Finding Parallels: Advancing Creativity and Innovation in Engineering Through the Visual Arts

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Abstract

If the United States is to remain a strong leader in the global engineering fields, graduates of engineering programs will not only have to be technological competent, but they will also have to possess skills in the area of creativity and innovation. In fact, as the US competes in the global market of ideas these skills and abilities will be the discriminating factor between the US engineer and those educated in other countries.

This paper will provide a review of the literature concerning the use of pedagogy techniques used in the engineering curriculum to prepare entering graduate engineering students in creativity and innovation. The paper will outline how artist skills can serve as a basis for the teaching engineering students to integrate more creativity and problem-solving skills into the curriculum. Further, the paper will show the connection of visual art and engineering through sketching, visualization, model-making, and exploration of spatial relationships visually. It will also examine the problems and impediments of the inclusion of arts-based creative learning activities to the engineering classroom. Finally, it will provide some recommendations on how the skills of art can be directly included in the engineering curriculum.

Keywords:

Innovation, creativity, STEAM, academic skills

Introduction

With exponential increases in technology and communication, our world is becoming smaller. Countries such as China and India are graduating significant numbers of engineers each year especially compared to the United States. For example, in 2005, the United States graduated 70,000 engineers compared to India at 350,000 and China at 600,000[1]. With this kind of competition it is important to ask the question: "What sets engineering in the United States apart from engineers in other countries in the world?"

The United States has excellent engineering programs and schools already in place nation-wide, however, the field of engineering and the needs of society are rapidly changing beyond the programs and curriculum currently in place. This paper considers why especially United States engineers— to have a competitive edge — must develop creative and problem-solving skills. This paper identifies art skills and inquiry processes that are already found or thought to be needed in the undergraduate engineering classroom, and when enhanced, how such art skills and inquiry processes might better prepare engineering graduates for the 21st century workplace. It also identifies some obstacles to integrating visual arts skills and inquiry processes into the undergraduate engineering curriculum. Interestingly, there may be an accepted thought amongst the U. S. public that engineering students are taught what they need to know to immediately start working professionally upon graduation. After all, a Bachelor of Science degree in engineering is considered an entry-level professional degree[2]. One study found that in actuality, many engineering firms require one post-baccalaureate year of *on-the-job training* before they feel new employees are ready to tackle real-life engineering problems[3]. This was further supported by another study that employees who graduate as engineers with bachelor's degrees usually spend a year or two completing their "studies" on the job[4].

What skills are not taught or developed in the undergraduate engineering program? Do art-related educative skills fill a gap in the undergraduate education of the engineering student? Research suggests that artistic creativity and creative problem-solving skills are highly underestimated and underdeveloped in engineering schools[5,4] and that the engineering professional would benefit greatly if creative problem solving were more directly addressed in their undergraduate studies. Scholars argue that such skills and dispositions would strengthen ingenuity and innovation on the job[6].

Based on the aforementioned beliefs, an investigation was undertaken by the first author (Lallement) to develop a rationale for teaching and learning art-based creative and design processes in undergraduate engineering programs of study. This study showed relationships to skills learned in visual arts and design and engineering, outlining similarities in thinking processes across these fields. It considered the views of faculty who favor divergent thinking with faculty who favor convergent thinking in engineering departments.

Rationale and Significance

The development of programs in secondary schools that promote STEM (**S**cience, **T**echnology, **E**ngineering, and **M**athematics) is gaining popularity in the US. Some educators have expanded the STEM initiative to include the significance of art education. These scholars and educators have modified the STEM initiative to become STEAM, which includes an "A" in the acronym to include the *arts*[7]. Such initiatives have stimulated investigations into the relevance of creativity and innovation taught and learned through the visual arts to other core subjects in K-12 school settings[7]. Scholars observe that creativity and divergent thinking need to be developed in undergraduate programs of study as well, especially in subjects that *involve innovation and problem-solving like engineering*[8,5]. This paper adds to this ongoing conversation about the role and value of visual arts education in relation to other subjects, including and in particular engineering.

Literature Review

This literature review discusses selected themes and findings emerging in this paper. These themes include ideas about creativity in engineering, visual arts skills and processes that are found in engineering, and project-based learning activities used in the engineering classroom.

Looking for creativity in the profession of engineering was one of the main objectives that motivated the first author's research efforts. Both art and engineering are creative process.

