial experience following graduation (Fordyce 1988, 283). In a recent conference, the American Society for Engineering Education (ASEE) appeared to embrace this approach to engineering skills development pertaining to design. One outcome of the conference was a recommendation that the ASEE promote the development of courses in design methodology which would provide a basis for the enhancement of design skills (Evans *et al.* 1990, 520).

1.3.5. Creativity and Design Education

The movement to increase the emphasis placed on design education is aimed at enhancing the creative abilities of student engineers. As the Ver Planck report noted, "In distinction to a purely analytical problem, a problem in design leaves wide latitude for the play of creative imagination..." (Evans *et al.* 1990, 518). A National Research Council (NRC) report from 1985 emphasized the need to prepare students to face problem situations whose details might pose unfamiliar challenges to the students (Evans *et al.* 1990, 520). The ABET-sponsored National Congress of Engineering Education (NC2E) report of 1986 observed that,

> ABET should continue...intensifying effort if possible, on the design, innovation, and creativity requirements... quality of the design experience is more important than the quantity. (Evans *et al.* 1990, 520)

These reports emphasize the desirability of developing creative abilities through design experiences. Engineering educators must be careful, though, as the NC2E report suggests, that the quality of the experiences be controlled so that creative abilities are developed as an outcome of the activities. McNeill *et al.* cautioned that the redirection from information-based orientation to a problem-solving strategy focus will require new approaches to instruction, and that as result faculty will need to be well-versed in the nature of the design process (McNeill *et al.* 1990, 551). This will also mean familiarity with principles relating to creativity.

1.3.6. Creativity and Traditional Instruction

Whitman, in his review of creativity teaching at the college level, noted that courses that teach specific skills within a professional training program do not usually consider creativity skills explicitly (Whitman 1983, 12). He attributed this trend to the fact that creativity training courses have been stigmatized as superfluous for serious professional preparation programs. Whiting observed that creativity has in the past been presented as a panacea to the problems of engineering education (Whiting 1958, 141). This type of reckless overenthusiasm for the benefits of creativity training has contributed to the image problems it suffers in comparison to more traditional and well-established subjects such as mathematics and physics. Another reason for the lack of development in the area of creativity training could be the perceived difficulty in implementing a course that would improve students' creative abilities, both because of the nature of the activities and the type of instructional guidance that would be required. The purpose of creativity training should not be to supplant traditional learning, but rather to complement it.

Olken predicted in the 1960's that technological advances were going to require engineers to have more sophisticated analytical abilities in order to creatively manipulate technologies. He also noted, however, that in order to maintain the balance between analytical and creative ability, "...the future need for creativity training of engineers will therefore far outrun the measures being developed for providing it" (Olken 1964, 160). In the years since he made this observation, analysis training has indeed attempted to keep pace with technology, but creativity training has meanwhile been neglected. Whitman noted that those courses that do attempt to foster the development of creativity skills tend to focus on the products of creative thought, with the premise that students can improve their creative abilities by building a repertoire of first-hand creative experiences (Whitman 1983, 12). This approach, though, neglects the teaching of generalized heuristics for creative problem-solving. There still exists a strong need for the development of skill-based creativity training programs within engineering curricula.

Cowan echoed the need for "...deliberate planning and operation of a carefully planned and effective training program..." to ensure the development of skills which are the component abilities of a genuinely creative designer (Cowan 1981, 743). Olken likewise supported the establishment of a new breed of courses that will stimulate creative thought processes by promoting "idea-compounding mental activities," or, in other words, those activities that involve synthesizing individual concepts to form a new compound concept whose value is greater than that of the sum of the individual concepts

(Olken 1964, 156). Rutherford and Rowe felt that this type of training was necessary in preparing students to, "...produce new inventions and discoveries..." (Rutherford and Rowe 1987, 377). Clearly, there is a strong desire among some engineering faculty to integrate explicit creativity training into the undergraduate engineering curriculum. Such training would need to be introduced in the context of its role in engineering problem-solving, and it would require purposeful planning and execution by faculty.

1.4. Creativity Teaching

The introduction of creativity training as an educational objective in undergraduate engineering programs would affect several aspects of the traditional teaching environment. Teaching methods in existing courses might require modification, and methods employed for new creativity-training courses would depart from the traditional lecturing technique.

1.4.1. Developing Synthesis Skills

> ...Synthesizing ability is the last to develop and the first to be inhibited or destroyed...synthesizing abilities must also be explored, explained, and exercised.... (Evans *et al.* 1990, 518)

Creating ideas -- synthesizing them -- is a fundamental process in creative engineering design and invention. Students enter the engineering curriculum with some degree of synthesizing ability. Given the opportunity, students could polish their rough skills and later channel their talents to help them develop successful engineering designs. The Ver Planck report stated that exercises in synthesis and design facilitate the intellectual development of engineering students (Evans *et al.* 1990, 518).

Problem-solving in traditional courses is evaluated on the basis of product of thinking (Fordyce 1988, 285; Whitman 1983, 11), rather than the process of thinking. Arnold termed the traditional type of problem "analytical" and noted that such problems, which allow only a single correct answer, are stressed in the educational system (Whiting 1958, 15). The emphasis on well-defined, quantitative problem exercises in undergraduate engineering education has spawned the development of cognitive habits that do not promote creative solutions. Adams discussed the behavior that this type of exposure reinforces: people try to avoid problem situations by immediately pursuing the first possible solution to a problem rather than spending time and mental effort to consider alternate solutions (Adams 1976, 7). As a result of this first-answer orientation, students rarely attempt to generate multiple answers, and so they tend to cut off their mental efforts before considering creative solutions. Because analytical-type problems are stressed throughout the curriculum, students may not even realize that their problem-solving efforts are incomplete.

Arnold identified a second type of problem, a creative problem, for which several possible solutions exist (Whiting 1958, 15). This type of problem-solving exercise would be more open-ended, and so the process of thinking, rather than the product, would provide a basis for evaluation. The process of conceptualization -- that is, forming new ideas -- could be stressed. Unfortunately, as Adams observed, although the conceptualization of ideas should be treated as a major activity in problem-solving situations, it rarely is (Adams 1976, 7). Course emphasis needs to be shifted to promote creative mental activity. This suggests the need for an increased emphasis on process-oriented teaching approaches in engineering. Evaluation techniques need to move away from the philosophy of appraising performance based on some ideal standard, which one-correct-answer types of problem support, for such a philosophy will condition students to mimic past thought paths rather than create new ones of their own.

1.4.2. Process-Oriented Teaching in Engineering

Koen contended that engineers, and the various engineering disciplines, share the bond of a common "engineering method, or design process..." (McMasters and Ford 1990, 527). This process seems to refer to a systematic approach to problem-solving that is characteristic of the engineering profession. Engineering faculty members are not alone in calling for a process-oriented approach to teaching in engineering education. Students enrolled in a freshman engineering course indicated on a survey that the most desirable content item for the course was an introduction to the engineering method of problem-solving (Beakley and Price 1968, 829). In a larger sample size of engineering students, student critiques recognized the value of a general approach to problem-solving (Mathews and Bailey 1965, 88). These demands are not impractical suggestions. Engineering courses that highlight the process of engineering discovery have been developed, and they demonstrate the possibilities of a new approach (Ion and McCracken 1989, 197).

1.4.3. Instructional Considerations

A focus on process-oriented teaching and synthesis skills would require modification of several aspects of instruction in the undergraduate engineering curriculum. The nature of student involvement, teaching methods and evaluation techniques would have to be adapted to accommodate the development of creative skills. In order to determine how these aspects might change, it is instructive to consider educational methods recommended for teaching higher-order thinking skills. Perkins asserted that creative abilities, "...can be understood as exceptional versions of familiar mental operations, such as remembering, understanding, and recognizing" (Whitman 1983, 13). The basic mental processes are used to synthesize new ideas, synthesis being the second-highest level thinking skill in Bloom's taxonomy of cognitive skills (Cowan 1986, 72).

Cowan set out a list of considerations for teaching courses that encourage high-level thinking skills (Cowan 1981, 747). The most important of these considerations is that students be given the opportunity to learn the processes involved through practice and reflection. This type of exercise would encourage students to consciously examine their own thinking strategies. The role of the teacher in this recommended educational environment becomes different from that of the lecturer. In Cowan's view, the teacher is responsible for devising appropriate activities for the students that will support a "do it, review it, do it again" style of learning. The activities must be process-oriented, open-ended, and relevant to the engineering profession (Cowan 1981, 748). Fordyce also advocated non-knowledge-based strategies to complement traditional educational techniques, and in this context he defined the teacher's role as that of a facilitator, or coach, to students as they participate in experiential learning activities (Fordyce 1988, 284).

New types of activities and the shift in the teacher's role would require reinforcement through a new emphasis in evaluation methods. Duck extolled the importance of grading methods that emphasize process as well as factual information if instructors wish to encourage higher-order thinking among students (Duck 1985, 132). A process orientation would also need to eliminate "hidden agendas" such as preferred examples that might influence grading decisions. Standards for evaluation of the process -- for example, completeness, orderly progression through process, and clarity of expression -- would become the new foundation for grading.

A major concern among engineering educators might focus on students, specifically whether or not undergraduates will be able to successfully -- and perhaps willingly -- meet the challenges of a classroom environment that is designed to develop high-level thinking skills. There is evidence that such concerns may not present a significant problem. McNeill *et al.* reported that first-year students who were exposed to open-ended design problems responded positively when asked if they enjoyed that aspect of the course (McNeill *et al.* 1990, 552). Apart from the motivational aspect, the same authors also reported that the exposure to open-ended problem-solving experiences seemed to improve the students' ability to tackle open-ended design projects in later, higher-level engineering courses (McNeill *et al.* 1990, 553).

1.5. Summary Analysis of Literature

The study of creativity in the field of engineering requires a multi-disciplinary perspective. Although creativity has been discussed in connection with engineering for over 30 years, the field is still young in terms of how it has influenced the development of teaching strategies and curriculum components. There has been little study of activity based, skills-oriented courses specifically targeting the development of creative abilities, yet this seems to be what is required in order to meet the needs of the contemporary undergraduate engineering curriculum. Such courses need to be developed to serve as test-beds for new teaching techniques that will promote creative skills in an engineering context. Until data on such experiments can be collected and analyzed, engineering educators shall have to base their initial course plans on recommendations growing out of research in the areas of process-oriented teaching and open-ended problem-solving/design activities in educational settings. The initial theoretical framework for the future study of creativity in an engineering context should likewise be based on the foundation already existing in the literature.

Chapter 2
THEORETICAL BACKGROUND

2.1. Overview

Some take a behavioral view of creativity, contending that external stimuli and other environmental factors determine an individual's level of creative ability. Others believe that creativity is a purely cognitive process. These two views on the fundamental nature of creativity lie at the heart of one of the unresolved issues that have plagued research on creativity within the field of engineering education. This chapter will weave together a comprehensive theoretical framework for the study of creativity and related mental activities, drawing material from theories that concern specific aspects of creativity.

2.2. Theory Foundations

The first, and most basic, need within this research area is for a universal set of definitions that can provide a common vocabulary to facilitate the discussion of key issues. Creativity, design, imagination, invention, and other terms are related, but each term is often interpreted differently by individual authors. Several key terms are defined in Appendix A as they will be used in the remainder of this paper. It should be noted that these definitions, while reflecting many accepted conventions, do not necessarily coincide exactly with their usage in some of the published literature. The definitions for these terms are important because they help define not only what creativity is, but also what it is not.

At this point it should be mentioned that problem-solving and design are treated here as closely related processes. Problem-solving is considered as a sub-process of design. Problem-solving implies addressing a single, independent technical issue, while design may involve many independent and interdependent considerations.

Figure 2 illustrates the interrelated nature of the various processes related to creative problem-solving and design in an engineering context. Within a problem-solving activity, an individual can engage in one or more sub-activities. Some of these sub-activities are dependent on others, while two can stand alone. Problems begin with an initial condition. This condition is delineated in the problem definition, and as result the problem definition can significantly influence what type of solutions are considered. The first step in finding solutions to a problem is to identify all existing solutions that could be applied. In conventional problem-solving, a typical solution is selected from existing technologies, and the problem-solver enters the "fitting" process to determine the appropriate parameters for the solution to be applied in the given problem situation. The creative problem-solving process has multiple possible sequences. In the case of adaptive creativity, creative thinking is applied to change the nature of a known solution so that the final condition can be achieved in some superior manner than if the conventional solution were applied in its unaltered form. In the case of original creativity, any known solutions related to the problem are dismissed altogether, and fresh solution approaches are generated. When creative solutions constitute some physical entity, an engineer engages in the invention process to develop the specific form of the entity. Beyond this stage, or in the case of creative solutions that are intangible, the final step in creative problem-solving is that of innovation. Creative solutions typically encounter resistance because of their newness and lack of established precedent. Therefore, in order to achieve the final condition that constitutes the end of the problem-solving process, the engineer must actively communicate creative ideas and work to implement them.

It is worth noting here that engineers who are engaged in the design process may work along one problem-solving sequence, find the approach unsuitable, and begin a new sequence. For example, if a conventional solution proves to be unsuitable, the engineer may re-examine the problem definition and attempt a more creative solution approach. Similarly, an engineering team may divide work so that several possible solutions to a problem are investigated simultaneously. To sum up, the various problem-solving sequences are not mutually exclusive. The parallel structure described, and depicted in Figure 2, is intended to illustrate the possible problem-solving processes that are available for engineers.

