Creativity and Engineering Education

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INTRODUCTION

Creativity, invention and innovation are accepted as major drivers for the significant improvements in the quality of life. Many professional associations, national academies, political leaders, managers and educators suggest that creativity, invention and innovation will be crucial to addressing the present and future challenges for humanity such as "restore and improve urban infrastructure" and "provide access to clean water" (National Academy of Engineering, 2010). It is, thus, critical that we educate engineers to be creative [1].

Although it is widely acknowledged that creativity has driven human intellectual, emotional, and social development and is crucial to the knowledge-based age of the 21st century, higher education can be still characterized by a focus on transmission of knowledge rather than creativity. It is important to realize that higher education is facing increasing pressure to be aligned with a society that is constantly transforming with new technologies and ideas, which impose on individuals increased levels of cognitive complexity and a need to innovate continuously. To meet these demands higher education needs to better understand creativity and create learning environments embodying forms of pedagogy and extracurricular activities that teach and nurture the skills of creativity and develop assessment methods that reflect the ability of students for individual exploration. This paper explores how higher

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education institutions are addressing the demands for understanding and nurturing creativity. The paper examines how creativity is viewed and incorporated into curricula in engineering education and what are some of the barriers to fostering creativity in engineering education.

1 NEED FOR FOSTERING CREATIVITY IN ENGINEERING EDUCATION

With the pressure on engineering education systems “to accommodate the fundamental changes necessary to produce highly skilled creative and innovative engineers who can stand up to the challenges of modern industry”, teaching the skills of creativity and innovation has become essential to any engineering education system [2, 3]. Yet engineering students typically feel they lack the element of creativity in their educational experience [1, 4]. This is essentially due to too little focus of our teaching in higher education being on nurturing students’ ability to think in creative ways [5]. A key finding from the Advancing Inventive Creativity Through Education Workshop [6] is that “education in general is yet somewhat aimed at fulfilling industrial needs as opposed to enhancing currently needed creative capability.”

The beliefs that engineering is strongly connected with increasing the quality of life and that it is a creative enterprise are not shared by the general public. The Harris Poll survey of "American Perspectives on Engineers and Engineering" released in 1998 by the National Academy of Engineering revealed that an overwhelming majority of Americans believe that technology makes a positive contribution to society and that engineers are to be credited with creating economic growth and preserving national security. However, science is seen as improving the quality of life more than engineering (71 percent vs. 22 percent); and as caring more about the community than engineers (51 percent vs. 37 percent) [7]. Less than 3 percent of the public associate the words ‘invents’ and ‘creative’ with engineering [8].

The desired outcomes for a well-educated engineer as stated by the Accreditation Board for Engineering and Technology (ABET) in Engineering Criteria 2000 (EC2000) include the following:

- An ability to design a system component or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- An ability to identify, formulate and solve engineering problems
- A broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context.

The EC2000 focuses on the student learning outcomes, stresses continuous improvement, and accounts for specific missions and goals of the individual institutions and programs. The intention of EC2000 was to enable innovation in engineering programs. “Nowhere in the eleven ABET outcomes criteria, however, is there reference to creativity or the need to teach creativity to students” [8] although it is assumed that the above abilities demand “new and innovative solutions” and creativity. It is interesting that ABET has included “an ability to apply creativity” for the first time in the Criteria for Accrediting Engineering Technology Programs, which will be effective for evaluations during the 2010-2011 accreditation cycle: **“**an ability to apply creativity in the design of systems, components, or processes appropriate to program educational objectives” (Criterion 3. Program Outcomes d).

We may anticipate that creativity in design will soon be included in the Engineering Criteria as well.

2 CREATIVITY

Although “[c]reativity is certainly among the most important and pervasive of all human activities” and “is seen as a good attribute for people to possess” [9], there is no single or authoritative perspective or definition of creativity. Classical definitions of creativity view it as an aspect of problem solving. “According to these definitions, creativity is exhibited when an individual solves a problem in a way that is novel and appropriate (or valuable)” [10]. While creative functioning is a constituent part of all human activities, creativity typically “takes place within a particular artistic, scientific, or intellectual discipline” [9] and is expressed in different ways in different domains [11]. Domains are also acknowledged in several theories of creativity [e.g. 12, 13, 14].

