Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perceptions

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1 Introduction

Creativity is a prerequisite in any ingenious design: the harvest of electricity; the airplane; the Apollo program; the silicon chip; the internet. Time and again, America has proven that creativity results in design and technological breakthroughs that change the course of human history. The history of achievements reveals a process in which knowledge of the mathematical and natural sciences converged with the skills of critical judgment and creativity, an understanding of economics, the adoption of iterative processes that embrace failure, and the desire to create technological miracles. This amalgamation is now known as “engineering.” To foster and further evolve this legacy of engineering ingenuity, it is critical that we educate engineers to be creative thinkers and educators. This fact is repeatedly echoed by educators, industrial managers, professional associations, national academies, and political leaders. If creativity is so central to engineering, why is it not an obvious part of the engineering curriculum at every university? Part of the answer might come from reviewing the history of engineering education in the United States and Europe. Engineering education in Europe and the United States has gone through at least three distinct phases in the past 50 years. The nature of these phases, in turn, largely defined the perception and implementation of creative thinking in engineering education.

1.1 The Historical Phases of Engineering Education in Western Countries. Soon after World War II in the United States and in Great Britain, large numbers of war veterans with significant informal, hands-on technical training entered formal engineering programs and shaped the culture and pedagogical paradigms of engineering education. In the 1950s and early 1960s, in the United States and in Europe, engineering education heavily emphasized learning by doing and hands-on skills. As a result, students emerged from these programs as highly trained engineering technologists who were able to produce practical, workable systems and technical machines. Engineering schools in Asia and the Middle East adopted similar approaches.

In the late 1960s, the 1970s and early 1980s, the space race, nuclear era, cold war, energy crisis, and emergence of computers began to transform engineering education. More complex applications exceeded the limits of the engineers’ intuitions and demanded a superior mastery of the natural and mathematical sciences. The paragon of engineering education became one in which students entered a program well-versed in mathematics and sciences and graduated with an even greater mastery of these areas. The pendulum had swung to the opposite side, with theoretical aspects of engineering predominating. Engineers were being trained just like scientists.

In the late 1980s, experts in industry began to question the pedagogical premises of “knowledge transfer.” Their assessment was negative. Engineers, they claimed, generally lacked the skills needed to excel in an increasingly competitive environment. They cited skills relating to critical thinking, team dynamics, societal and cultural awareness, communication, creativity, problem solving, economic analysis, and so on; skills that scientists were rarely expected to have mastered. In response to these criticisms, educators responsible for designing engineering programs, first in the United States, then in Europe and finally in other parts of the world, renewed their attempts to strengthen the “design component” of engineering curricula. Executing this transformation proved more difficult than they had anticipated. The “design components” they introduced were, in most cases, scarcely more than exercises in the rigorous synthesis of various applications of the same fundamental sciences. Many engineering educators felt very uncomfortable abandoning a structured and rigorous scientific paradigm and adopting the more flexible approach required in “design.” Nowhere was this more apparent than in The Accreditation Board for Engineering and Technology’s (ABET’s) design requirements for engineering curricula in the 1980s [1,2], which ironically spelled out a very rigid (and quantifiable) method for eliciting “creativity.”

In the 1990s, the evolution of engineering education continued. Over the past decade, ABET advanced a major reform effort designed to encourage curricular innovation and to improve the accreditation process. These efforts have given rise to new criteria for evaluating engineering programs, Engineering Criteria 2000 (EC2000) [3], which have once again shifted the emphasis of engineering curricula, this time moving away from using prescribed measures and toward evaluating student outcomes in a
process of continuous self-assessment and improvement. Although the subject of creativity is not addressed directly in the (EC2000), these new accreditation criteria have sparked much debate among engineering educators and have significantly promoted interest in engineering education and its challenges and consequences [4–7].