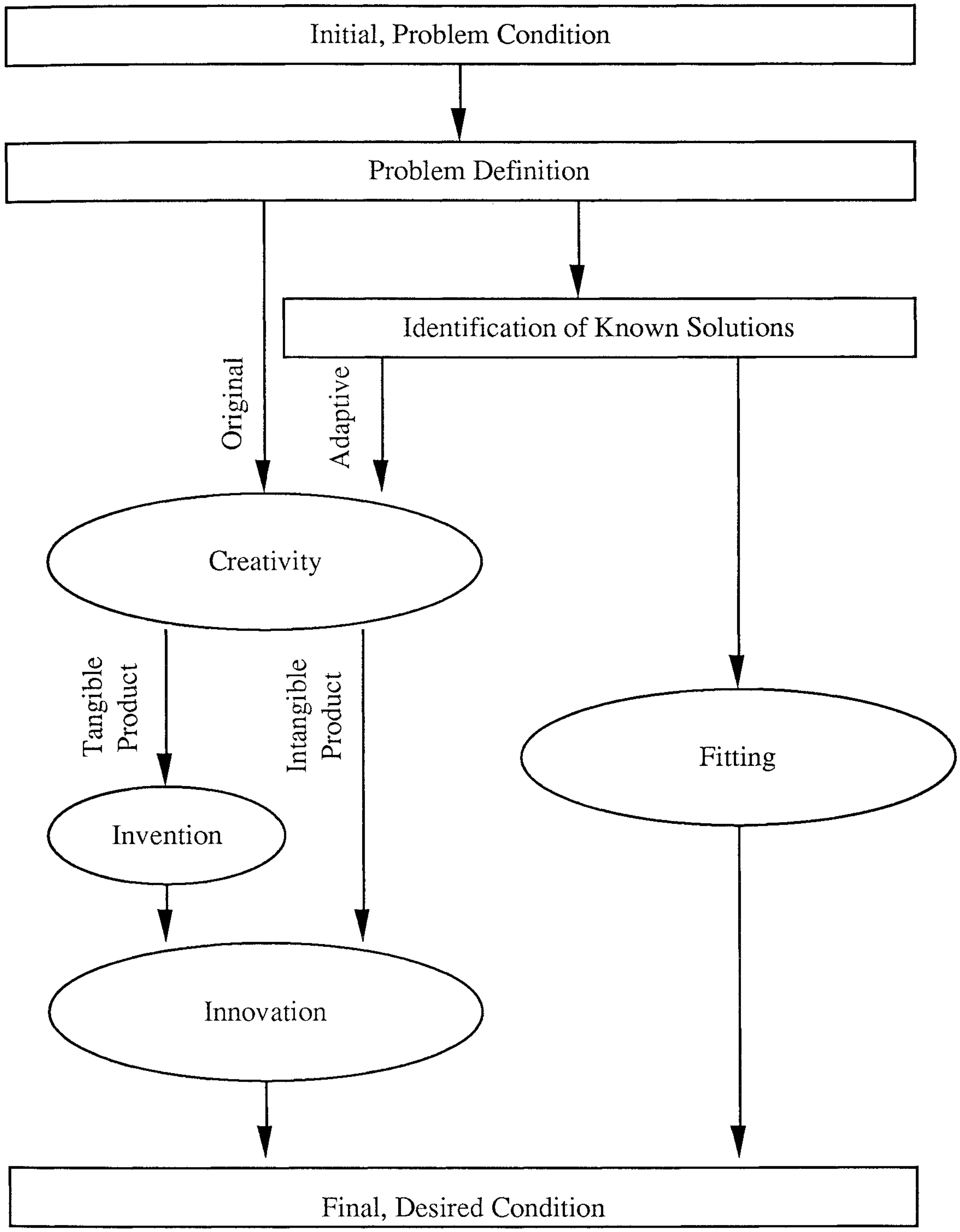

Figure 2. -- Processes in Engineering Problem-Solving and Design

2.3. Stimulated Response vs. Cognitive Process

Having defined some key terms for the discussion, it is now time to consider the following question: is creativity a result of environmental stimulation or is it a cognitive process? The answer here is... yes. Creativity has both behavioral and cognitive aspects; the two facets cannot be divorced. From a behavioral standpoint, individuals can be encouraged or discouraged from creative thinking by both internal and external factors. When engineers do engage in creative problem-solving, they follow certain generalized cognitive processes. If inhibited, engineers will not attempt these creative thought processes. Similarly, motivation to be creative alone will not be sufficient to enable engineers to produce new conceptualizations without the compliment of cognitive thought. A certain degree of creative cognitive thought is always available through the free-association mode of the subconscious, so motivational '"training" can positively affect creative output without corresponding training in specific cognitive strategies. This would explain why many subscribe to a behavioral view of creativity.

Easton identified three types of creative processes:

1. <u>Imagination</u>

    -- new ideas woven from remembered ideas

2. <u>Inspiration</u>

    -- ideas from accidental stimuli

3. Illumination

    -- new ideas from forgotten ideas in the subconscious

(Gjesdahl 1955, 769)

Since Easton's "imagination" term has a slightly different meaning from that defined for this discussion, the processes will be referred to as Types 1, 2, and 3. These three modes of creative thinking embody both behavioral and cognitive aspects. Type 1 uses cognitive manipulation based on old ideas. Type 2 relies on stimulation from the environment. Type 3 requires cognitive concept manipulations in the initial phase, but then depends on free-associations with external stimuli to produce creative ideas. During creative thinking processes, ideas can develop as a result of any, or all, of these three types of creative process. Therefore, for a balanced and complete perspective on creativity, any universal theory must consider both behavioral and cognitive factors that affect creative activity.

2.3.1. Environmental Factors Affecting Creativity

Those investigators who have considered creativity from a behavioral perspective have identified many external factors that affect the demonstration of creative ability. Hallman identified nine obstacles to creativity that individuals typically face:

1. Pressure to conform
2. Authoritarian attitudes

3. Ridicule
4. Rigidity of personality
5. Grades as rewards
6. Quest for certainty
7. Overemphasis on success
8. Hostility towards the divergent personality
9. Intolerance of "play" attitude

(Hallman 1967)

Hallman's factors are similar to the 10 "mental locks" described by Von Oech (Von Oech 1983). Considering the educational environment and how it measures up in terms of these obstacles to creativity, the odds seem to weigh heavily against the encouragement of creative thought in traditional engineering curricula. Whiting called for the development of a more permissive atmosphere, an "...environment in which new ideas are encouraged and permitted fair hearing" (Whiting 1958, 23). Environmental factors should be the first concern in developing creative ability. If detrimental factors exist, creative expression will not be encouraged -- in fact, it is more likely that creativity will be actively discouraged, though perhaps not intentionally. This type of dis-motivation can easily, and quite effectively, abrogate creativity in all but the most outspoken individuals. Adjusting environmental factors through appropriate organizational structuring and policy-making will encourage creativity. In addition, increasing general awareness of dismotivating factors can both decrease sensitivity to them and reduce unwitting contribution to their damaging effects.

2.3.2. Internal Factors Affecting Creativity

Masi reported three characteristics common to engineering students that inhibit their creative thinking: their tendency to form thinking habits; their tendency to establish rigid categories that prevent insight; and their tenseness (Masi 1989, 288). Masi's work demonstrates the need to consider internal factors that can impair the ability of an individual to exercise creativity.

Arnold considered factors affecting creativity according to a three-part model. He categorized inhibitors, or blocks, to creativity into these groups: emotional, cultural, and perceptual (Whiting 1958, 11). The first two groups relate to environmental factors, but the perceptual category refers to internal factors for an individual. Arnold noted that tendencies such as considering too narrow a problem or failing to see uncommon relationships can prevent individuals from performing to their full creative potential.

Whiting developed, based on the work of Guilford and others, a set of characteristics that are typically found in creative individuals. These characteristics delineate the internal factors that affect a person's creative ability:

1. Problem Sensitivity
    -- observant, questioning attitude

2. <u>Constructive Discontent</u>

   -- effort to suggest improvements in devices, processes of ideas

3. <u>Idea Fluency & Facility at Combination</u>

   -- operational techniques, combining ideas

4. <u>Flexibility in Thinking</u>

   -- orientation, familiarity with creative principles

5. <u>Vision</u>

   -- future focus, thinking on a grand scale

6. <u>Controlled Imagination</u>

   -- use of fantasy to an end

(Whiting 1958, 26)

The characteristics that Whiting identified influence the nature of an individual's cognitive processes. Problem sensitivity and constructive criticism are character traits that determine an individual's propensity to actively consider alternatives to common conceptualizations. Once such consideration processes have been triggered, the individual's degree of idea fluency and flexibility affects the quality of the creative activity. Finally, vision and the control aspect of imagination channel products of creative activity into useful conceptualizations.

The danger of labelling Whiting's factors as observed characteristics is that such a naming convention implies that nothing can be done to enhance the development of positive change in any one of the areas. This study was built upon the thesis that activities can be structured to expose students to cognitive processes in an explicit manner, and that through such experiences students can improve their creative cognitive abilities. The specific nature of the most effective methods for enhancing these abilities should become a topic for continued research. Knowledge of internal inhibitors to creativity contribute to the theoretical framework from which activities can be developed to improve creative abilities in regard to each of the six areas discussed by Whiting.

2.4. Creativity and the Problem-Solving Process

At the heart of all engineering disciplines is the process of solving problems. Some are technical, some financial, etc., but all share a common series of steps in the problem-solving process. Many variations of the problem-solving process model exist, but the following version reflects the universal basis for the majority of the models:

1. Problem Definition
2. Identification of Restrictions
3. Generation of Possible Solutions
4. Analysis of Possible Solutions
5. Selection of Optimal Solution(s)

This model is compared in Table 2 to other problem-solving models found in the literature. In an engineering context, the restrictions mentioned in the second step of the universal process model represent limitations imposed by technological considerations, while the fourth and fifth steps employ analysis techniques taught in traditional engineering curricula. The first step is often considered trivial in the engineering classroom, where most problems are already well-defined. Meanwhile, the third step is often not examined explicitly at all beyond acknowledging the fact that an answer of some sort should be produced. The first and third steps of the process, though given the least attention in the engineering curriculum, are the crucial steps that affect creativity in engineering problem-solving and design. The third step is particularly important, since multiple solution possibilities must be considered in order to reach beyond conventional approaches to reach creative solution alternatives.

The problem definition stage of the creative problem-solving process is important because it influences the solution-generation stage. A problem that is defined too specifically prevents the consideration of creative approaches because it will contain inherent assumptions about the nature of the problem. These assumptions can surreptitiously influence the thrust of solution efforts. This hidden directional influence may not be harmful if the solution approach that it induces is a profitable one. But if the approach is inappropriate, the inherent assumptions may cloud problem-solvers' perceptions,

Table 2. -- Relative Positions of Steps in Various Problem-Solving Models

MODEL TYPE

Universal	Stanford	Helmoltz	Osborn	Synectics
•Problem Definition	•Problem Definition		•Orientation	•Problem as Given
		•Preparation	•Preparation	•Purge
•Identification of Restrictions	•Fact-Finding			•Problem as Understood
	•Analysis		•Analysis	
			•Ideation	•Excursion
		•Incubation		
•Generation of Possible Alternatives	•Incubation		•Incubation	•World
		•Illumination		
			•Synthesis	•Force-Fit
				•Viewpoints
•Analysis of Possible Alternatives				
	•Decision	•Verification		
•Selection of Optimal Solution				

reducing their ability to break out of a pattern of thought to consider fresh solution approaches.

Several authors have discussed an alternative problem-solving model. The model has four steps:

1. Preparation
   -- gathering of "raw material" stimuli
   (Helmholtz called this step "Saturation")
2. Incubation
   -- combination/recombination of ideas without conscious effort
3. Illumination
   -- flash of genius, insight
4. Verification
   -- evaluation of solution as related to facts of the problem being solved

(Olken 1964, 155; Whiting 1958, 8)

The first and last steps in this process model group the first two and last two steps respectively of the original five-step model. The new model emphasizes the creative aspect of problem-solving in that it attempts to examine more closely the solution-generation phase of the problem-solving process. The term "incubation" refers to the subconscious processing activity of the human brain. The shortfall of this four-step model of creative thinking is that it treats cognitive processes as a collective "black box" -- unseen and unobservable. Such a theoretical orientation would preclude the development of explicit creativity strategies. Osborn incorporated the concept of incubation into his problem-solving model, but he also developed the model of creative processing further so that the solution-generation stage of the process comprised three steps:

1. Ideation
   -- tentative alternatives produced
2. Incubation
   -- generation of ideas without conscious effort
3. Synthesis
   -- several ideas combined into one new idea

(Whiting 1958, 8)

This model suggests the process of combining and recombining ideas to form new ideas, a process that Olken termed the “mental fusion” of "idea-compounds" (Olken, 1964, 156). Osborn's development suggests that techniques for combining ideas could constitute rudimentary strategies for creative thought. An effort to develop one such technique was reported by Yokel. He described the Synectics model of problem-solving, in which the generation of possible solutions is achieved through the following steps:

1. Excursion
   -- group incubation

2. World

   -- search for unrelated stimuli

3. Force-Fit

   -- forced relationships

4. Viewpoints

   -- possible solution paths

(Yokel 1964, 811)

The Synectics approach to creative problem-solving demonstrates that a specific methodology can be applied to generate possible solutions. In the case of Synectics, the specific technique involves forcing analogies between the problem being considered and the "world" selected for the Synectics session. It should not, however, be inferred that the force-fit method is the only specific creativity technique that is available. Whiting described at length several thinking strategies, which he called operational techniques (Whiting, 1958), that could be used to help generate possible solutions during problem-solving activities. Whiting defined an operational technique as:

> ...a system, procedure, or method designed to enable an individual or group to produce a large quantity of original ideas, in the hope that one or more may be creative. (Whiting 1958, 35)

The fundamental mental activity of creative thought seems to be one of mental manipulations. That is, ideas are broken down into sub-elements, and then these sub-elements are shuffled about and recombined to create new ideas. Operational techniques such as those discussed by Whiting guide problem-solvers through the process of breaking down concepts into sub-elements and then recombining some or all of the sub-elements, often with the addition of new elements taken from previously-conceived ideas or from external stimuli.