Readings about creativity led to conclude that this was a broad and varyingly defined concept, but creativity is describable, nevertheless. Zimmerman[9] observes, "Many contemporary psychologists and educators agree that creativity is a complex process that can be viewed as an interactive system in which relationships among persons, processes, products, and social and cultural contexts are of paramount importance". Scholars such as Dr. Richard M. Felder have advocated for creative and innovative learning in the field of engineering. Felder[10] writes, "It would seem to be our (engineering professors) responsibility to produce some creative engineers—or at least not to extinguish the creative spark in our students". In his article "Creativity in Engineering Education," Felder[5] suggests characteristics to look for in creative students. These characteristics include "independence, inexhaustible curiosity, tolerance of ambiguity in problem definitions, willingness to take risks, persistence in pursuit of problem solutions, and the patience to allow the solutions to take shape in their own time". He explains that many professors don't or aren't able to see these characteristics because of the analytical manner of most engineering classroom activities[5].

Creativity may be thought of as both *a process and a way of thinking*. Convergent and divergent thinking are both necessary for the practice of engineering. Convergent thinking is defined by Merriam-Webster as "thinking that weighs alternatives within an existing construct or model in solving a problem or answering a question to find one best solution"[11]. This type of thinking is found in analytical, solution-oriented, problem solving endeavors in engineering learning. Divergent thinking is a kind of thinking associated with open-ended and multi-solution problems. Merriam-Webster[11] defines divergent thinking as: "...creative thinking that may follow many lines of thought and tends to generate new and original solutions to problems…". The problem lies not in types of thinking engaged, but in goals sought. Adams, Kaczmarczky, Picton and Demian[8] observe, "Excellence in engineering problem solving is synonymous with skill at convergent production since engineering education normally involves only problems with a single correct answer. However, this is not particularly true of engineering practice in general".

The above statement suggested a problem in engineering education, that is, the goal to produce a single correct answer. Yet writings indicate a need for creative and innovative engineers to solve societal problems today and in the future[5,6,12]. Engineers need to be good problem solvers, able to solve both problems that are analytical in nature and problems that may have more than one solution. Stouffer, Russell, & Oliva[12] claim "What 'normal' civil engineers do is inherently creative, as comparisons between the creative process and the design process demonstrate. The same can be said for chemical, electrical, industrial, mechanical, and systems engineers".

Kazerounian and Foley[3], authors of "Barriers to Creativity in Engineering Education: A Study of Instructors and Students Perception" stress the value of arts based learning in engineering classes. In their examination of the significance of the relationships between creativity, the college professor, and the student, they found that engineering professors are resistant to creative work finding the work not serious-minded. They also found that current engineering education can suppress creative characteristics. They established that the environment can suppress creativity in students and changing this environment can foster more creativity in the engineering learning[3].

Visual Skills Found in Engineering

It is apparent that the development of visual art skills such as drawing, sketching, model-making, and spatial relationship skills are considered to be essential to engineering problem-solving, analyzing, and communication. Spatial and visual ability can be described in engineering by orthographic (two dimensional) images, "created by theoretical projections of the object onto perpendicular reference planes"[13]. An example of spatial and visual ability in drawing is the ability to render the orthographic drawing of a pictorial concept or model[13]. Being able to translate a two-dimensional object to a three-dimensional object and vice-versa is necessary especially in mechanical, civil, and structural engineering. For engineers, being able to "see" the whole picture as it relates to a project is indispensable.

Engineers often use sketches in communicating plans and projects between engineers and clients or non-engineers. Engineering sketching or freehand drawing is defined by Voland[13] as, "…drawing without the use of instruments". Voland[13] asserts that the engineer, "must be able to graphically record and communicate ideas with speed in the absence of drawing equipment". Drawings can be simple or highly detailed and can include various lines, dimensions, and symbols.

Communication is a big part of engineering practices. For example, an engineer needs to communicate ideas to other engineers, clients, and to contractors. Through sketching and drawing these ideas are visually represented. Therefore, the better the drawing, the better the communication. Dr. Joakim Juhl and Hanne Lindegaard[14] looked closely at sketching, visualization and design skills found in the visual arts and how they relate to engineering practices. They found *representations to be an important part of engineering learning*. Moreover, representations aid in the transfer of knowledge and ease the "actual synthesis" in the design process[14]. Juhl and Lindegaard[14] suggest that working in collaborative groups when learning observational drawing is significant to engineering. They also observe that more research is necessary regarding visual representation in engineering education.