Studies on creativity have explored the creative person, the creative process, the creative product or the creative environment [15]. Although most of the creativity studies have taken either a person or process focus, “product definitions are generally considered as ultimately the most useful for creativity research” [13, p.22]. In most studies “creative output is the final benchmark on which judgements are made upon which consensus is achieved or disputed regarding the merit of work” [15]. In both art and design, one of the most important criteria for performance quality is the creativity of the product [16].

Models of creativity intended as a comprehensive theory of creativity take into account cognitive, personality, motivational, and social influences on the creative process. Amabile’s Componential Model of Creativity [13] considers task motivation, domain-relevant skills, creativity-relevant processes, and social environment as distinct but interrelated components influencing creative performance. Amabile’s theory assumes that the level of domain-relevant and creativity-relevant skill will determine what a person *can* do, while task motivation is the most important determinant of what the person *will* do. It is proposed that “[t]he levels of the three components for an individual’s attempt at a given task determine that individual’s overall level of creativity on that task” [13, p.95]. “The theory proposes that the social environment has its primary influence on creativity by influencing task motivation.” [13, p.115]. Factors that are expected to influence individuals engaged in any creative activities positively include sense of control, importance of work, reward that confirms competence.

3 HOW TO FOSTER CREATIVITY IN ENGINEERING EDUCATION?

The need to foster and assess creativity in engineering education is evident in many engineering programs [18]. Some schools (e.g. The Franklin W. Olin College of Engineering) state that their students must have “[t]he creativity to envision new solutions to the world's problems” [19]. However, successful individual engineering courses that offer students opportunity for creativity are rare (1). Some of these courses include creativity fostering activities following the guidelines proposed by creativity researchers. Stouffer et al. [8] and Kazerounian & Foley [1] describe how Torrance’s guidelines such as “confrontation with ambiguities and uncertainties” and “looking at something from several different psychological, sociological, physical, or emotional points of view" can be incorporated into engineering classrooms. It is hoped that such opportunities will allow students to develop and practice their creative problem-solving skills.

[3] describe three required courses (industrial communication, creative problem solving, and scientific research methodology) developed as part of an industrial engineering and management curriculum reform which was intended to enhance students' creative problem solving ability. Their study showed that Yuan-Ze University undergraduate students had significantly improved their creativity as measured by Torrance Tests of Creative Thinking (TTCT) after completing the reformed curriculum program.

On the other hand, engineering education may suppress creative potential in some people, which "can be unleashed in the right environment" as shown by Wilde [20] in his study on the participants in an American Society for Engineering Education creativity workshop [1]. Such a negative effect is not surprising and some studies suggest that particular educational experiences have not been able to provide the right environment to set the creative potential of students free in architectural design studios [21, 22].

Kazerounian & Foley [1] have compiled the following Ten Maxims of Creativity in Education to characterise an educational environment conducive to fostering creativity in engineering education:

- Keep an open mind.
- Ambiguity is good.
- Iterative process that includes idea incubation.
- Reward for creativity.
- Lead by example.
- Learning to fail.
- Encouraging risk.
- Search for multiple answers.
- Internal motivation.
- Ownership of learning.

Through examining the perceptions of the students and the instructors in engineering, sciences and humanities disciplines, Kazerounian & Foley [1] have studied the status of creativity in the contemporary engineering education at the University of Connecticut. Their study has "unfortunately shown that the current engineering student experiences almost none of these criteria as a part of their academic experience. Like in the case of architectural design studios [21], the responsibility for inducing the creative potential of the students is with the instructors. Kazerounian & Foley [1] suggest that "[t]his means providing inducements to take risks, inspiring with stories of successful innovators, teaching that failure is a realistic part of engineering that students must learn how to embrace so they can learn and make corrections, and by explicitly requiring and rewarding creativity."

Badran [2] proposes the following to achieve "a good education system [that] would lead to less engineering students to be non-creative or passive engineers":

- appropriate curriculum design;
- supporting co-curricular activities;
- collective team work and diversified activities;

- strong ties with industry;
- establishing a creative and innovative environment in the engineering school through *engineering and technology facilitators* who can steer the imagination and enthusiasm of students.

Advancing Inventive Creativity Through Education Workshop [6] made the following recommendations to higher education institutions:
a. Offer a wide variety of courses on invention and the inventive process, including hands-on activities, visual thinking experiences, and “how things work” exercises for all students—spanning majors in humanities, social sciences, engineering, natural sciences, the arts and other field or domains.
b. Infuse design-oriented activities and realistic, open-ended application into all courses.
c. Lead in the development and energetic use of exchange mechanisms for the sharing of materials and approaches for effectively teaching of inventive creativity.