1.2 Our Hypothesis: Creativity is Not Valued in the Contemporary Engineering Education. It is our belief that despite the intense efforts toward embracing creativity in engineering education in recent years, progress has not been significant. Very often, creative work by the students is viewed by faculty as an excuse for sloppy work. They believe that engineering is serious business that demands tedious attention to details and an absolute need for accuracy. Often, embracing ambiguity and exercising flexibility is equated with holding lower standards. Even in the design process in assigned projects, faculty require the students to mostly follow well-proven design techniques that they have covered in the text books or lectures rather than challenge students to think through a new process or innovate a unique solution.

Further, although we have not been able to find any authoritative research in the literature, we believe that the factors and the environment that impede creativity are far more profound and dominant in the engineering education than they are in sciences education and naturally far more than those in liberal arts education. A few engineering programs represent notable exceptions to this but they remain just that; exceptional, and the differences seem to have more to do with the individual instructors than with the overall curriculum.

Through our informal interviews with engineering faculty and students, and reflections on our own experiences as educators, we have established anecdotal evidence that identifies some creativity blockers in engineering education. Although this evidence cannot be considered scientific or statistically significant data, they led us to form the hypothesis (conjecture) that is the premise of our work: Creativity is not valued in contemporary engineering education. To examine the validity of this conjecture, we have undertaken a more formal study as described in this paper. Examples of the anecdotal comment we received were:

- Engineering is serious business, engineers must be accurate not creative.
- Creativity leads to chaos and disorder in the school and later to design uncertainties and therefore legal liabilities in practice.
- Creative behavior contradicts or violates academic standards at school and national engineering standards in practice, standards that are results of tens of years of experience.
- Musicians, artists, and poets do not build automobiles, bridges, and cell phones.
- Anyone can produce a draft design. Engineers must only use fundamentally sound equations and established procedures and precedents to design.
- Engineers cannot take risks. The example of building bridges, making mistakes, and loss of lives comes up often.

We also received critiques of the status quo from some colleagues. Some are noteworthy:

- The typical engineering program teaches that there is a known correct answer that we are aiming toward and that we should find this particular answer as quickly and efficiently as possible.
- There is no room for the student to wonder, discover, and innovate.
- Engineering programs tend to be highly competitive and sufficient grades are very important, in fact grades will likely determine whether a student can stay in the program. Although it may be a valuable experience to learn to work under pressure, such restrictions also inhibit students from taking risks. Without learning to fail, students have an unrealistic view of what the engineering profession is truly about.
- Curiosity, inherent in those who actually choose to be engineers, has been limited to “how something works” rather than the equally important “if something could work” in the school environment. Regurgitating known solutions has become the norm without the balance of allowing students to keep that sense of wonder.
- The majority of the engineering faculty are educated themselves in very structured programs in which scientific and mathematical accuracy was the unequivocally dominant factor. The current administrative philosophies in the schools of engineering and the evaluation, tenure and reward systems for the engineering faculty, further encourages such structured mindsets.
- Women constitute a small minority among the engineering faculty. According to the American Association of University Women, they constitute between 3% and 15% of the engineering faculty [8,9]. There is solid researched evidence that diversity and creativity of an environment are strongly linked [10].
- Infusion of design activities in the engineering curricula has been in practice mostly limited to “synthesis” exercises using known methodologies. Capstone design projects in the senior year are very valuable exercises that widen the view for engineering students. However this stops far short of embracing and harvesting creativity as an integral part of their four-year college education in engineering.