2.5. Explicit Creativity Methodologies

Olken believed it possible to train engineering students in the "...imaginative, conceptual phase of creativity by using known procedures" (Olken 1964, 160). By his statement, he referred to introducing students to the cognitive strategies that can be employed to synthesize creative ideas. Whiting advocated the use of operational techniques in educational settings as purposeful mental methods for generating creative problem solutions and techniques that would increase students' awareness and confidence in their own creative abilities. Whiting stressed that introducing and applying techniques such as brainstorming in the classroom would supplement, rather than supplant, innate individual creativity strategies (Whiting 1964, 158). There are two distinct manners in which this type of exposure would enhance students' creative abilities. First, by introducing formal creativity techniques, students would perceive creativity as a developable skill and the classroom as a receptive environment for creative suggestions. Second, students would stimulate each other's thinking as they verbalized their thoughts. Ideas feed on previous ideas, so any method for generating ideas could trigger additional creative output. The technique of brainstorming is built on this piggyback principle for idea generation. But brainstorming considerations do not consider the nature of an individual's cognitive thought processes, which is the true, fundamental source of creative ideas. Operational techniques do address the individual aspects of creative mental activity and seek to enhance them.

Instead of a superficial "party game" approach to creativity, operational techniques would provide a structured approach to the production of novel ideas and creative design. Masi advocated the presence of such structure (Masi 1989, 289). Operational techniques are "mechanical" mental strategies that can be applied in problem-solving situations. Whiting is not the only person who has suggested the use of operational techniques. Rossman, Simon, and Harlow have also examined the mechanics of various creativity strategies (Olken 1964, 155). Bailey advocated using the knowledge of the order existing in the creative process to "harden" such operational techniques, developing them sufficiently so they could be applied regularly for creative problem-solving (Bailey 1978, xii). Bailey's recommendation appears to be a sound one from an educational perspective; such a treatment would provide engineering students with a repertoire of mental tools to amplify the effectiveness of their problem-solving efforts. In order to reinforce the credibility of these methods, operational techniques need to be applied to suggest solutions that will then be implemented. This approach would demonstrate the usefulness of the techniques with tangible examples.

Operational techniques support the dual nature of creative activity, cognitive and behavioral. Some strategies support cognitive activities in that they break down existing ideas to facilitate the synthesis of new idea compounds. Others encourage responses to external stimuli to introduce new ideas and integrate them into new conceptualizations. Whiting organized the operational techniques into three categories:

1. Analytical
2. Free Association
3. Forced Relationship

(Whiting 1958, 37)

Whiting's three categories of operational techniques conform to the two-part model of operational technique functions: analytical techniques apply to cognitive activities, while free association and forced relationship techniques make use of relationships made between solutions and external stimuli.

A list of operational techniques described in the literature has been compiled to give an indication of the variety of operational techniques available. This list is given in Appendix B. Operational techniques are essentially "mental gymnastics" routines that in some ways support, and in other ways mimic, the unseen workings of the mind during creative activity. These techniques are structured approaches that guide individuals or groups through various thinking processes. Some employ unusual terminology in referring to the fundamental stages of the problem-solving process. This terminology serves a purpose by eliminating stereotypical attitudes about the various stages of problem-solving, particularly synthesis-related stages, and thus it removes some inhibiting preconceptions and allowing creativity to flow more freely. The relative effectiveness of the various techniques has yet to be studied. These techniques should be employed, along with any new techniques that can be developed, so that they can be refined enhanced for general use.

2.6. Summary Appraisal of Theory

Much is already known about factors that affect the degree of creative ability demonstrated by individuals. A good deal is also known about cognitive processes that take place during creative activities. Creativity has both behavioral and cognitive aspects, the former associated with stimulation-induced creativity, while the latter refers to cognitive processes that form, break, and re-form ideas as necessary to generate more creative ideas. "While a considerable body of theory and experience has been evolved for encouraging creativity, systematic attempts in the engineering sciences have been at best extremely rare" (Bugliarello 1969, 877). The time has come to apply the principles of the evolving comprehensive theory to develop appropriate segments for the undergraduate engineering curriculum to encourage and support the development of creative abilities.

Chapter 3
DEVELOPMENT AND TEACHING OF A CREATIVITY UNIT

3.1. Overview

An activities-based unit in creativity was developed and taught at The Pennsylvania State University to demonstrate the feasibility of teaching creativity in an explicit fashion within an introductory engineering course. The unit was incorporated into a freshman course, ENGR 297E, that was taught during the Spring 1991 semester. The course was an experimental engineering preparatory course conceived as part of the NSF-funded Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL) project. The objective of the course was to introduce students to aspects of engineering design early in their undergraduate experience. The creativity unit was one of several units taught in the course, the other units being catastrophic failures, engineering ethics, materials and manufacturing processes, and technical drawing. This chapter will describe the principles that the creativity unit espoused and the manner in which it was taught.

3.2. Organizational Structure for ENGR 297E

The ENGR 297E course was team-taught by four faculty members, one graduate student, and the author, who was a senior undergraduate teaching intern. During the course, teaching-team members typically sat in on their colleagues' classes, often posing questions for the featured lecturer, thus promoting an atmosphere conducive to active exchange of information and ideas. Thirty-two students were enrolled in the course; all but one were second semester engineering students. The remaining student was a senior in Engineering Science.

Technical drawing classes were held once per week. The remaining class periods for the semester were divided among the other units. The creativity unit occupied six two-hour class periods, spanning three weeks of the semester.

3.3. Planning Considerations

Several aspects of the creativity unit were deliberately planned in accordance with the published findings and theoretical principles discussed in Chapters 1 and 2. The two underlying concerns were that students be actively encouraged to be creative and that they learn about creative processes through direct participation in classroom exercises. In regard to the first precept, the teacher's role was to reassure students that they could put their creative skills to use without fear of ridicule. This was accomplished by exhibiting enthusiasm for creative behavior, offering specific examples of creative solutions in action, and demonstrating to students the worth of even their most outrageous suggestions. The most laughable ideas were discussed in terms of their positive implications, and they often proved to be among the best ideas. Students were informed that they would not be graded for the creativity portion of the course, although it was later decided to include one graded homework assignment based on the activities in the unit. The no-grade policy was designed to alleviate students' anxiety about grading and so remove an inhibiting environmental factor.

The second planning principle was addressed by developing a series of group activities that required students to engage in creativity-promoting thinking patterns during various stages of the problem-solving process. These small-scale activities were structured so as to develop a more general approach to creative problem-solving. The activities, examples of which are given in Appendix C, involved the re-design of common objects as well as the production of new problem solutions. These two types of activity addressed adaptive and original creativity modes respectively. Students worked on the activities in groups of four during the class periods. Feedback was given by soliciting ideas from each group at the end of an activity and discussing these ideas with the entire class. In addition to this immediate feedback, students were given specially-designed tests at the beginning and end of the six period unit. The responses on these tests were evaluated and compared to give the students individual feedback on the development of their creativity skills.

3.4. Class Structuring

The classes in the creativity unit were designed to address the following four basic facets of creative problem-solving:

1. Attitude Considerations
2. Problem Definition
3. Conceptualization
4. Solution Synthesis

One class period was dedicated to each of these topics, with the remaining two periods devoted to introduction and summary of the material in the unit, as well as testing.

Each class began with a calling of the roll that required some unusual response. This was planned as a mental warm-up exercise that would break students out of passive thinking modes. Next, the topic for the class was introduced, along with a brief outline of the activities for the period. At the beginning of the class series, the periods were dominated by lecture and discussion, but later an increasing amount of class time was allotted for group activities. Throughout the duration of the creativity unit, students had take-home assignments on which to work between classes, although all but one of these assignments were merely short readings on topics related to creativity. A more detailed discussion of the individual lesson content follows.

3.4.1. Lesson #1: Pre-Test and Introduction

The first class period of the creativity unit was devoted to administering a pre-test and introducing the creativity unit. Students were assured that although the test would be used to evaluate the development of their creative skills, their performance on the test would not affect their grade in the course. This policy was established to alleviate fears about detrimental effects on their grades as result of the unfamiliar, open-ended type of problems. It was hoped that this would reduce students' anxiety and promote creative behavior.

Once the tests had been collected, students were asked to give their definitions for creativity. A discussion of the importance of creativity followed, with the space shuttle Challenger disaster used as an example of where creativity was needed. Students were then divided into teams of four according to their alphabetical order, and they were given an ice-breaker activity that involved performing as a group in front of the class. This performance activity was designed to reduce students' fears about peer approval by forcing students to perform humorous acts, making students more comfortable about laughing together. At the end of the class period, students were given a short reading assignment.

3.4.2. Lesson #2: Attitude Considerations

The second class was devoted to the consideration of internal factors that inhibit creativity. At the start of the period, students were asked to respond to the roll call by stating their intended major. The lecture was based on von Oech's "mental locks" model of internal inhibiting factors, since this was a more colorful treatment than Hallman's list. An example of a creative invention, the soda can tab, was presented to lead off the lecture, and anecdotes were used to illustrate the effects of each of the inhibiting factors.

To keep students actively involved in the class, the lecture was halted at three points as students individually attempted exercises related to a topic in the lecture. The first of these exercises demonstrated the importance of looking for multiple, as opposed to solitary, solutions. The second stressed the usefulness of ambiguity in defining problems, and the final activity attempted to help students acclimatize themselves to the possibility of failure. In addition to the exercises, some inspirational quotes from leading figures in the history of engineering and science were woven into the lecture. At the end of the period, students were given another take-home reading assignment.

3.4.3. Lesson #3: Problem Definition

The third lesson focused on the problem definition phase of the creative problem-solving process. Class began with students responding to the roll call by describing their breakfasts. Next, students individually attempted an activity designed to demonstrate that assumptions made in defining a problem can restrict thinking and preclude the consideration of possible solutions. Next, students viewed a videotape in which the steps of the problem-solving process were discussed. In the discussion that followed, special emphasis was given to the importance of the problem-definition and idea-generation stages of the process and their role in creative problem-solving.

Following the videotape, the first group activity for the unit was introduced. The students were given a written problem statement. This problem statement was called a "task definition" to disassociate it from any preconceptions about traditional, narrowly-defined problems. The student groups were asked to identify any assumptions that were inherent in the given task definition, to formulate alternate task definitions -- called "parallel task definitions" -- that eliminated one or more of the assumptions, and finally to create an "ambiguous task definition" that did not contain assumptions that would restrict solution suggestions. This activity was designed to give students practice in recognizing hidden assumptions made in problem definitions and re-defining the problem so that a wider range of possible solutions could be considered.

The students were told follow certain guidelines while working in their groups. These amounted to basic guidelines for brainstorming sessions. Four positions were created for students in each group to fill: leader, moderator, secretary and speaker. Each position carried with it a different set of responsibilities relating to the facilitation of the group activities. With each activity, students took on a different role within the group. This approach to group moderation was designed to facilitate the individual activities as well as to develop in students an appreciation of the responsibilities and challenges of each position during group creativity sessions. After a discussion of the activity, students were given another short take-home reading assignment.

3.4.4. Lesson #4: Conceptualization

This class dealt with forming new ideas. The operational technique of attribute listing was employed as a basis for the conceptualization activities.

The students were first given a review of problem-definition principles. The task definition activity that had been used for lesson #3 was presented in completed form as an example, and another similar exercise was assigned to reinforce the students' skills in this area. A brief discussion of the relationship between problem definition and engineering design specifications followed the review activity.

To introduce the topic of conceptualization, students were shown a videotape that chronicled a Synectics-style creative problem-solving session. The importance of drawing analogies and building on other people's ideas was emphasized in the ensuing discussion.

Students were then given a group activity in which they were told to list the attributes of a designated object and then compare it to other objects based on individual attributes. Following this activity, the groups were told to select an object themselves and compare it to other objects based on attributes. Then each team in turn described their analogies to the rest of the class, and the groups competed to guess at the object originally selected. These conceptualization activities were designed to give students practice at drawing comparisons between dissimilar objects in preparation for synthesis activities.

At the end of the period, students were given a homework assignment. This assignment is described in greater detail in section 3.5.1.

3.4.5. Lesson #5: Solution Synthesis

This class period was structured to give students experience manipulating sub-elements of ideas to synthesize problem solutions. Students practiced adaptive creativity by adding, subtracting or changing attributes of existing conceptualizations, and original creativity by building solution conceptualizations from lists of desired solution attributes.

Students were shown examples of engineering solutions that had resulted from adaptive and original creativity. They were then given a series of group activities on which to work. The first activity required the groups to find alternate uses for objects based on attributes other than function. Next, groups engaged in adaptive creativity as they redesigned an object by altering one or more of its attributes. Finally, the groups were given a problem description and were asked to list desirable attributes for the solution, make comparisons to objects based on those attributes, and then use the comparisons to generate solutions for the problem.

3.4.6. Lesson #6: Summary and Post-Test

The final class period of the creativity unit consisted of a brief lecture on the role of creativity in the engineering design process an the application of creativity principles in both industrial and academic settings. The complementary function of the engineering sciences was also discussed. The remainder of the period was devoted to the administration of the post-test and a course evaluation questionnaire for the creativity unit.

3.5. Evaluation Activities

Students participated in two types of individual activities during the course unit: a process-oriented homework assignment and a set of creativity tests. These activities were to be used to evaluate the development of the students' creativity skills.

3.5.1. Homework Assignment

At the end of Lesson #4, students were given a homework assignment that was to be completed in a week's time. The assignment was designed to lead students through the stages of the creative problem-solving process to re-design a device of their own choosing. Students were required to analyze and modify the problem definition, delineate their conceptualization of the product or device, and suggest alternatives to and/or modifications of the design. A copy of the assignment sheet is given in Appendix D.

