AC 2011-894: A COMPARISON OF DESIGN EDUCATION ACROSS TWO FIELDS:LESSONS FROM INDUSTRIAL DESIGN AND MECHANICAL ENGINEERING

William Besser, University of St. Thomas

William Besser is a graduate of the University of St. Thomas in Saint Paul, MN with degrees in Mechanical Engineering and Business Management. His academic interests include design, design processes and design thinking, multidisciplinary collaboration, consumer behavior and organizational behavior. William is currently working as a product design engineer for a medical device company.

AnnMarie Thomas, University of Saint Thomas

AnnMarie Thomas is an assistant professor of Engineering at the University of St. Thomas, and co-director of the UST Center for Pre-Collegiate Engineering Education. Her teaching and research focus on Engineering Design and K-12 Engineering Education. Prior to her appointment at UST, she was a faculty member at Art Center College of Design.

A Comparison of Design Education Across Two Fields: Lessons from Industrial Design and Mechanical Engineering

Introduction

It is generally accepted that familiarity with design processes is knowledge needed by engineering students. However, due to individual teaching styles and the large variety of design processes, there is a wide array of processes taught to students [1, 2]. Both industry and academia have called for engineering institutions to place a stronger emphasis on teaching creativity and the design process in the mechanical engineering curriculum, especially as engineers are being asked to work on wider arrays of tasks [3, 4, 5, 6, 7, 8]. To meet these demands, engineering design education must also adapt to properly prepare students for both industry and academia [9,10].

In order to teach design, one must define design. As stated by Evans, "The subject of design seems to occupy the top drawer of a Pandora's box" [11]. While students in many fields claim to practice design, the overall process and tools used can vary greatly. As shown by Evbuoman et al. there exists a vast array of deign processes, and it could be argued that since undergraduate mechanical engineering students are only exposed to the processes contained in their respective schools curricula, their view of the design process could be limited[2].

The goal of this paper is to investigate methods from Industrial Design that may be beneficial for undergraduate Mechanical Engineering programs to consider incorporating into their curriculum. Courses that emphasize industrial design could help mechanical engineers develop a better understanding and appreciation of design and its many facets. This understanding is essential to professional engineers because mechanical engineers often work with industrial designers in a collaborative, productive environment[12, 13]. By incorporating disciplines outside of mechanical engineering at the collegiate level, mechanical engineers can gain interdisciplinary experience with direct applications to business [5, 13, 14, 15] before entering the workforce. In this paper we will review related literature, and examine engineering programs, which incorporate industrial design concepts and practices into their classes. Finally, we will end with suggestions for methods that could be incorporated into an engineering design curriculum.

Background

Prior research on the ways that design, and its process, is taught to industrial designers and mechanical engineers, has often focused on the concept of systematic thinking. In general, engineers are often characterized as convergent in their thought patterns. Eris explains that, "convergent thinking is based in the knowledge domain and, as the name implies, directs the individual towards a single concrete solution to the problem at hand" [9, 16]. Industrial designers, on the other hand, have been described as, "divergent, or concept based, in their thought patterns" [17]. Eris summarized divergent thinking as, "based in the concept domain, where answers are not directed to a specific solution, but instead known facts are used to think of several possible solutions" [16]. This illustrates one possible explanation for the differences in understanding of design that exists between industrial designers and engineers. Dym et al. concluded that divergent thinking is not typically taught, or utilized in engineering curricula [9]. It seems likely that differences in the design processes of industrial designers versus mechanical engineers stem, at least in part, from the differences in academic curricula between these two fields. Further investigation between the two disciplines, can help engineers obtain a better understanding of both groups and a more thorough definition of the design processes that they carry out.

Mechanical engineering curricula tend to be similar to one another in content. Most curricula strongly emphasize understanding science and mathematics [18]. The similarity among programs can be, in large part, attributed to the requirements outlined for accreditation by the Accreditation Board for Engineering and Technology [19]. The specific processes required in order to achieve and maintain accreditation mandate mechanical engineering programs to become structured and defined [3]. Mechanical engineering students are required to apply principles of engineering, basic science, and mathematics, in order to model, analyze, design, and realize physical systems, components or processes. Furthermore, ABET states that engineers need to be able to apply their knowledge towards creative solutions to mechanical problems. However, some studies have suggested that creativity and design principles are often overlooked, downplayed, or not taught as thoroughly as they should be [20, 21].

Educators who seek information about encouraging creativity in mechanical engineering courses would do well to consider other design-oriented disciplines, such as industrial design. Lois Fichner-Rathus states, “Industrial design refers to the planning and artistic enhancement of industrial products ranging from space shuttles and automobiles to microcomputers and MP3 players. To a large degree, the functional and mechanical aspects of these products are the work of engineers. Designers wrap the inner workings in attractive skins or housings” [22]. Conversely, the Industrial Design Society of America (IDSA) defines industrial design as, “the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both the user and manufacturer” [23]. This second definition describes objectives for industrial designers beyond just aesthetic concerns. According to the accreditation board for industrial design programs, National Association of Schools of Art and Design (NASAD), industrial design is a conglomerate of visual arts and technology disciplines that requires the use of problem-solving and communication skills to produce products and systems that benefit both the user and manufacturer [24].