1.3 Our Approach. This paper entails some of the outcomes of a study at the University of Connecticut. The overriding goals of this study are to determine the factors that define, impede, or foster creativity in engineering education, its social and technological consequences, and to develop, test, and recommend modifications to the engineering curriculum that facilitate embracing creativity. This paper looks specifically at the current status quo at the University of Connecticut’s School of Engineering which we believe is a good example of mainstream engineering education in the United States. To validate or disprove our hypothesis, the focus of this paper is on the followings

1. Identify factors and traits that delineate creativity, as appropriate to education based on established research in the fields of psychology, educational psychology, and in current creative work practices of innovative product designers.
2. Evaluate the self-perception of engineering as well as nonengineering faculty of how they may or may not elicit creativity in their classrooms.
3. Evaluate engineering students as well as nonengineering students on how they perceive factors contributing to creativity in their educational environment.
4. Identify the specific factors (if any) that impede creativity in engineering education and determine whether they are more or less prevalent in engineering education than in other disciplines.
5. Use these factors that impede creativity to suggest recommendations to modify the engineering classroom experience to include creativity development.

2 What is Creativity?

2.1 Intrinsic Creativity. A large body of knowledge exits in the psychology literature on the definition of, and traits that constitute creativity, [11–23]. Sternberg lists 61 different definition of “creativity” [15] from various viewpoints including those of behavioral psychology, social psychology, cognitive science, philosophy, design research, innovation, and many others. Psychological research [20,22] has shown that most people have a similar implicit definition of creativity. When being creative, a person tends to take chances [14,19]; to have the ability to make unique
connections between ideas [12]; to be flexible and imaginative [12,15,17]; to question the normative ways of doing things [11]; and to be motivated, intuitive, and inquisitive [14]. The expression of these creative tendencies depends largely on the type of setting or field in which creativity is being studied [14,16,20]. One encompassing definition of creativity recently offered by education researchers Plucker et al. [24]: “Creativity is the interaction among aptitude, process, and environment by which an individual or group produces a perceptible product that is both novel and useful as defined within a social context.” A simpler and less formal definition of creativity is the ability to generate new ideas or new association between existing ideas. Even simpler, a more intuitive definition is the ability to make new things.

2.2 Fostering Creativity. With the physiological definition of intrinsic creativity, as discussed previously, in mind, in this paper we focus on the environment and the attitudes that foster creativity from a cross section of psychology, education, and engineering practice [11,25–36]. Although some teachers may believe that students enter into programs as creative or noncreative (i.e., that this is an individual difference that cannot be changed), psychological research [34–36] strongly supports the notion that creativity and insight can be nurtured within the educational context. One way that creativity can be augmented is through increasing the rewards of creative output [14,19]. Contrary to early works that stressed that rewards would decrease both intrinsic motivation and creativity [17,37], more recent research has shown that when the rewards for creativity are salient and instructions to the students are clear, rewards increase creativity [38,39] with an increase in extrinsic motivation and no decrease in intrinsic motivation. Moreover, Eisenberger and Rhoades [39] found that when either students or employees within the workplace believed there was a strong connection between high performance and reward they felt increased self-determination (or the ability to determine their own outcomes) and this led to more creativity in the classroom and workplace environment. This leads to a second and more complex issue which is whether students are more focused on potential high achievement versus avoiding low grades. Although these may seem similar, psychological research has shown that [40–42] whether students take a “promotion” (also called an “approach”) focus versus a “prevention” (also called an “avoidance”) focus affects their levels of creativity and problem solving. When researchers manipulated the learning environment such that students felt it is more accepting of risky behavior, students’ creativity increased [29–32]. Students were more excited about the potential to excel and less worried about the possibility of failure [36,39]. On the other hand, when the environment reinforces the penalties for failure, students become more prevention focused and, therefore, less creative in their work. The cues in the classroom environment that foster a more creative, promotion focus can be quite subtle [41].

2.3 Creativity in Engineering Education. The literature on the study of creativity in engineering education is far more sparse compared to psychological or general educational studies on creativity. Nevertheless, several important points and observations exist in the literature about creativity in engineering education. Some of the earlier work on creativity in modern engineering education includes the works on creative engineering synthesis [43] and innovation in engineering [44].