Blicblau & Steiner [24] state that “routine assignment problems do not encourage creativity and original thinking” while final year projects that stimulate realistic design are “a showcase for engineering students’ creativity.”

The vision for the future at the Advancing Inventive Creativity Through Education Workshop [6] proposed curricular reforms covering:

- A robust combination of courses throughout the curriculum specifically on design, visual thinking and invention.
- Problem solving, invention and design are a key organizing framework for courses teaching fundamental principles in engineering, and in other domains, including the sciences, the social sciences and the humanities.

4 BARRIERS TO FOSTERING CREATIVITY IN ENGINEERING EDUCATION

The first barrier to fostering creativity in engineering education is due to the mindset shaped by the Industrial Age. Engineering education, as well as the rest of higher education and K-12, “is not centered on invention as a goal” since in the industrial era “education and socialization of industrial workers did not require or even desire fostering inventive creativity” [6].

Some of the maxims by Kazerounian & Foley [1] mentioned above are difficult to reconcile with “the serious business of engineering which demands tedious attention to details and an absolute need for accuracy.” Such a technical education with its emphasis on obtaining correct solutions to mathematical problems “is especially deadly to creativity” [24]. Kazerounian & Foley [1] state that “embracing ambiguity and exercising flexibility is equated with holding lower standards.” “Even in design 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.”

The Advancing Inventive Creativity Through Education Workshop [6] identified the following “disparities between the education methods/mindsets and invention processes”:

- An over-emphasis on deductive learning and an under-emphasis on experimental and inductive learning.
- A separation of principles from their context, use and application.

- Curricula providing insufficient support to individual initiative and self-discovery.
- Rigid separation between disciplines ignoring the need for multidisciplinary approaches to real-world problems.
- Highly structured learning formats that constrain the expression of ideas.
- A rapid pace of learning (such as endless problem sets) that can undermine the open-ended reflection and self-assessment necessary for invention.
- An inadequate balance between the importance of discipline in building a body of knowledge and the importance of the creative use of the knowledge (such as insufficient use of open-ended problems).
- Insufficient attention and appreciation of the important role of failure and learning from failure.
- Rewards and reinforcements in educational institutions, including appointment, promotion and tenure requirements, that usually do not emphasize invention or teaching of inventive creativity and that may even discourage these activities.
- Inadequate appreciation for the importance of individuals developing and constructively channeling their personal passions which are crucial enablers of invention in society.
- Insufficient mechanisms to help instructors develop the capability to foster interactive, self-directed learning.
- Insufficient mechanisms linking together instructors who are innovating in the way that they teach about design, engineering and creativity.

Some of these symptoms have been personally experienced when the first author of this paper attempted to initiate curricular changes to foster creativity in the Computer Science program of a Southern university in the US. The author's decision to conduct research about design and creativity was questioned and criticized. The author co-developed a multidisciplinary research proposal entitled "An Exploration of the Relationship Between Design Creativity and Configurational Properties of Designs" which would involve computer science, software engineering, architecture and arts in which creative synergy would be sought in the unifying activity of design. When he wanted to submit the proposal to National Science Foundation's CreativeIT Program in Fall of 2009, the Department and College did not support it, questioning the Program's value for Computer Science and indicating concerns on its potential impact on teaching, and advised to consider doing research and publishing in core Computer Science subjects instead. When the author tried to offer a special topics course entitled Multidisciplinary Design Studio to be cross-listed with a special topics course offered by Fine Arts and co-taught, the College did not approve.

5 SUMMARY

To meet the demands of the society that is constantly transforming with new technologies and ideas, which impose on individuals increased levels of cognitive complexity and a need to innovate continuously, higher education needs to better understand creativity and create learning environments embodying forms of pedagogy and extracurricular activities that teach and nurture the skills of creativity and develop assessment methods that reflect the ability of students for individual exploration. The engineering education community is aware of this need and believes that a culture of creative thinking and inventiveness can be fostered to the benefit of society. However, successful fostering of creativity in engineering education has been limited to few isolated cases. In order to better align with a society that demands innovation continuously, the engineering education community needs to better understand the barriers to successful fostering of creativity in engineering education and demand changes to the structures that support the barriers. The provision of sufficient mechanisms to help instructors develop the capability to foster creativity is the prime responsibility of the leaders and administrators in higher education, while the instructors and researchers are responsible for creatively resolving the tensions created by the value-based issues that must be considered in conjunction with teaching creativity.

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