Project-Based Learning

Another area where we see visual arts and design skills being practiced in the undergraduate engineering classroom is in project-based learning encounters. Project-Based Learning is used as a means for motivating the student and enhancing the engineering program by providing engineering students with real world scenarios, problems, and learning experiences that involve collaboration and communication[4]. Project-Based Learning is defined by the Buck Institute of Education[15] as "a systematic teaching method that engages students in learning essential knowledge and life-enhancing skills through an extending student-influenced inquiry process structured around complex authentic questions and carefully designed products and tasks". These skills include "communication and presentation skills, organization and time management skills, research and inquiry skills, self-assessment and reflection skills, and group participation and leadership skills"[15]. The Dym, Agogino, Eris, Frey, & Leifer[4] suggest that project based learning addresses transfer in the cognitive science in their observation that, "*transfer,"* which may be defined as the ability to extend what has been learned in one context to other contexts".

Creativity and Innovation for the Future of Engineering

The experience of a visual arts education can "expose us to many tantalizing examples of ambiguity and to a lot of sensations and to forms of perception which do not exist in the normal realm of Science and Engineering"[17]. In order to solve future world problems, there is a great need for creative and innovative engineers. To do this, the use of both divergent and convergent thinking is fundamental in improving engineering innovation and engagement with newly emerging, unusual problems emanating from real world issues is essential. Current engineering students are taught to solve traditional problems that are pre-determined by their engineering teachers, problems that have one solution. They are not necessarily current problems with multiple solutions. One of the readings confirms this insight with "If we focus our intentions too strongly on solving problems in only our chosen discipline, in which the range of perception and expression is limited-especially so in Engineering and Science-then we lose suppleness in our thinking, as well as insights that often come from obscure analogies"[17]. Pre-determined question and solution instruction does not aid in solving problems that have yet to exist or solving problems with no known solution.

Fundamentals of Visual Arts Skills in Engineering

Skills learned in the visual arts, design, and engineering have similarities. Skills identified in this research and were found to be important to engineering include but are not limited to visualization, spatial relationships, and drawing and sketching. Esparragoza[16] defines visualization by "… the ability to process and interpret visual information and to generate visual ideas that can be transformed into concrete drawings and objects". These skills became more evident in the articles on creativity. Visual art skills like drawing and sketching found in engineering that can aid in the advancement of creativity and innovation but can also aid in communication and collaboration. Juhl and Lindegaard[14] write, "The activity of drawing translates individual cognitions into a process of collective re-cognition". In an email communication for this research with Dr. Juhl, he noted, "…the traditional engineering curriculum promotes and emphasizes engineering sciences and mono-disciplinary skills and gives less priority to important collaborative skills such as sketching and visualization" (J. Juhl, personal communication, September 13, 2013). Visualization and spatial relationships are important to observation, good drawing, and in the translation of three-dimensional and two-dimensional objects. It is important that engineering students are able to do this. If these visual art skills like drawing and observation are enhanced in engineering learning, they cannot only aid in observational skills but improve visualization and understandings of spatial relationships. Esparragoza[16] states, "The ideal situation for engineers is not only to process the visual information fast but to enhance visualization skills to be used in the design process and in the solution of engineering problems".

Drawing and sketching play a big part in communication in engineering. The better the visual, the better the communication. Communication is essential to good engineering. An engineer needs to be able to communicate the big ideas of an architect or designer to other engineers or construction contractors to make the idea practical and function properly. Professional engineers need to communicate the functionality of objects to people that may not understand engineering terminology. Good drawing abilities aid in communicating those ideas.

Project-Based Learning in Engineering Studies

The inclusion of creative learning activities helps bring real-life professional experiences to the engineering classroom. Seeing a need for creativity in engineering schools, an example of a creative learning activity is with project-based learning. The advantages to project-based learning for students are listed by Stouffer, Russell, and Oliva[12] as, " increased critical thinking, increased self-direction, higher comprehension and better skill development, self-motivated attitudes, enhanced awareness of the benefits of teamwork and a more active and enjoyable learning process". These advantages are proven to be reasons for incorporating and learning visual arts in secondary education. Some engineering professors and programs have developed exciting project-based learning (PBL) approaches as a way to develop these skills. However, the use of PBL is not consistent in engineering programs. Many engineering professors that have been taught more analytically and methodologically do not see PBL as a critical part of learning[4]. Some engineering professors believe that these types of lessons are created for accreditation purposes only and have little or no value to engineering education.