More recent studies have already taught us that innovative behavior in engineering students can be increased if students are offered a few specific creative problem solving methodologies to follow [33] or if students are given individual creativity assessments that expose weaknesses or gaps in creativity potential and address individual creativity blockers [45]. A study at the Louisiana State University attempted to teach engineering students how to use critical and creative thinking skills simultaneously, while designing a product or solving an open-ended problem [33]. Strategies offered to the students included a user role-playing exercise, the use of proper brainstorming techniques and problem solving methodologies. As a result, engineering students were able to design an innovative product. This concept was further verified by a study at the Department of Mechanical Engineering at National Central University in Taiwan [46]. This Taiwan study integrates the teaching of creative problem solving into a sample mechanical engineering classroom. Students were required to solve open-ended problems using the method stemming from Wallas’s four stages of creative problem solving: 1. preparation—research on the problem, 2. incubation—leaving the problem in your mind for some time, 3. illumination—when the solution emerges and becomes clear, and 4. verification—verifying that it works [47]. Students in the study self-reported increased curiosity and ambition but instructors negatively commented that “students might understand the theories and procedures they learned in class, but [are] unable to transfer it to the design of the project” [46]. In both the Louisiana State study and the Taiwan study limited incorporation of creative techniques was followed with small but encouraging success.

Other research suggests that an engineering education may suppress creative personality characteristics but that engineers can unleash this innate creativity in the right environment. Douglas Wilde of Stanford University concluded that engineering education has been shown to inherently block creative potential [31]. His brief study measured the Creativity Index (CI) computed from the Myers–Briggs Type Indicators of participants in an ASEE (American Society for Engineering Education) creativity workshop. The mean CI of participants showed an increase after participants were in the open and creativity-friendly atmosphere of the workshop. As he found that under ordinary circumstances personality type is immutable, Wilde attributed these changes not to a change in the personality type but to the workshop atmosphere unlocking the creative tendencies of the true personality type which had been suppressed by participants’ engineering education. Two important points are recognized in Wilde’s study. First, that engineering education might be suppressing creativity even in naturally creative people and second, that creative potential can be unleashed in the right environment.

But do engineers have personalities that are inherently less creative? This is not true according to a study at Monash University in Melbourne, Australia [26]. This study suggests that it is actually the environment of the engineering programs that hampers creativity and further recommends that we apply creativity encouragement approaches from the business world to engineering education. Hadgraft compares the idea of total quality in business to that of problem-based learning in education, suggesting “more balance towards the needs of real work engineers, and not academic engineers.” Hadgraft also recommends a total focus on a creative environment for the entire department—students, faculty, and staff—is necessary.

Rare but successful individual engineering courses that offer students opportunity for creativity have been recognized by engineering educators [48]. This paper studies engineering courses at the University of Iowa, the University of Nevada–Reno, the U.S. Naval Academy, and Olin College. In these courses problem-based learning is enlisted to help encourage creative thought by students. Following the recommendations of Dr. Paul Torrence [48], a renowned creativity researcher, some of these courses include creativity fostering approaches such as “looking at something from several different psychological, sociological, physical, or emotional points of view,” “tasks structured only enough to give clues and direction,” “going beyond the obvious encouraged.” Unfortunately these courses remain the exception rather than the rule.

The bottom line is that the literature shows that creativity is possible for engineering students. The next step is to identify what the impediments are to creativity in engineering education.
The Ten Maxims of Creativity in Education

Based on a large body of literature on creativity, our own experience, as well as interviews with successful innovators, industrial designers, and practicing engineers, a list of ten factors that constitute and foster a creative educational paradigm is proposed in this paper. We call these factors the Maxims of Creativity in Education and we propose that these maxims constitute an educational environment conducive to fostering creativity in students. These maxims form the basis for our work in judging current engineering education.

A note of caution: This list is not the result of our original research in the psychology of creativity. Almost all of the proposed maxims, in one form or another, either explicitly or implicitly, and with alternative terminologies and expressions, have been studied in the cited literature. The maxims should not be examined from a viewpoint of mathematical accuracy. A list that has half as many or twice as many criteria might be as or even more effective. Last, these maxims should not be considered as an ad hoc and arbitrary conjecture either. As indicated earlier, this proposed list is a unique compilation and culminating result of an extensive literature search, our own experience, and extensive discussions with a broad spectrum of educators and practitioners.