3.5.2. Pre-Test and Post-Test

The pre-test and post-test were developed to measure the development of students' capacities in four areas:

1. Exhibiting dissatisfaction with conventions
2. Breaking assumptions in problem definitions
3. Relating unlike objects
4. Determining alternate uses

These four areas are related to Whiting's list of internal factors discussed in section 2.3.2. Copies of the pre-test and post-test are given in Appendix D. Questions number 1 on the pre-test (designated Pre-1) and number 9 on the post-test (designated Post-9) were knowledge-based questions intended to determine students' perceptions on the meaning of key terms. Questions Pre-6 and Pre-7 were determined to be invalid and were subsequently not used in the evaluation process. The remaining questions on the tests corresponded to one of the four question categories. Their correspondence is shown in Table 3. Also shown in Table 3 are the individual question type designators that will be used in later figures.

3.6. Summary of Course Unit Execution

A compact, activities-based unit was developed and taught without following any previously established guidelines for such a course. The principles introduced in the creativity unit were incorporated into discussions during each of the other units in the course. The principles from the unit were

Table 3. -- Correspondence of Test Question Items to Question Categories and Designators

Question Category	Question Type Designator	Pre-Test Number	Post-Test Number
Dissatisfaction	A	2	1
	B	8	6
Assumptions	C	3	4
	D	4	3
Relationships	E	5 a	5 a
	F	5 b	5 b
Alternate Uses	G	9	8

especially useful in preparing the students to work on their own synthesis activity, a design project required at the end of the ENGR 297E course.

Chapter 4
RESULTS FROM
EXPERIMENTAL CREATIVITY UNIT

4.1. Overview

Four types of data were collected during the experimental unit. The first category of data was anecdotal evidence, observations made during the class periods. The second type consisted of the results from the homework assignment given in Lesson #4, which evaluated students' ability to apply the creative problem-solving techniques on an individual basis and in an unsupervised setting. The third class of data was comprised of the students' scores on the pre-test and post-test. The final type of data was in the form of student responses to direct questions; these responses were gathered from a unit-evaluation questionnaire administered at the end of the last creativity class.

The primary data for the research was intended to be that collected from the pre-test and post-test. These tests were specifically designed and incorporated into the class to measure any change in students' skills related to creative problem-solving. The other three classes of data also serve an important function, though, by giving an indication of the atmosphere in which the creativity unit was conducted and the students' response to the principles and teaching methods used in the unit. A more detailed presentation of the data from each of the data categories is given in the sections that follow.

4.2. Anecdotal Evidence

Observations about the events in the classroom were recorded at the end of each of the creativity classes. A synopsis of these observations is given for each class period.

4.2.1. Lesson #1

Students appeared to work on the pre-test at a vigorous pace. They seemed to be generating many ideas and rushing to get them down on paper. Question Pre-6 was confusing to some students because they did not understand what a metaphor was. In an attempt to clarify the question, an example of a metaphor was given.

During the lecture that followed the testing, the students exhibited a good understanding of what creativity was, as evident by their oral definitions of creativity. They seemed a bit bewildered at the generic references made about problem-solving processes. They did respond well, though, to de Bono's analogy of problem-solving as akin to hole-digging. This favorable response was probably in part because the analogy clarified the concept under discussion and in part because the students were required to actively engage in the discussion at this point. The student response suggested the need to include more examples and encourage student participation during the course of the lecture.

The students reacted somewhat hesitantly to the ice-breaker activity conducted at the end of the period. This response was predictable considering the age and emotional maturity of the students. In performing their assigned tasks, the groups tended to cluster behind their desks, retreating from the rest of the class. This reduced the impact of the activity, which was intended to rid them of the fear of being embarrassed publicly by exposing them to embarrassment. The activity would probably have been more effective if the groups had been required to get up in the front of the classroom to perform.

4.2.2. Lesson #2

Students seemed to enjoy the many examples of creative ideas that were presented during this period; many of the anecdotes even evoked laughter from the students. Of the three individual activities, the first two successfully conveyed their intended messages. The third activity was not successful in communicating its intended message, but it illustrated a more powerful point. The third activity had been conceived as an impossible task that would expose students to the frustration associated with failure. The students, unaware of this intention, applied creative principles that had already been discussed. Consequently, they devised two credible creative solutions to the problem and so demonstrated for themselves, and the faculty team, the results that are possible when personal inhibitions are removed. This result also reinforced the philosophy that the role of the teacher should be considered to be that of a coach responsible for encouraging students to apply their innate creative talents.

Time constraints circumvented the assignment of group creativity exercises in this period.

4.2.3. Lesson #3

The opening exercise for this period successfully demonstrated that premature assumptions about problems restrict the solution-generation process. Most of the students were stumped by the exercise; a few solved the puzzle using a standard method, while one student suggested a creative alternative solution.

Students seemed a bit restless during the videotape presentation, although the examples shown on the tape seemed to hold their attention.

During the problem-definition activity, students seemed confused about how to form parallel task definitions that would eliminate one or more assumptions made in the original problem statement. The student groups' activity sheets confirmed this confusion and suggested that more time needed to be spent explaining the process instructions and presenting examples before the students were asked to attempt activities themselves.

4.2.4. Lesson #4

The review of task definition principles seemed to eradicate the lingering confusion about how to eliminate assumptions in problem statements. After viewing the worked example from the previous class, the groups successfully completed a similar problem definition activity as a review exercise.

The Synectics videotape did not visibly affect the students either positively or negatively. At the end of the tape, students said they were intrigued at the way members of the Synectics group interacted to produce new ideas from previous ideas.

At the outset of the day's group activities, the students as a class generated a list of attributes that could be used to characterize objects. During the course of the activities, the students seemed to understand how to make comparisons based on attributes, and they followed the process as intended. The students were prone to making rather conservative analogies, perhaps indicating the need to entreat more outlandish ideas while emphasizing that these often lead to the most creative solutions.

The comparison contest generated a great deal of excitement among the students. At the beginning of the activity, students were advised that a good strategy would be to select unusual comparisons for their analogies in order to conceal their chosen object from the other groups. The students did indeed devise some peculiar comparisons, but in most cases their peers were able to guess the nature of the objects within the allotted 30-second period. The ability of the students to rapidly determine the original object being described by the analogies seems to indicate well-developed skills for synthesizing solutions from bits of information.

4.2.5. Lesson #5

During this lesson, which was devoted primarily to group activities, the detrimental effects of time limitations became painfully apparent. With three types of complex activities to cover, students were not given much time for meaningful reflection and practice for each activity. Group discussions during activities in this part of the unit appeared more lively than in previous sessions. This observation suggests that students were either warming up to the nature of the activities, to working with each other, or to both.

The activity that stressed adaptive creativity, titled "Activities in Attribute Manipulation" and reproduced in Appendix C, produced several creative suggestions for re-design options. The exercise in original creativity, titled "Activities in Solution Synthesis" and also found in Appendix C, was not completed in sufficient time to discuss its outcome, although students seemed to understand the process that it required. The overall indication from the experiences of this class period was that more time was needed to discuss each activity in terms of its process and its implications.

4.2.6 Lesson #6

The material for this class period was covered quickly. The intent of the lesson was to alert students to the analysis-oriented nature of conventional engineering courses and to encourage them to practice their creative abilities on their own once they completed the ENGR 297E course.

The remainder of the period was devoted to the post-test activity and the completion of the unit evaluation questionnaire.

4.3. Homework Assignment

The homework project assigned at the end of Lesson #4 was designed to determine whether students could adopt the problem-solving process introduced in class. It required them to follow the steps studied during the unit to suggest a re-design for an object of their own choosing. The students' use of the process steps and the nature of the creative ideas that they produced accounted for 70% of the grade for the assignment . The remaining 30% of the grade was based on grammar, spelling, and other communication considerations. Students were given a handout describing the specific method of the content grading. A copy of the handout is given in Appendix E.

Figure 3 shows the mean scores that the students received for the content portion of the homework against the number of students receiving each score. The majority of the students attained a score of 60% or more, indicating either one major difficulty in a single process step or minor problems in two or more steps. Figure 4 shows a more detailed break-down of the scores, giving the mean score, out of a possible ten points, for each of the steps in the process outlined for the assignment. The results indicate that students understood and successfully applied the principles from the class to identify and eliminate individual assumptions in problem definitions. The mean scores for the ambiguous task definition and conceptualization steps were 7.66 and 7.03 respectively, suggesting that more attention needed to be paid in these areas. The mean score for the final step was 9.125. While not perfect, this score indicates good comprehension and application of the principles relative to this phase of the process, particularly as only two students received scores below 7 for this section.

There are two likely causes for the deficiency in the ambiguous task definition and conceptualization steps of the process. The first is that insufficient time was allowed for the examination and application of the thinking strategies involved. The second is that students might have been confused at what was meant by an ambiguous task definition and a conceptualization of an object. In both instances, the problem might have been avoided by spending additional class time illustrating these concepts.

4.4. Pre-Test and Post-Test Evaluation

The literature reviewed for this research project did not prescribe any testing instruments for measuring creativity skills in the context of engineering problem-solving and design. In order to measure the development of students' creativity skills as a result of course unit, it was necessary to create a prototypic testing instrument for this project. The end result was a pair of test forms -- one for pre-testing and one for post-testing -- that measured students' performance in design-related activities. Due to the inexperience of the students in regard to the engineering program, the test questions involved common objects rather than more complicated engineering systems.

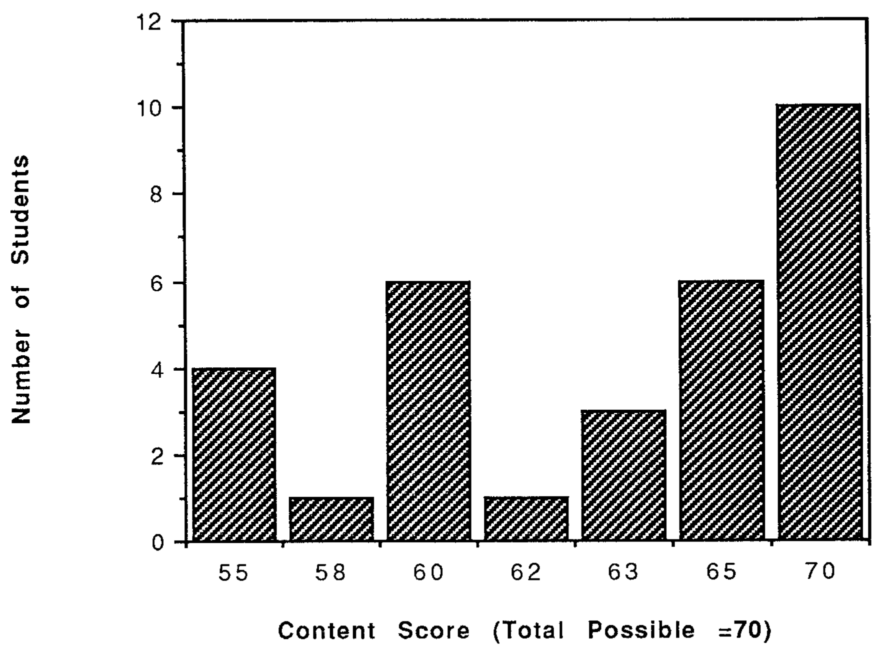

Figure 3. -- Mean Homework Score for Content vs. Number of Students

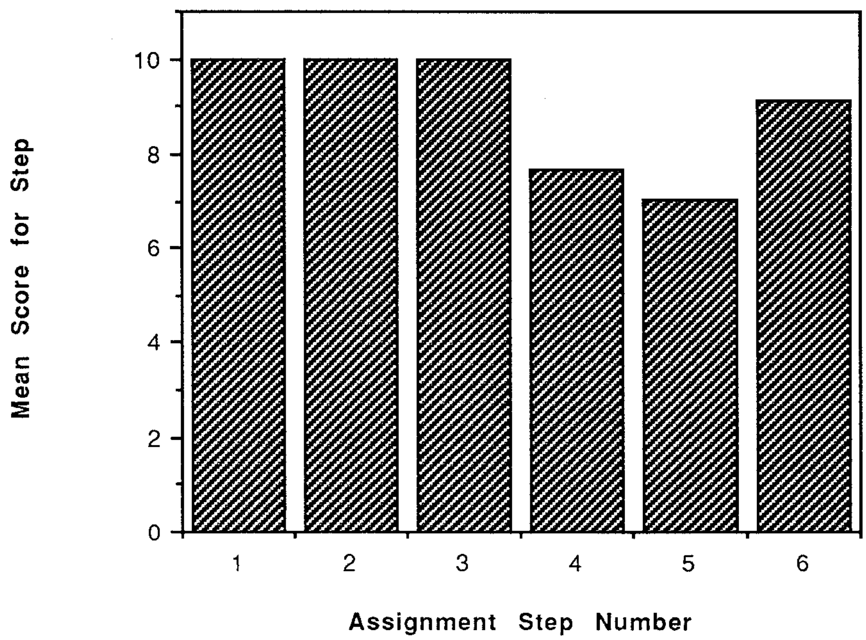

Figure 4. -- Mean Scores for Individual Process Steps in Homework Assignment

4.4.1. Structure of the Tests

The pre-test and post-test were designed with similar question types so that the students' performance on the two instruments could be compared. This comparison was planned to be the basis for evaluating the development of their skills in four areas relevant to creative problem-solving.

The first question type evaluated the students' level of dissatisfaction with conventions. In question Pre-2 and Post-1, students were asked to list as many shortcomings of a particular object as possible. Later, in Pre-8 and Post-6, students were asked to suggest ways to improve the design of another designated object. These questions were intended to determine how well students could see beyond conventional conceptualizations to suggest more desirable configurations.