Others believe that PBL oriented learning has additional value. In engineering programs, student retention and motivation is a major issue[4]. Engineering students fail to gain critical thinking skill through the common practice of only analytical and mechanical problem-solving (D. Fallon, personal communication, September, 2013). Project-based learning bridges student learning to real-world problem solving and adds excitement to otherwise monotone lessons[4]. Stouffer, Russell, and Oliva[12] believe that project-based learning is an essential tool to encouraging creativity in engineering students.

Challenges and Impediments in the Engineering Curriculum

There are many aspects to engineering learning that share similar features with learning in the visual arts. Creativity, sketching, visualization, model-making, design, design thinking, and visual spatial relationships are all found to be valued skills found in visual arts that aid in engineering innovation, creation, and communication. This research, found that there are current engineering institutions and programs that see some value to such interests and approaches; however, these areas are under-developed. Moreover, engineering schools may be asking engineering professors (individuals with little or no experience in art) to be the ones teaching these valued artistic skills and processes to students. Art faculty members are specialized and trained to develop these skills and could help engineering professors teach these skills and better prepare students for their professional careers as engineers

It would seem as if the problems discussed here could be an easy fix. Engineering curriculum designers could modify the engineering curriculum so that more time would be devoted to the development of professional problem-solving, and art-related, and creative skills. Unfortunately, to add art, design, or creative processes-oriented courses to an already overloaded engineering curriculum is not feasible. Standalone courses could add too much pressure to an already charged curriculum. For example, some undergraduate engineering programs already have requirements up to 130 hours for graduation. At the same time, states are requiring those institutions to scale down to 120 hours[2]. In response, programs of study in engineering tend to eliminate humanities courses (including the arts) when more fundamental courses are required[2]. Another major difficulty with teaching art and design-based skills is changing the engineering faculty's perceptions about art education. In most engineering programs, program requirements include little or no artistic content, design thinking courses, or courses devoted to creativity. Even when the engineering curriculum includes design courses as fundamental to the program, these courses are often taught in an analytical manner by engineering professors.

The question that remains, then, is *how can engineering programs teach art-based, creative, and critical thinking skills to new engineering students?* It is widely recognized that university studio art and design courses involve and develop creative thinking skills, visual skills, collaboration, and problem-solving. Rather than adding new courses to an already overcrowded engineering curriculum, rethinking certain courses in the engineering curriculum may be one solution. Selected engineering courses could incorporate methodologies learned in the visual arts and design fields. Art and design faculty could easily teach creative generating skills in short mini-lessons or problems within existing courses, or they could be engaged as consultants to engineering professors wishing to integrate some creative and art/design-related learning encounters into an existing course. In fact, some engineering schools have hired design faculty to help teach these design courses. Unfortunately, problems arise when design faculty are not viewed as equals to engineering faculty[4]. The authors believe that through sustained, collaborative relationships between faculty from these diverse disciplines such prejudices would dissipate over time. Innovative, successful models resulting from such collaborations would set the stage for future integration of the art skills and inquiry processes into engineering problems that students are asked to so.

Concluding Remarks

This study began with wanting to find out how art education might be useful in engineering programs of study. What has been learned through this study is that engineering is not just the scientific and analytical field that is perceived to be. It is also very creative, artistic, and in some cases misperceived as only methodical and analytical. Engineering, although publicly perceived only as a non-creative, analytical, and methodological subject, is creative, like the visual arts. Engineers advance, develop, redefine, and produce for society's needs. William Wulf [2] asserts, "Science is analytic—it strives to understand nature, what is. Engineering is synthetic—it strives to create what can be". The Visual Arts, in some cases, are also misperceived as being a pastime, frivolous, or not a contributor to education. This research shows neither is true. These close relationships found in Engineering and in Visual Arts suggest a need to better integrate art and design thinking skills and art education practices in engineering learning. The authors would argue it would be necessary to re-conceptualize the engineering undergraduate curriculum to integrate these skills and practices so that they may benefit innovation and creativity in future engineering. It also can be concluded that emphasizing visual arts in the engineering curriculum can also help build and benefit the significance of art education. This study strongly suggests a need for engineering faculty who favor open-ended problem solving, artistic visualization, divergent thinking, and collaboration with their colleagues in art and design education.

More research should be undertaken regarding what the visual arts bring to education in other fields such as engineering in the post-secondary universities and colleges. There is much to be learned from engineering that might inform art education practices. There are more aspects of engineering that can be related to visual arts than those mentioned in this research and should be further explored. It is with hope that this research motivates future research into relationships between art and engineering education.

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