3.1 Keep an Open Mind. Students can be taught creativity by learning to see common things in a new light; this pushes students to understand that the best answer may not be the most obvious one but rather something unexpected. Brain teasers and riddles are simple examples.

3.2 Ambiguity is Good. Students can be taught that the uncomfortable period between getting the question and the answer should be tolerated. Keeping a possible answer just out of reach for a while allows for more thought on a topic and for a greater wealth of information to be collected before a decision or answer is made. During the process, discoveries are made and innovation can happen. The opposite is giving a set answer or process quickly. This greatly limits the possibility of innovation.

3.3 Iterative Process that Includes Idea Incubation. A creative process can occur in stages: preparation, incubation, illumination, and verification [47]. Time must be allowed for this process: (1) to collect a wealth of information and understanding surrounding a given problem, (2) to incubate the idea or relax and “back burner” the problem so that the student can have unconscious thought dedicated to discovery of a solution, (3) to discover a working solution or solutions, and finally (4) to test discovered solutions. All steps are equally important and the concept of backburnering an idea is essential.

3.4 Reward for Creativity. Educators can encourage creativity by explicitly rewarding it. Behaviorists believe creativity to be a response to positive reinforcement. If innovative solutions are rewarded, the student will be more likely to strive for an innovative solution. If only a set answer is rewarded, students are unlikely to bother thinking beyond the offered solution.

3.5 Lead by Example. Students will also learn creativity by example or inspiration. Educators can share with students, stories of the innovators in their field and how progress has been made in the field in the past.

3.6 Learning to Fail. Mistakes can lead to deeper topic understanding and innovation. But when students fear harsh discipline for mistakes during the learning process, their environment is no longer conducive to exploration and discovery. Learning how something does NOT work offers insights into how it MIGHT work. Educators who allow this temporary failure practically encourage innovative solutions by students.

3.7 Encouraging Risk. Risk-taking is considered a personality trait of creative individuals. But sensible risk-taking can be discouraged by educators who create a strong negative impact for a sensible risk in the form of low grades or lack of recognition for the higher difficulty of a risky project. Educators who give constructive critique of a risky project can encourage creative solutions.

3.8 Search for Multiple Answers. Creativity is encouraged when students look beyond one correct answer. Educators can teach proper brainstorming as well as requiring alternate solutions after a correct answer is determined by students. “What if” scenarios for a moment of freedom from practical thinking can also be used to generate creative problem solvers.

3.9 Internal Motivation. Students are more creative when internally motivated in their studies. Educators can foster a deeper sense of interest or deeper curiosity by making a topic relatable. Emphasizing how the understanding of a topic will affect the student beyond class requirements and grades can also help with motivation. This stronger grasp of the topic can allow for creativity.

3.10 Ownership of Learning. Students reveal creative ability when they feel some ownership of or control over their learning process. This control can range from students having a choice in project topics to participation in individual curriculum development. This greater investment can unleash creative potential.

4 Determining the Factors Impeding Creativity—Surveys

Numerous attempts have been made to develop a creativity quotient of an individual similar to the intelligence quotient (IQ). However, a recent study shows that these attempts have mostly been unsuccessful [49] and many depend on the personal judgment of the tester. Our approach was to examine the creativity and its impediment factors in the contemporary engineering education through examining the perception of instructors and students on the value they place on creativity and their self-perception on the practices in their classrooms.