The second question type measured the students' ability to break out of assumptions inherent in problem definitions. In Pre-3 and Post-2, students were given a problem situation description and were asked to suggest possible solutions to the problem. The Pre-4 and Post-3 test items were similar to Pre-3 and Post-2 questions, but in addition to asking for possible solutions, these questions first asked students to list the assumptions inherent in the problem definition. The idea of this additional requirement was to have students consider the assumptions made in the problem statement. This was hoped to prompt them to break out of those assumptions.

The third type of question was designed to determine the students' ability to draw comparisons between unlike objects. Questions Pre-5 and Post-5 required students to describe ways in which pairs of objects were alike. The process of drawing such comparisons relates to the process of using external stimuli to trigger new ideas The ability to manipulate characteristics from one object to another is key to the stimulation process, just as identifying common characteristics is basic to comparison process.

The final question type tested the students' ability to several uses for a designated object. The questions in this category were constructed to see how students might make use of common objects outside of their normal context.

Since the tests were prototypes, some of the questions that were included on the pre-test forms were later found to be invalid because the students did not comprehend the intent of the questions. Similarly, an experimental question was included on the post-test that had no match in the pre-test. As result, these three questions, Pre-6, Pre-7, and Post-4, were not considered during the evaluation and interpretation of the data.

4.4.2. Evaluation Method

The pre-test and post-test were administered to two student groups. The first group consisted of the ENGR 297E students. The other group was comprised of students enrolled in a freshman Engineering Graphics course (EG 50), the course that the ENGR 297E students would have been taking if the ECSEL experiment had not been initiated. As such, both groups were deemed to have similar backgrounds in terms of their academic experiences. The EG 50 group was chosen at random, as was the ENGR 297E group when the experimental course was planned. The EG 50 students were used as the control group for the creativity testing. They took the pre-test on the same day as the 297E group; scheduling problems caused their post-test to be administered approximately two weeks after the ENGR 297E creativity unit had been completed. The control group received no explicit creativity training during the period between their testing sessions.

A graduated scoring system was devised to evaluate the responses on the two tests. The students' responses to the test questions were evaluated for both flexibility and fluency of thought. Fluency was measured by the quantity of responses that students generated at each flexibility level. Flexibility was determined by the nature of the answers. Suggestions that were prevalent in many of the students' test or which were similar to commonly-available design options and/or uses were designated "apparent" answers. These answers were the product of either conventional thinking or adaptive creativity. Responses that were distinctly unconventional and indicated the application of original creativity were labelled "unorthodox" answers. A handout describing in detail the criteria used for this system was given to the students after the creativity unit had been completed and the test results had been evaluated. A copy of the handout appears in Appendix E. To evaluate the tests, a master list of responses was compiled, categorizing specific answers into the two response classifications. This list was created to maintain uniformity in the evaluation process and reduce the subjectivity of the evaluation.

A point system was devised to reflect both the flexibility and fluency dimensions for responses. An description of the system is given in Table 4. Flexibility was given precedence over fluency: multiple "apparent" answers earned a score of 2 points, while a single "unorthodox" answer warranted a score of 3 points.

4.4.3. Test Data Analysis

Data on responses for the pair of test was collected for 31 students in the ENGR 297E group and for 19 students in the control group. A summary of the data statistics is given in Table 5.

The statistical indicators from the ENGR 297E group's tests show a significant improvement over the course of the unit. The group's overall mean score for the post-test increased by 1.0725 points over the corresponding pre-test value. In addition, the lowest mean score out of the test items on the post-test surpassed the highest mean score out of the items on the pre-test. The mean of the standard deviations for this group decreased for the post-test, indicating tighter grouping of the scores in the higher range.

The control group's scores, meanwhile, did not show the same improvement. Their overall mean score for the post-test increased only 0.2340 points over that for the pre-test. The mean scores for some of the test questions actually decreased. While all but one of questions' mean scores for the ENGR 297E group's post-test exceeded 3 points, only one of the control group's mean scores did so, and that mean score was the only one within 0.5 points of the 3-point threshold. The mean of the standard deviations for this group also decreased, but in this case it indicated a tighter grouping within a range of lower scores than that for the ENGR 297E group.

Graphical representations of the test results data, given in Figures 5 through 11, reveal some significant trends. Figure 5 shows the overall mean scores for each test and for both groups. Figures 6 and 7 compare pre-test and post-test mean scores for individual test questions. These two figures show that the ENGR 297E group's mean scores increased noticeably for each question type, while the control group's scores did not exhibit any uniform trend. Figures 8 and 9 depict similar comparisons of pre-test and post-test results. In these figures, mean scores are graphed according to the four question categories that

Table 4. -- Graduated Scoring System for Evaluating Creativity Test Scores

Score	Criteria
0	The student did not provide an answer to the question.
1	The student provided a single "apparent" answer.
2	The student provided multiple "apparent" answers.
3	The student provided one "unorthodox" answer, either on its own or with additional "apparent" answers.
4	The student provided two or more "unorthodox" answers, either on their own or with additional "apparent" answers.

Table 5. -- Statistics on Creativity Test Results

	ENGR 297E Group		Control Group	
Question Number	Mean Score	Standard Deviation	Mean Score	Standard Deviation
PRE-TEST				
2	2.8710	0.7928	2.8421	1.1816
3	2.3548	1.0333	2.4210	1.3105
4	2.3871	1.0977	2.5789	1.2697
5a	2.4194	1.2121	2.1053	1.4471
5b	1.0932	1.6135	2.1053	1.6510
8	1.0932	1.4448	1.5263	1.2298
9	1.9677	1.6556	2.0526	1.2343
Test Avg.	2.2581	1.2643	2.2331	1.3320
POST-TEST				
1	3.1613	0.7661	2.4737	0.8188
2	3.4839	0.7980	2.3684	1.4220
3	2.9677	0.8224	2.3158	1.2162
5a	3.2903	0.8498	2.4210	1.2697
5b	3.1613	1.1387	1.5789	1.2697
6	3.4839	0.8751	3.1053	1.1650
7	3.4516	1.0728	2.4737	1.2298
Test Avg.	3.3306	0.9033	2.4671	1.1987

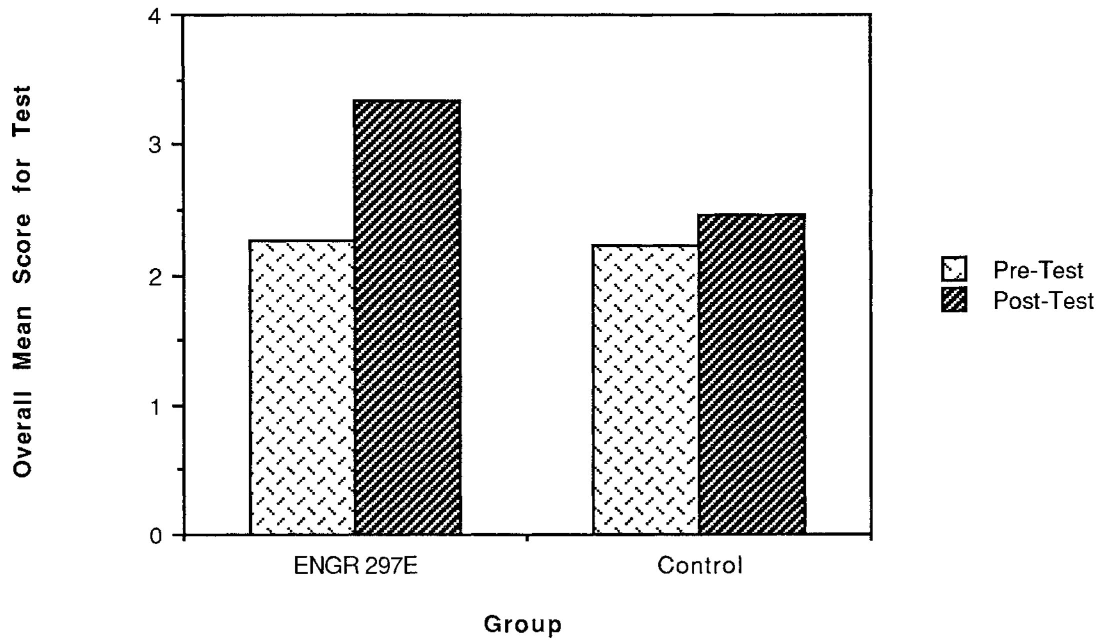

Figure 5. -- Overall Mean Test Score Comparisons
(ENGR 297E and Control Groups)

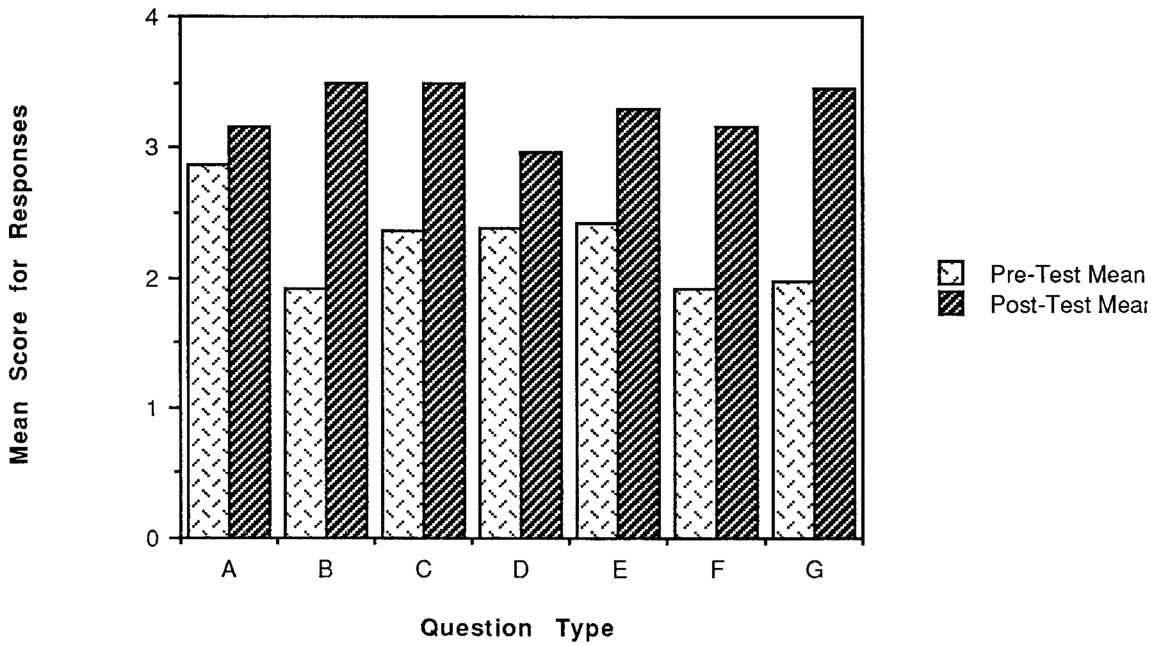

Figure 6. -- ENGR 297E Group: Question Item Comparisons for Pre-Test and Post-Test

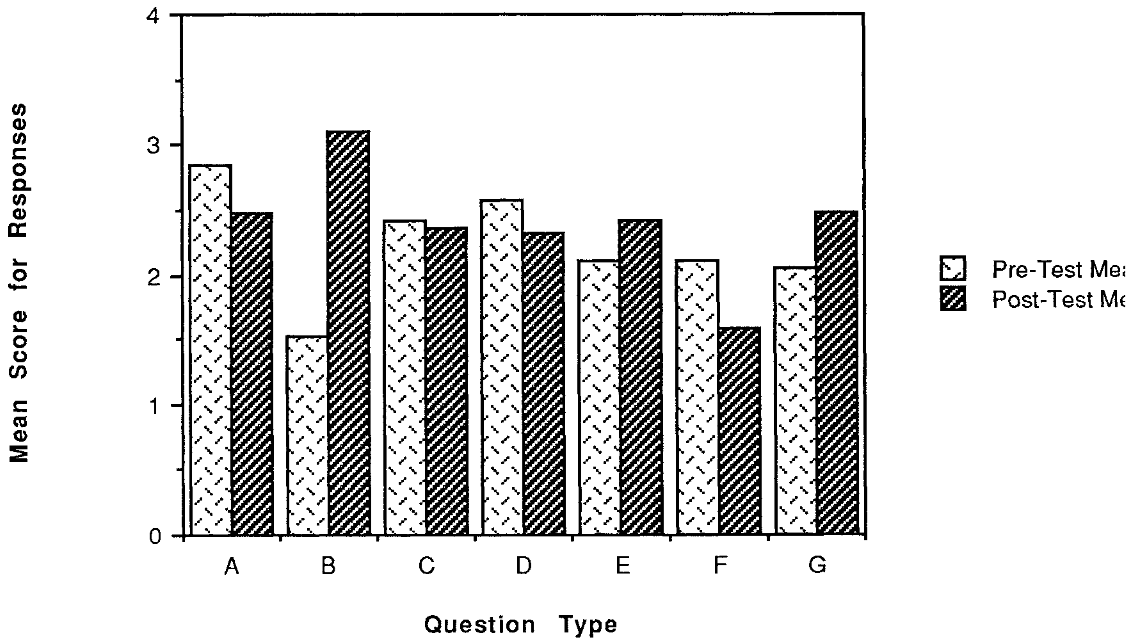

Figure 7. -- Control Group: Question Item Comparisons
for Pre-Test and Post-Test

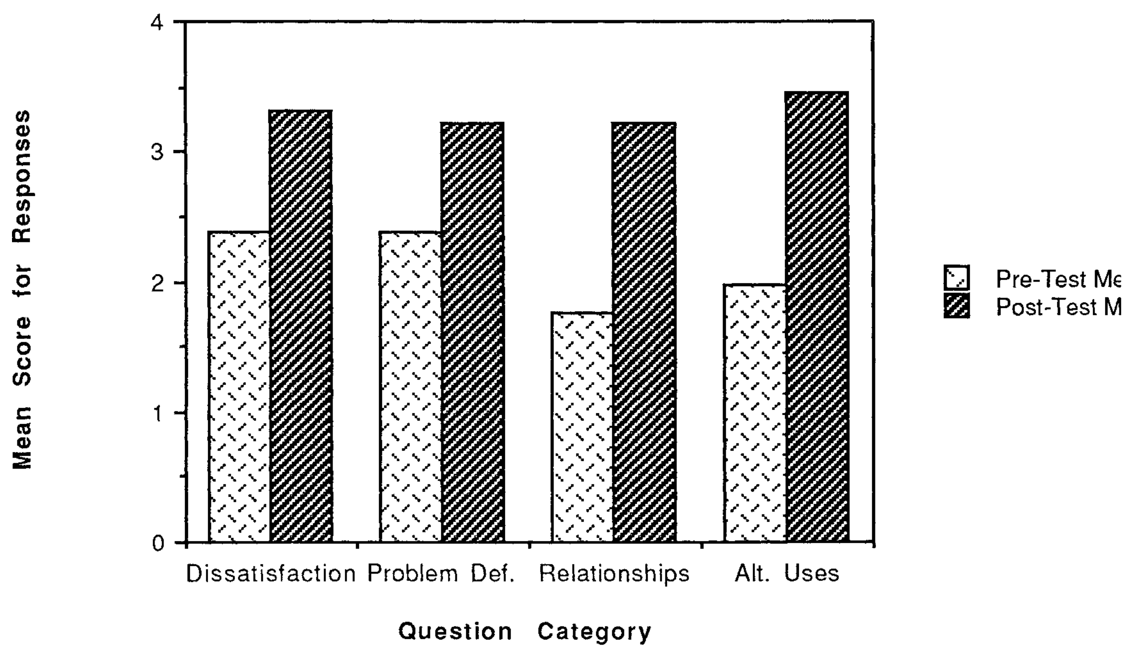

Figure 8. -- ENGR 297E Group: Question Category Comparisons for Pre-Test and Post-Test