For this purpose, surveys [50,51] were prepared to question students and instructors at the University of Connecticut. Survey questions attempted to uncover the presence or absence of the creativity criteria in the classroom settings. Each survey question was linked to one or more of the Ten Maxims of Creativity. Two separate surveys targeted students and instructors in three general academic areas: engineering, science, and humanities. The engineering group consisted of mechanical, biomedical, electrical, computer, civil, environmental, materials, and chemical engineering. The “science” group was comprised of math, physics, chemistry, computer science, and biology majors. The “humanities” group was comprised of education, anthropology, and language majors. Over 400 students (sophomore through senior) were surveyed. Instructor surveys totaled 75.

Every single one of the questions for each discipline group resulted in a statistically normal distribution. Principal components factor analyses were conducted in order to ascertain the factor structure and the correlating factors. MINITAB was used for this purpose. The details of the statistical analysis as well as the distribution of answers to each question are included in Ref. [50]. For each question, groups of students: engineering, science, and humanities were compared in order to determine if there was an overall single trend in the questions for all students or whether the groups differed. Groups were compared question by question.

Particular attention was paid to questions revealing absence of the corresponding creativity criteria for engineers as well as a strong disagreement with other student groups. This tells us where engineering students were uniquely missing an opportunity for creative expression in their academic experience.

The process used to analyze the student data was repeated for the instructor groups as well. Additionally, the creativity criteria revealed to be missing by students in each group by the above-mentioned process was compared to criteria revealed to be miss-
ing by instructors in that same group. Several instances occurred where within a group, instructor and students disagreed as to which of the criteria were being provided to students.

Some of the survey results are presented graphically in Figs. 1–3. Please note that the numbers in diagrams correspond to the Ten Maxims of Creativity in Education list. Figures 1–3 show those criteria perceived to be missing. Therefore numbers within each group’s circle indicate the absence of particular criteria for that group.

The following immediate observations can be made directly from the Venn diagrams:

- Out of the three groups of students and instructors surveyed: engineering, sciences, and humanities; engineering students and instructors have the greatest number of disconnects or instances where students feel a creativity criteria is absent but instructors do not report this same criteria absent (seven disconnects for the engineering group versus five for the science group and three for the humanities group).
- Engineering students report by far the greatest number of absent creativity criteria (9 out of 10 versus science: 6 out of 10 and humanities: 2 out of 10).
- Agreement versus disagreement between engineering, science, and humanities—student surveys:
  
  a. There was never an instance in the surveys when engineering students felt a creativity criteria was present in their education and science and humanities students also did not feel it was present; meaning engineering students did not report any unique strong point on the creativity criteria list.
  
  b. Science student surveys and engineering student surveys only overlapped when they were agreeing that a creativity criterion was absent from their educational experience.

  c. Science students tended to fall in the middle ground between engineering students and humanities students.

  d. Engineering students and humanities students only agreed on a question in the survey when all students (engineering, science, and humanities) agreed on a point, i.e. only when it was a common issue for all students.

Other interesting general conclusions on the perceived value of creativity were revealed in these surveys:

- All groups of students report that they themselves valued creativity.
- Student perception of how instructors value creativity varied:
  
  a. Engineering students felt that instructors did not value creativity.
  
  b. Humanities students felt that instructors did value creativity.
  
  c. Science students’ answers were inconclusive.

- All groups of instructors report value in creativity but they did not all uniformly see creativity in their students:
  
  a. All instructor groups reported that they value creativity in their students.
  
  b. Humanities instructors see creativity in students.
  
  c. Engineering and science instructors did not see creativity in students.

5 Discussion of the Survey Results With a Focus on Engineering Students

A closer look at the observations made for the engineering students reveals noteworthy indications. There are four common
threads among the creativity maxims and what these maxims imply. The common threads or groupings are: Criteria that determine a thought process students can learn to use (maxim #1 and #2); criteria that determine steps in students work process (maxims #3 and #8); criteria that provide a teaching/learning process instructors can supply (maxim #4, #6, and #7); criteria that provides motivation and inspiration for students (maxim #5, #9, and #10).