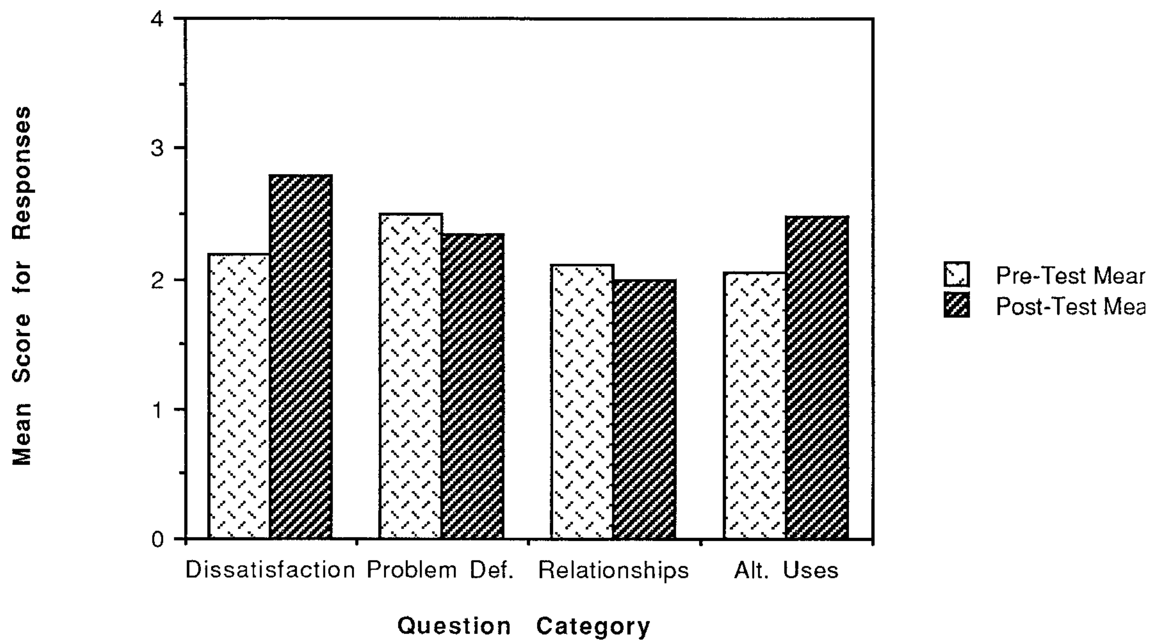

Figure 9. -- Control Group: Question Category
Comparisons for Pre-Test and Post-Test

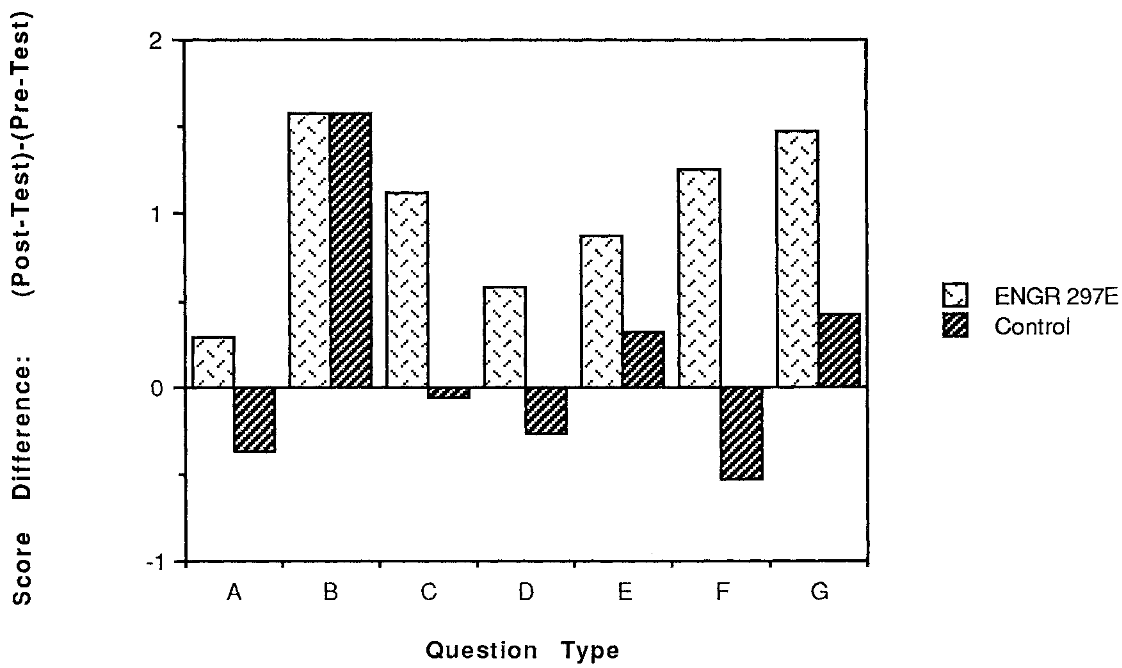

Figure 10. -- Net Differences in Mean Scores for
Individual Question Items
(ENGR 297E and Control Groups)

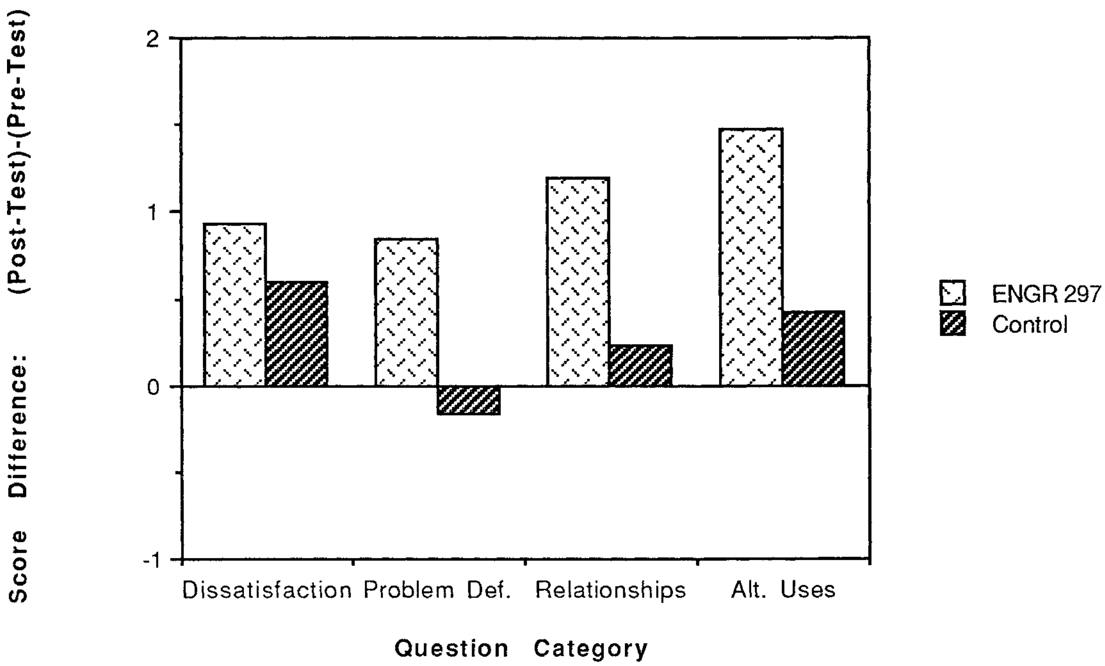

Figure 11. -- Net Differences in Mean Scores for Question Categories (ENGR 297E and Control Groups)

corresponded to the four skill capacities assessed by the tests. Figure 8 demonstrates that the ENGR 297E group's scores not only uniformly increased, they surpassed the three (3) point threshold. Figure 9, on the other hand, shows that changes for the control group were not monotonic and did not change as significantly as those for the ENGR 297E group. Figures 10 and 11 further illustrate the relative changes in performance. Differences between mean scores on the post-test and pre-test are compared graphically for both groups. Figure 10 compares on the basis of individual question types, while figure 11 does so according to the four (4) question categories.

4.5. Unit Evaluation Questionnaire

The questionnaire administered at the conclusion of the creativity unit was intended to gather information about students' reaction to particular portions of the lessons and the creativity unit in general. Most of the question responses were used for planning a revision of the unit. The responses to three of the questions, however, indicate the effect of the unit on students' motivation. Out of 32 questionnaires completed by the ENGR 297E students, 23 students indicated that they had not previously been exposed to the principles of creative problem-solving in a structured educational setting; 28 students responded that the creativity unit had affected the development of their creativity skills in a positive manner; and

24 students felt that they were more motivated to become an engineer because of their experiences in the creativity unit.

4.6. Summary Discussion of Results

The data collected from the four sources indicates that this initial experiment in teaching creativity positively enhanced the ENGR 297E students' creative abilities in areas related to engineering design. The lesson presentations, despite some shortcomings, successfully cultivated an environment conducive to creative expression while at the same time imparting principles and developing skills critical to the creative problem-solving process. The homework project demonstrated that the students were able to adopt and apply a structured process for creative design. The performance data from the tests showed significant improvement among the ENGR 297E students as compared to students enrolled in the traditional Engineering Graphics course. The ENGR 297E group's abilities improved in all four areas related to the creative problem-solving process. In addition, responses to the questionnaire showed that the exposure to creativity training in an engineering course gave the students confidence in their own creative abilities and increased their motivation to become engineers.

Chapter 5
CONCLUSIONS AND RECOMMENDATIONS

5.1. Overview

The experiences of the course unit revealed several improvements that could be made to improve creativity course units patterned after the prototype unit. The research work also leads to several implications for new emphasis on creativity in engineering education and, subsequently, in industry. This chapter will present recommendations on both levels based on the insights developed as a result of this research

5.2. Conclusions from Project Experiences

The unit that was developed for this research was designed both a prototype and a test-bed for teaching techniques. The unit could be used in its experimental form, but it could also be enhanced to give a more comprehensive and/or detailed treatment of creativity theory and skills application.

5.2.1. Methods and Results

The course unit developed for this research project was a prototype. The goal of the course planning was to develop a practical unit that could be incorporated into a regularly-scheduled engineering design course. Two aspects of the unit detracted from the standard format for engineering classes -- the lack of grading for the unit and the nature of the testing. In regard to the first factor, it was feared that any traditional type of grading system would immediately become an environmental inhibitor and restrict students' creative ability. As result, both test groups were told that their performance on the tests would not affect their grades for the course. The tests themselves were unconventional. They ascribed numerical ratings for each response to the open-ended questions. At first it might seem that creative responses would defy such a limited scoring system. In addition, it would seem that experimental error would be introduced due to the apparent subjectivity involved in differentiating between conventional and creative responses. These arguments are not a concern, however, since the important metric for the testing results is not how well students performed on either of the tests in an absolute sense, but rather the magnitude of their relative improvement in performance. The scoring procedure made use of a master list of responses categorized according to established criteria. This ensured consistency in the grading process and yielded a greater degree of validity for the the comparison results.

From a statistician's viewpoint, the sample sizes used for the research were less than ideal. The strength of the improvement trend for the ENGR 297E group's scores would seem to reduce concerns over the credibility of the experimental outcome. From a researcher's perspective, additional time for the unit would have been desirable since it would have given the students more time to reinforce their creativity skills through additional activity experiences. This might have produced an even greater improvement in the student's creativity scores. On the other hand, there is no explicit evidence that the improved test scores prove that students used the attribute-based technique taught during the course unit. Even if the improvement resulted primarily from reduced inhibitions, though, it appears that the classroom activities helped reduce those inhibitions. The techniques were therefore at least indirectly, if not directly, responsible for the improvements.

The final conclusion from the data is that the creativity unit did improve the ENGR 297E group's performance in the four designated skill areas that relate to creative problem-solving processes.

5.2.2. Literature-Induced Issues Addressed by Creativity Unit

The findings reporting that General Electric's creativity program graduates producing more patents than non-graduates did not consider the possibility that the screening process for the program biased the results (Mathews and Bailey 1965, 85). For the ENGR 297E creativity project, both the experimental and control groups were selected in a random fashion, eliminating concerns about group selection methods biasing the results.

Bailey assumed that suitable teaching methods can enhance students creative abilities and that the individual is the basic source of creativity (Bailey 1978, xii). These same axioms were espoused for the creativity unit development. Instructional methods were targeted at teaching creative thinking strategies for individuals, and the testing evaluated each student's creative ability level independently. Group involvement in activities was designed to provide a dynamic environment to facilitate individual creative thinking. The cognitive techniques presented in class provided the "...ingredient or spark which sharpens the imagination with intellect" (Gjesdahl 1955, 769) mentioned in the literature. The classroom activities were open-ended in nature, but each was structured to achieve a specific learning outcome by requiring students to follow a predetermined thought process. These target-driven exercises satisfied Cowan's criteria for purposeful design problems that ensure development of design skills (Cowan 1981, 743).

Cowan cited evidence of the value of metacognition in problem-solving (Cowan 1981, 745). The creativity unit was designed to teach students about cognitive processes in creative problem-solving processes while also considering attitudinal factors that affect creativity. These facets of creative problem-solving were presented using an interrelated process, as Whitman discussed (Whitman 1983, 12). The unit's composition also allowed for Rutherford and Rowe's finding that teaching theoretical principles alone would not result in students immediately adopting new practices (Rutherford and Rowe 1987, 377). The incorporation of activities in the creativity unit ensured that students immediately practiced applying their new knowledge. The organization of the lessons in the unit reflected Mathews and Bailey's objectives; that is, to illustrate steps for problem-solving and to provide students with practice in solving engineering problems. The activities also satisfied Evans *et al.*'s three criteria for such learning exercises. They felt that activities should involve competition between groups, realistic or unsolved problems, and the synthesis of a new device instead of the analysis of an existing one (Evans *et al.* 1990, 518).

McNeill *et al.* and Masi noted the detrimental effects that grading can have on students (McNeill *et al.* 1990; Masi 1989).

McNeill *et al.* called for instructors to foster a supportive environment so that students can build confidence in their creative abilities (McNeill *et al.* 1990, 550). The ENGR 297E creativity unit provided for non-inhibiting evaluation of students' creative abilities. Although no official grade was assigned for this portion of the course, students did receive feedback on their performance through the evaluation of their test results. Traditional stigmatics about grades were eliminated, though, because of the non-traditional nature of the grading system. Since scores for the questions were not tallied into a single numerical score, students could easily identify areas in which they could improve their performance. As the scores were not reduced to a single percentage, students did not compare their scores to an ideal numerical score, which would have prompted them to attribute a simple "good" or "bad" connotation to their performance. The scoring system instead showed students their strong and weak areas, focusing their attention on where they needed to improve while at the same time building their confidence in their strong ability areas. Thus, students and faculty received feedback on the results of the teaching without the students becoming discouraged by grades. This method did require a greater amount of time for grading than for a more traditional test, so some type of hybrid evaluative tool might need to be developed in the future.

5.2.3. Peripheral Outcomes

Whiting discussed the beneficial effects that regular application of operational techniques for creativity can have in conveying the importance of creativity (Whiting 1958, 142). Awareness, in turn, can affect individuals' attitudes, which have been identified as being of greatest importance to successful nurturing of creativity (Courses in Creative Problem-Solving" 1967, 7) . But Whiting seemed to sum up best the possible benefits of creativity units such as the one developed for this project:

> Proper orientation is one of the chief benefits to be gained from courses dealing with creativity...These experiences give an individual an indication of the importance of creativity and at least some knowledge of the principles affecting it. Through such knowledge and the confidence gained in one's creative ability through actual experience in using it, creativity becomes less of a mysterious concept, and more of a skill or ability which the individual knows how to exploit. (Whiting 1958, 21)

Teaching specific techniques for creativity should motivate students to use the techniques, along with their own creative strategies, more often. The ENGR 297E students' responses on the unit-evaluation questionnaire seem to bear this out: in general, the students felt more creative as a result of the unit, and so they would probably be more inclined to apply their creative abilities to solve problems. Bugliarello warned of tendencies to abandon limitations of physical laws once creative principles are introduced. To a certain degree, such relaxations of physical laws might be allowable to try to generate new solution approaches. Students must be taught to link solution ideas to existing technology, though, and they must be shown that the scientific method should be applied to investigate possibilities for developing new technologies. Bugliarello's observation emphasizes the need to introduce creativity within engineering courses so that it can be developed in a supervised environment. In such a setting, students should be exposed to the significance of creativity, the factors that affect it and be given practice applying their creative skills so that they can learn to appreciate how and when to use them effectively in engineering activities.

5.3. Improvement Suggestions for Creativity Unit

Although successful in its initial format, many aspects of the creativity unit could be improved. This section identifies some issues that should be addressed to improve the unit. Some concerns are drawn from the literature, while others were realized from first-hand teaching experiences during the project.

5.3.1. Experience-Based Improvement Suggestions

The fundamental format for the unit was lecture and discussion to introduce principles and thinking strategies, followed by activities that gave students practice in applying theoretical principles and mental strategies. This basic structure appears to be effective. Several improvements could be made, however, in three fundamental areas: presentation, activities, and evaluation.

The presentation of theoretical principles should not be viewed as strictly lecture in the traditional sense. It should give cohesion to the learning process and also serve as a source of stimulation for ideas. In light of this, teaching materials should be developed beyond the primitive resources used for this project. Examples should be used more frequently to illustrate the processes involved in creative problem-solving. A provision should be made to supply student with stimuli that can be used to spark ideas during group activities. All this should be presented within the auspices of a comprehensive theoretical framework that explains pertinent terminology related to creativity and engineering problem-solving.

Whiting noted that creative individuals are distinguishable by their vision, that characteristic that enables them to see the potential value of new ideas (Whiting 1958, 10). Students should be encouraged to develop their skills in this area, too, through classroom experiences. This would mean more time spent giving examples of creative solutions and discussing the implications of student-generated solutions. This would demonstrate the utility of the students' own answers, and it would also indirectly demonstrate the value of the techniques that the students used to generate those solutions.

During the activities for the unit, students should be given problem activities that are more visibly related to engineering applications. Industrial problems or activities derived from patent records should be integrated, at a suitable complexity level, to give the students a sense of the challenges that engineer typically face. In addition to these more realistic activities, manipulation of physical objects could be incorporated into some activities to reinforce the notion that the end result of design activity usually involves the manufacture of an artifact. This might be used to illustrate the role of creativity in design for manufacturability (DFM) considerations. In general, the activities should be designed to be goal-oriented, rather than haphazard, design experiences.

In its existing form, the creativity evaluation test could be improved in three ways. More time could be given for the test, permitting more varied, and perhaps more complex, questions. The criteria for the answer categories could be refined and made more explicit. Finally, additional fluency levels could be added for the scoring to give more differentiation of scores within the high-flexibility range. The paper-and-pencil format of the test might not be the most desirable for a engineering creativity evaluation tool, however. Competitions and/or performance in activities could be used, as could tests that involve the manipulation of physical objects. Perhaps the best evaluation system would contain elements of all of these to give a multi-faceted appraisal of students' creative abilities. No matter what their format, evaluation systems should be designed while considering the effect of the feedback on the students. The attitudinal aspect of creativity must be developed in a positive manner rather than being suppressed. Evaluation system designers will also need to be mindful of complexity considerations to ensure that evaluation systems can be used with consistency by many faculty members and teaching assistants.

5.3.2. Literature-Induced Improvement Suggestions

Several improvements that could be incorporated into the creativity unit are suggested by two authors. Cowan felt that the the following steps must be taken:

1. Students must be given the opportunity to acclimatize themselves to new modes of learning by repeating each activity at least once.
2. Activities must be shown to have relevance to actual engineering activities

3. Forms of assessment must be refined to ascertain levels of ability in each stage of the design process.

(Cowan 1981)

Based on Hallman's list of aids for creative thinking (Hallman 1967), the following suggestions could be proposed for the unit:

1. Students should be saturated with stimuli (e.g. information, imagery, meanings, etc.) to provide intellectual fuel that would drive creative thought processes.
2. Students should be sensitized to look for unsolved problems and overlooked opportunities.
3. Students should be motivated to engage in self-initiated learning.
4. Students should be given the opportunity to manipulate materials and structures as well as ideas.
5. Students should be forced to face failure and shown strategies for coping with it.

Their are no doubt various methods that could be employed to reduce these suggestions to practice. The important requirement is that the activities developed be goal-oriented to achieve a specific desired outcome.

5.4. Opportunities for Future Research

Bailey recognized the need for directed, coordinated efforts to examine the nature of creativity and apply the findings to develop design techniques and appropriate teaching methods: "What is needed is the development of a discipline in this field; our knowledge must have structure to be truly useful" (Bailey 1978, xiii). Creativity should be treated as a teachable subject; this research project has demonstrated that explicit teaching can affect students' creative abilities. Before creativity can be incorporated into the curriculum on a more widespread basis, though, research will need to be conducted in two affiliated areas: cognitive strategies and testing methods.

The cognitive facet of creative thinking is served by operational techniques. The procedures taught in the creativity unit were primitive, first iterations, experimental in nature. Research is needed to determine mental strategies employed by creative individuals and to develop methods for teaching these strategies to engineering students. Olken reported that eminent inventors employed mental "cues" to spur their creative thought processes (Olken 1964, 160). These reports should be corroborated and the nature of these "cues" should be examined. Bugliarello noted that students had difficulty formulating abstract images of a concept (Bugliarello 1969, 880). Research on the use of mental "languages" might be applied to teach students to break out of stereotypical perceptions. Bugliarello also warned of students difficulties in using imagination to identify with an element of a problem and in bridging the gap between ideas and practical suggestions (Bugliarello 1969, 880). Research is needed on teaching techniques that would foster the development of such insight. Research reports on techniques will need to be prescriptive as well as descriptive so that successful techniques can be exported.

Evaluation instruments that are relevant to the engineering educational environment need to be developed and validated. These instruments will be needed to identify the most successful operational techniques as well as student's level of skill development. The construction of these instruments will involve determining the creative outcomes that are desired and devising metrics accordingly. Mathews and Bailey observed years ago that, "...there is no generally accepted test which measures creativity in general, or, specifically, creativity in solving engineering problems" (Mathews and Bailey 1965, 89) This situation still exists today. It is time to apply creative approaches to develop methods for appraising creative ability. It may be necessary to abandon the idea of a single, pencil-and-paper test and to develop instead composite evaluation systems that independently evaluate various aspects of engineering creativity.

5.5. Implications of Results for Curricular Reform

Several authors have discussed the imbalance that currently exists in undergraduate engineering curricula between the emphasis placed on teaching engineering science and analysis skills and developing creative problem-solving abilities (Evans *et al.* 1990; McMasters and Ford 1990). The overemphasis on analysis skills has been recognized as impairing the development of design skills. Cowan asserted that, "...there is a great obligation on the engineering teacher to provide simultaneously a complementary programme of creative and open-ended course activities" (Cowan 1980, 252). The results from the creativity unit experiment clearly indicate that attempts to teach creative thinking strategies can facilitate creative design idea generation. Activities-based course units that treat creativity in an explicit manner could be an important means of adjusting the emphasis of the undergraduate engineering curriculum to achieve a more equitable balance between teaching analytical skills and teaching design strategies. Educators will need to realize that the two types of teaching require two distinct instructional approaches. Success in teaching creativity skills will require faculty to embrace some non-traditional teaching methods.

Now that creativity teaching has been demonstrated to influence the development of students' creative skills, the question becomes one of how such teaching should be integrated into the existing undergraduate curriculum for maximum effect. In an ideal situation, creativity would be nurtured in every aspect of the engineering program. Since this would need to be a long-term goal, in the short-term creativity is likely to be introduced within engineering design courses. Bailey recommended that creativity principles be introduced in a student's senior year, once they have had sufficient engineering experience (Bailey 1978, xi). There is a problem with this approach, however. While students would be more familiar with the tools and materials commonly employed in engineering, at this point students would not have pondered creative applications for engineering science principles as they learned about them. Since they would learn scientific principles while functioning in an analytical thinking mode, students would not be motivated to look beyond the the material to consider creative implications. Early creativity training could enrich students' undergraduate learning experiences.

The results of this research project demonstrate that it is possible to teach, with a definite impact, principles of creativity within an engineering design context as early as the freshman year. The most effective strategy for developing students' creativity skills might follow McMasters and Ford's recommendation. They voiced the desire, from an industrial perspective, for good conceptual design courses at both the beginning and end of the engineering curriculum to give context for engineering science learning. Creativity teaching, at two different levels of sophistication, should be an integral part of such course offerings.

5.6. Final Remarks Concerning Teaching Creativity Explicitly

The problems in engineering education are not all centered on the need for creativity development, nor will they be solved by integrating creativity teaching into a few isolated design courses. The need for creativity training in engineering design courses is a critical one all the same. Engineering educators rely too heavily on traditional quantitative exercises and evaluation methods to teach engineering courses. While analytical methods are certainly a prominent aspect of an engineer's training, it is time to recognize the equal importance of developing creative synthesis abilities. Creativity has long been considered by many to be unteachable. This is largely due to conventional thinking about what constitutes engineering teaching. Creativity teaching requires more emphasis on the process and less on the products of thinking. Teaching creativity is a challenging endeavor, and it may require more effort on the part of the faculty involved than for a traditional engineering science course. Yet engineers, of all professionals, should be the last to avoid a challenge because of its difficulty.