5.1 Thought Process for Students.

5.1.1 Keep an Open Mind (Maxim of Creativity #1). Engineering students uniquely perceive a strong weakness in thinking with an open mind when doing their work. They report that they have not learned to think of problems in a new and unusual way and that they are not encouraged to think freely about problems as assigned problems have known solutions they are expected to repeat. Inconsistent with this student view, engineering instructors report that they feel it is valuable for students to try many, even unusual, methods to a problem solution and that they feel they show students examples of problems with unexpected solutions. Where is the instructor/student disconnect on this creativity criteria? The problem seems to lie in the type of assignments given to engineering students more than the in-class experience. Assignments usually have a known solution students are expected to recognize and regurgitate rather than use learned tools to draw their own unique conclusions. Although this is sufficient for training capable engineers it is not effective for developing innovative thinkers.

5.1.2 Ambiguity is Good (Maxim of Creativity #2). All student groups reported that they thought mulling over an assignment is a waste of time; they would rather just get to the answer. This makes sense for engineering students as their instructors reported that they often push students to more quickly come to the point of a project because they need to learn the value of working efficiently. The idea of staying in an open-ended state of thought for as long as possible seemed foreign to most engineers. What this means for engineering students is that they are not being given the opportunity to keep the answer just out of reach, allowing more thought on a topic and time for a greater wealth of information to be collected and innovation to happen.

5.1.3 Iterative Process that Includes Idea Incubation (Maxim of Creativity #3). Engineering students uniquely lacked this criteria. Engineering students did not show any knowledge of this process particularly the “incubation” step in the Wallas creative thinking stages [47] that contributed to development of maxim #3. This step is where an idea is allowed to sit with a student for a while so that it can be thought about while doing other activities (i.e., back burner the idea). Contrary to science and humanities students, engineering students report that they did not take time to discover a solution by back burning the idea for a period. Engineering instructors report that they like to assign projects as far ahead of the due date as possible. This process was similarly revealed in the discussion of creativity criteria #2 (Ambiguity is good). Science and humanities students acknowledged the concept of back burning an idea when working on a project suggesting that they do indeed have a different work process than engineering students.

5.1.4 Search for Multiple Answers (Maxim of Creativity #8). Engineering students and instructors both agree that creativity criteria #8 (search for multiple answers) is missing from engineering education. Engineering students uniquely perceive this criteria to be absent from their education. Humanities students report that they feel professors have taught them there is always more than one right answer. Open-ended assignments and the search for multiple answers are more common in humanities classes.

5.2 Teaching/Learning Style Conducive to Creativity.

5.2.1 Reward for Creativity (Maxim of Creativity #4). Both engineering and humanities instructors report that they reward students who choose a riskier stance on projects and that they encourage students to be creative. They do not however report that they explicitly reward creativity in projects. This last fact may explain why criteria #4 (reward for creativity) is absent as reported by engineering students. Engineering students report that they do not feel instructors value an unexpected answer and that professors do not reward creativity with a good grade.

5.2.2 Learning to Fail (Maxim of Creativity #6). Not surprisingly, surveys revealed that all students (engineering, science, and humanities) feel this creativity criteria is missing from their education. Students are concerned about grades. All student groups report that they fear that a wrong answer on homework will negatively affect grades and that they are afraid to make mistakes on homework and tests even if they feel they have still learned an important lesson in the process. Getting a good grade supersedes satisfaction in learning a lesson. Additionally, engineering and science students are afraid to answer questions during class if they might get the answer wrong.

5.2.3 Encouraging Risk (Maxim of Creativity #7). Not unlike explicitly rewarding for creativity (creativity criteria #4) and allowing students initial failures (creativity criteria #6), promoting risk guides students through an open and encouraging learning process. Both engineering and science students report that professors do not encourage them to take risks on assignments. This lack of encouragement toward risk is strongly linked to students feeling that professors do not value unexpected answers. And like creativity criteria #6 (learning to fail) what students do not want to risk is a good grade. Similar to other creativity criteria in this section (criteria #4 and #6) engineering instructors do not report this as absent from the students’ education experience, instead reporting that they strongly encourage students to take risks on homework and projects.

5.3 Encouraging Motivation and Inspiration.

5.3.1 Lead by Example (Maxim of Creativity #5). Sharing examples of innovators can encourage like behavior in students. However, both engineering and science students report they do not learn about innovative people in their field from professors. As professors in these same fields report that they do indeed relate stories of innovators to their students, we have yet another disconnect that does not exist between humanities students and instructors.

5.3.2 Internal Motivation (Maxim of Creativity #9). Only engineering and science instructors report a lack of evidence of internal motivation for students. These instructors report students are assigned identical assignments leaving individual student interest out of the equation and that students are unlikely to challenge things taught in class, revealing a lack of engagement on the students’ parts. None of the groups of students reported internal motivation missing from their education.

5.3.3 Ownership of Education (Maxim of Creativity #10). Engineering and science students both report that they do not have enough room for elective classes and that they don’t have any input into class choices in their field. Conversely even though humanities instructors reported students taking their class as part of a requirement, humanities students reported a feeling of ownership of their educational process in the form of elective class selection, plenty of input in class choices, and ease of tailoring a program to their specific needs.

6 Summary of Key Survey Results

Several key results are contained within the discussion.

- Engineering instructors are doing an insufficient job of passing on creativity inducements to students. The surveys suggest that engineering educators feel they provide some inducements for creative behavior in their students. The
students however have not picked up on these creativity hints and feel that instructors do not place any value on creativity. Only the criteria understood by students are those that can be utilized by students. Where there are student/instructor disagreements on whether criteria is present, the student perception must be considered the basis for change.  
- Of the three groups—engineering, sciences, and humanities—engineering students have the most room for creative improvement. Engineering students feel that their education lacks nine out of the Ten Maxims of Creativity. This is a startling number. Through the surveys, they express that creativity development has been almost entirely been left out of these students’ experiences.  
- The lack of creative work process was unique to engineering students in this study. Criteria relating to a creative thought process, #3 (iterative process that includes idea incubation) and #8 (search for multiple answers) were perceived by the engineering students to be foreign to them. No time or effort is perceived to be spent in learning divergent thought; a necessity for creative evolution.  
- Engineering students who need to problem solve are hampered by an inability to keep an open mind when viewing a problem. Even though it is essential to an innovative problem solving process, engineering students uniquely feel they have not been taught to keep an open mind. (Criteria #8)  
- Engineering survey results describe an emphasis on efficiency and reliance on old solutions over innovation and possible improvement. There are three criteria that engineering instructors and students agree is absent from their education process. They are: ambiguity is good, search for multiple answers, and ownership of education.  
- Two criteria stood out because they are perceived absent by all students. They are: #2 (ambiguity is good) and #6 (learning to fail). The latter is not all that surprising; most students do not want to fail. Their ability to graduate depends on passing grades. The former however refers to thought process where students keep an idea just out of reach for lengthy periods so that time is dedicated to gathering many thoughts during this an uncomfortable “fogy” concept period.

7 Conclusion  
In this paper we have proposed criteria in the form of the Ten Maxims of Creativity, necessary for a creative environment in engineering education. Through examining the perceptions of the students and the instructors in engineering, sciences and humanities disciplines, and the agreements and disconnect of these perceptions, we have studied the status of creativity in the contemporary engineering education.  
Our study has unfortunately shown that the current engineering student experiences almost none of these criteria as a part of their academic experience. Engineering students feel they lack the element of creativity in their educational experience. Engineering instructors need to be greater cheerleaders for innovation. This means providing inducements to take risks, inspirating with stories of successful innovators, teaching that failure is a realistic part of engineering that students must learn how to brace so they can learn and make corrections, and by explicitly requiring and rewarding creativity.

References  
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