It may seem contradictory to attempt to give structure to creative thought, which has traditionally been considered to be a chaotic, unstructured mental activity that relies heavily on serendipity. A process does seem to exist, though, and certain steps seem to be common to many forms of creative thought, no matter what the context may be. An understanding of structured approaches to creativity is important in the engineering design process not only to improve personal thinking strategies, but also because it can influence decision concerning the directing of investigation efforts on a supervisory level.

Arguments that creativity cannot be taught explicitly are not new -- it was this type of thinking that stunted the development of creativity-enhancing programs. Modern design education efforts have spoken about creativity as a desirable learning outcome, but few contemporary programs in engineering attempt overt teaching of appropriate principles and skills. It cannot be for lack of precedent to guide teaching efforts; numerous examples of creativity courses were in existence during the late 1950's and early 1960's, as the literature attests. The stagnation of developing educational programs in this area must therefore be attributable to perceptions about the importance and effectiveness of teaching creativity skills. Many engineering educators are now re-awakening to the importance of creativity; the results of this project demonstrate the outcome that can be achieved by teaching it explicitly.

The field of creativity is under-developed and ready to experience advances. There exists now an urgent need to establish axioms on which research in this area can be based. Common definitions need to be developed and accepted and primary directions for research efforts need to be decided upon. A theoretical framework should be erected on these foundations so that educational techniques can be developed and tested within its context. The creativity unit developed and taught during this research project was a coarse, first iteration. No doubt alternative, and perhaps more creative, teaching methods could have been employed. More experiments like this one need to be undertaken so that a set of effective creativity techniques can be identified and used to shape a course core suitable for widespread adoption in undergraduate programs. Such experiments will need to be reported in the literature, along with the dissemination of teaching materials through distribution networks, in order to ensure successful application of skills.

Engineering educators face a challenge in trying to develop creativity. It is a higher-level cognitive skill than analysis, and so it is not as easily developed. Modern engineering graduates, though, are entering environments where analysis functions are being automated on computers to an increasing degree. As result, the engineer's worth will soon depend largely on his or her ability to conceive creative solutions for design problems. Though analysis techniques will grow in complexity, engineering analysis tools will respond to the change. In the world of the future, creativity will be one of the most important skills that engineers possess. Engineering educators of today need to develop educational programs that will prepare graduates for this future. This means actively teaching creativity in the undergraduate curriculum, thus adding design strategies and creative thinking techniques to the engineering graduate's mental "tool box."

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Appendix A

GLOSSARY OF TERMS

Conceptualization -- idea that is synthesized by a mental fusion of concepts; an idea-compound

Creative Problem-solving -- using imagination and original thought to generate non-typical solutions for problem situations

Creativity -- generating non-typical conceptualizations

Adaptive: forming a new modification of previously-known conceptualization

Original: forming a completely revolutionary conceptualization

Design -- forming an appropriate solution configuration from a number of sub-configurations in order to fulfill one or more specific requirements.

Engineering -- application of known principles to solve problems

Engineering Science -- physical principles that are used to create technologies. Includes both subject matter and analytical methods

Fitting -- process of adjusting existing engineering solutions so that they meet the requirements of a specific problem situation (e.g. modifying materials specifications, increasing power output, etc.)

Imagination	-- mental activity that considers unusual concept configurations by disengaging thought processes from the restrictions of reality
Innovation	-- implementation of ideas that are the product of creative thought
Invention	-- application of physical principles to formulate a previously unknown system that performs some designated function(s)
Problem-solving	-- Determination of a suitable solution path to transform an initial, problem condition to a final, desired condition
Synthesis	-- Mental integration of concepts and/or creative ideas to formulate a conceptualization whose value is greater than the sum of the values of the initial, distinct ideas.

Appendix B

OPERATIONAL TECHNIQUES FROM THE LITERATURE

Source	Technique Name
Whiting (1958)	Attribute Listing Input/Output Focused Object Brainstorming Gordon Technique
Love (1980)	SCAMPER Morphological Analysis
SRI Journal (1967)	Alternate Uses
Olken (1964)	Wrong Approach Barrier Technique of Originality
Bugliarello (1969)	Analogies

Appendix C
GROUP ACTIVITIES

Engr 297E, Creativity Unit, Lesson #3

Activities in Task Definition

Situation: In the state of Maryland, the Howard county government was concerned with decreasing the number of bicycle-related injuries on public roads. With this in mind, the county government passed a law requiring all cyclists age 15 years & younger to wear bicycle helmets.

Task: List any assumptions that the Howard County government made about the problem.

Form parallel task definitions by breaking these assumptions.

Create an ambiguous task definition that would leave room for more creative problem-solving approaches.

Drawing Board:

Engr 297E, Creativity Unit, Lesson #4

Activities in Conceptualization

Situation: Your group will be given an object to conceptualize.

Task: Using the list of attributes generated in class, describe your object in terms of its attributes.

For each attribute, list at least one other object that has the same attribute. Try to make the second object as different as possible from the first.

Drawing Board:

Engr 297E, Creativity Unit, Lesson #5

Activities in Alternate Uses

Situation: Your group will be given an object to consider.

Task: List some of the attributes of the object.

For each of the attributes, compare your object to at least one other object on the basis of the attribute.

Suggest new uses for the object on the basis of the comparisons that you have made.

Drawing Board:

Engr 297E, Creativity Unit, Lesson #5

Activities in Attribute Manipulation

Situation: Fed up with her stapler continually jamming, a patent attorney decides to experiment with different brands of staples to see if stronger staples will prevent the jamming.

Task: Approach the problem from a product standpoint.

Conceptualize the product according to its attributes and compare it to other objects based on these attributes.

Alter and add to the existing attributes on the basis of the compared objects to re-design the product.

Drawing Board:

Engr 297E, Creativity Unit, Lesson #5

Activities in Solution Synthesis

Situation: A nursing home is being renovated to accommodate patients handicapped by hearing loss, blindness, and other physical disabilities. One of the problems raised by this project is how to ensure that the patients' safety will be looked after in the event of a fire. (Consider, for instance, a deaf patient could not hear a fire alarm.)

Task: Define the attributes for possible solutions.

Draw up lists of comparisons to other objects, each based on one of the attributes that you identified.

Combine compared objects from different attribute lists and generate solution ideas.

Drawing Board:

Appendix D

EVALUATION ACTIVITIES

ENGR 297E Homework Assignment #3

For the third assignment <u>only,</u> you will be working on a written assignment related to the creative problem-solving exercises that we have been conducting in class. This assignment is designed to take each of you through the steps of the creative problem-solving process that you have been exposed to in your group activities.

For this assignment, pick a product or device, either existing or from your own imagination, and discuss it in the following ways:

1. Identify the problem that it addresses.
2. List the assumptions of that problem statement.
3. Define parallel task definitions.
4. Identify a more ambiguous task definition.
5. Conceptualize the product/device.
6. Change your conceptualization(s) to generate alternatives and/or modifications to the design.

You should work on this assignment on your own rather than in your group. Assignments will be collected during the last creativity class on February 22, 1991.

CREATIVITY PRE-TEST

INSTRUCTIONS:

You may not have encountered questions like these before -- they are open-ended questions, which means they do not have specific correct answers. Do not concern yourself with finding the right answers, just give the best answers that you can generate. Place all of your answers on the sheets of paper provided.

1. In your own words, define creativity. Why is it important in engineering?

2. Consider a common telephone. List as many of its shortcomings and/or faults as you can.

3. Jim rides his mountain bike to classes each day. One morning, the strap on his bookbag breaks and his books fall onto the sidewalk. How might he prevent this from happening again?

4. The Federal Government, in an attempt to reduce the number of highway accidents, sponsors a research program aimed at improving the traction of automobile tires. What assumptions has the agency made in defining the problem associated with highway accidents? What other approaches might have been taken to achieve their goal?

5. For each pair of objects, list several ways in which the two objects are alike:
   a) a single-family home and a life raft
   b) a soda can and a double-glazed window

6. Create 3 metaphors for a book.

7. List several ways in which a barometer could be used to find the height of a building. (A barometer is an instrument that measures pressure.)

8. Suggest several ways in which the design of a pen could be improved.

9. Suggest several alternate uses for a trash can.

CREATIVITY POST-TEST

INSTRUCTIONS:

The questions on this test do not have specific correct answers. Do not concern yourself with finding the right answers, just give the best answers that you can generate. Place all of your answers on the sheets of paper provided.

1. Consider a walkman radio. List as many of its shortcomings and/or faults as you can.

2. The Pennsylvania Dept. of Transportation loads salting trucks for treating roads in winter storms by pouring the salt from funnel-shaped overhead holding bins. Sometimes air pockets, or cavities, form beneath the top surface of the salt as the salt below empties and the salt above fails to fill the void. There have been incidents where workers walking on top of the salt in the bin have been trapped as cavities collapsed below them. How might the DOT prevent these accidents from happening again?

3. An apartment-dwelling student finds that the food in her refrigerator is spoiling faster than it should. She attempts to correct the problem by turning down the thermostat controller's temperature setting in the main compartment. What assumptions has she made in defining the problem? What other approaches might she have taken to approach the problem?

4. Compare a drawing compass to 3 other items.

5. For each pair of objects, list several ways in which the two objects are alike:
   a) camera & campus loop
   b) pencil eraser & wristwatch

6. Suggest several ways in which the design of a lawnmower could be improved.

7. Suggest several alternate uses for an umbrella.

8. In your own words, describe the differences between problem-solving, design, innovation and creative synthesis.

Appendix E

EVALUATION METHODS

Engr 297E

Assignment #3 Grading Scheme

A total of 70 points were allocated for the content portion of your grade. The points were distributed as indicated below:

(10 pts) 1. Problem Definition -- Choose a device and describe the problem that it was designed to address.

(10 pts) 2. Assumptions -- List the assumptions that were inherent in the original problem definition stated in #1. These assumptions will have directly influenced the existing form of the selected device.

(10 pts) 3. Parallel Task Definitions -- For each of the items listed in #2, break the assumption to propose alternatives to the original problem definition.

(10 pts) 4. Ambiguous Task Definition -- re-state the problem situation so that it is more open to creative interpretation.

5 pts --> Problem is more broad in scope than the task definitions listed in #1 and #3.

5 pts --> Problem does not incorporate any of the assumptions listed in #2.

(10 pts) 5. Conceptualization -- Describe the selected device in terms of some of its attributes and draw comparisons to other items that are similar to the device in terms of the attributes that you selected.

5 pts --> Object described in terms of attributes.

5 pts --> Object compared to other objects.

(10 pts) 6. Alternate/Modified Designs -- Use the parallel task definitions of #3 and/or conceptual comparisons of

#5 to stimulate new ideas for the design of the device that you selected.

5 pts --> An alternate/modified design was proposed.

3 pts --> Ideas proposed are related to the parallel task definitions of #3 and/or the conceptualization comparisons of #5.

2 pts --> More than one change was proposed (not just one "right" answer given.)

(10 pts) Bonus -- For exercising your creativity. (Given to everyone)

The content portion of the grade assessed how well you followed the creative problem-solving process that we practiced in the class activities. The remaining 30 points of your grade were awarded on the basis of your communication skills, i.e. grammar, spelling, etc.

ENGR 297E
Pre- & Post-Test Evaluation Method

The creativity activities were evaluated using an assessment system consisting of 5 answer levels. A rating was assigned for the answer to each question by categorizing the answer into one of the 5 levels that are defined as follows:

Level	Description
N	The student did not provide an answer to the question.
A	The student provided a single "apparent" answer.
B	The student provided multiple "apparent" answers.
C	The student provided one "unorthodox" answer, either on its own or with additional "apparent" answers.
D	The student provided two or more "unorthodox" answers, either on their own or with additional "apparent" answers.

The results from your responses are shown below:
Name ________________________

Pre-Test

2	3	4		5A	5B	8	9
1	2	3	4	5A	5B	6	7

Post-Test

Question Types: The Pre-Test and Post-Test contained 4 types of question. The types were:

1. Describe shortcomings or suggest design improvements.
2. Propose approaches to a problem situation
3. Make comparisons to other objects
4. Suggest alternate uses for objects

Answer Categories: Answers to the test questions were differentiated into two categories, "apparent" and "unorthodox." For each of the four question types, the criteria for each category is described below:

Type 1: Apparent

- Suggested change in physical characteristics (e.g. size, color, material)
- Proposed improved performance for portions of the existing configuration (e.g. re-design handle, lower cost)
- Suggested already-existing options (e.g. cordless phone)
- Suggested a common complaint

Unorthodox

- Added features and/or capabilities to the system
- Altered the fundamental nature of the system and/or its elements

Type 2: Apparent

- Did not break out of the assumptions in the original problem definition
- Took a typical approach to the problem solution

Unorthodox

- Removed or added a constraint to change the problem definition
- Approached problem solution from an unusual angle

Type 3: Apparent
- Based on shared physical characteristics
- Based on common aspects of functional definition
- Based on shared elements related by normal conceptualizations
- Based on operational characteristics
- Based on naming conventions

Unorthodox
- Based on unusual possible applications
- Based on external requirements
- Based on shared elements related by unusual conceptualizations
- Based on unusual shared characteristics

Type 4: Apparent
- Related to original functional definition
- Suggested an already popular unusual usage

Unorthodox
- Suggested a usage not related to the common functional definition
- Suggested unusual usage not normally practiced

Interpretation of Results:

"Apparent" and "unorthodox" answers both have their place in the creative design process. "Apparent" answers are linked to the process of **adaptive creativity**, i.e. improving existing systems by making changes to their elements, finding ways to apply normal functions of systems to new situations, and suggesting alternative solutions for problems that are already well-defined and constrained. "Unorthodox" answers are related to the process of **original creativity**, i.e. changing a system by altering its fundamental composition, finding unusual applications for systems, and proposing solutions to a problem situation by changing the way the situation is approached. Both types of process, adaptive and original creativity, are important in creative design. Specific circumstances will dictate which process should be employed more heavily for each individual situation. Engineers can improve their skills in both areas with practice.