The curricula as posted on the websites of the top five design schools that teach industrial/product design, which were chosen by *BusinessWeek*, show that these schools all educate their students in a diverse array of subjects such as business, engineering, manufacturing, science, mathematics and art[25, 26, 27, 28, 29, 30]. These curricula suggest that industrial designers are trained to do more than simply concentrating on the aesthetics of the product. Likewise, the design processes that are taught to industrial designers are often categorized as creative processes[17]. The *Harvard Business Review* and *BusinessWeek* [31, 32] have featured ways that industrial designers rely on creative processes to shape other parts of their businesses.

Mechanical engineers have borrowed teaching techniques from other disciplines before. Shigekawa [33] published research on the relationship that may exist between architecture and civil engineering.

In our research, we have identified five institutions that had undergraduate programs, which blend mechanical engineering education with industrial design methodologies. The degree to which this integration takes place varies from institution to institution. This list is not exhaustive;

these universities were chosen to illustrate ways some engineering programs are approaching aspects of design education that are more commonly found in an industrial design program.

Three of the five universities we looked at include “industrial design style” classes in their mechanical engineering curriculum. These universities are Northwestern University in Evanston, IL, the Massachusetts Institute of Technology (MIT) in Cambridge, MA, and the University of Auckland in Auckland, New Zealand. Northwestern infuses mechanical engineering and industrial design by having professional designers visit their first-year student design classes[14]. The design professionals share their personal experiences from the industry with students, but they also work on and critique industry projects in the class [14]. MIT is similar to Northwestern in that they offer classes within the mechanical engineering curriculum that are focused on teaching industrial design methodologies, such as “Toy Product Design”, “The Product Engineering Process”, “D-Lab: Design”, “Invention” and “Product Design and Development”, through the use of open-ended design projects [34]. Lastly, the program at the University of Auckland is focused on teaching a multidisciplinary approach that integrates the various parts of mechanical engineering to prepare students to be successful upon graduation[5]. These are classes similar to the capstone design courses in US engineering universities, but instead of simply pairing students with professional engineers, they are also paired with individuals from art, business and design disciplines in order to work on a truly multidisciplinary project. These industrial design-style classes were created and carried out by the mechanical engineering departments of their respective universities. The result of this style of program is that undergraduate students are not only educated on the technical side of engineering, but also the creative/artistic side, which results in a more well-rounded engineering graduate [35].

We identified two universities, Stanford University in Stanford, CA, and the University of Glasgow in Glasgow, Scotland, in which new “hybrid” programs were created between mechanical engineering and industrial design departments. The Stanford program offers a Product Design undergraduate major created by the design group within the mechanical engineering department, as well as the departments of art and art history[36]. The Stanford product design program emphasizes four kinds of thinking to the students, “future thinking, design thinking, production thinking, and engineering thinking”[37]. The students in the product design program are not only educated on topics in mechanical engineering, but also in other industrial design classes such as kinematics and human factors. Courses in this degree program include diverse study in design methods, product design and need-finding. At the University of Glasgow, product design engineering is a collaborative effort designed to bring together school of mechanical engineering and school of design students. The program focuses on teaching engineering design knowledge through the use of directed and open-ended design projects[38]. The University of Glasgow has also collaborated with additional like-minded institutions from the UK, Holland, Germany, France, Denmark, Norway and Finland to further the understanding of engineering design knowledge through industrial design integration into mechanical engineering education.

Integration between mechanical engineering and industrial design at any level may be difficult for many institutions where an industrial design program does not exist at their college. We tried to identify techniques more common in industrial design programs than in engineering programs which could more easily be implemented by most engineering programs.

In our review of industrial design education literature, we have identified four promising areas where mechanical engineering educators could adopt new techniques. These are sketching, problem finding/defining, creativity, and divergent thinking.

Sketching

Sketching, which we will define as the creation of non-detailed drawings, appears to be a fairly simple skill. However, it takes a lot of time and patience for most students to develop strong sketching abilities. Sketching is a valuable skill for anyone involved in the design process because it allows designers to visually represent a concept instead of relying on verbal or written explanations[39]. Industrial design professionals use sketches and drawings as a means of visualizing and understanding their ideas[40]. Engineers benefit from representing ideas visually because a verbal or written description can be vague. Engineering students are typically educated in drafting and CAD drawing, but it is rare that engineering students are taught sketching[41].

Multiple studies have examined engineers' sketching ability and how it relates to the design process. Statistically significant correlations have been found to exist between the quantities of concepts generated, measured by the number of sketches, and design outcome [42, 43]. The study did not show that dimensioned drawings, more typically required of engineering students, at the end of the design process correlated to positive outcomes (higher marks on projects). This implies that planning ahead, and clear planning through visual conception at the start of the design process may, in the end, lead to more positive outcomes. With engineers being better educated on the topic of sketching they may be better prepared to understand and execute the steps of the design process [44].

Though it has been shown that sketching is beneficial to the design process it is still often perceived as not important in engineering education [38]. Some engineering design textbooks briefly mention sketching, but its emphasis is usually minor. Lack of available resources (textbooks) may be one reason that sketching may sometimes be overlooked[14]. However, sketching may not need to be included in an engineering textbook in order to be utilized effectively by mechanical engineering faculty. Sketching could be added into mechanical engineering curricula in several places. For example students could be taught about sketching in an engineering graphics course while they are taught about drafting and CAD. Additionally, sketching could be taught in any course where students would need to execute the design process or where they would need to take an idea from an abstract concept to a physical model. Educators could assign students work pertaining to sketching, or asking the student to keep a sketchbook while working on a project.

Problem Finding/Defining

Another area not usually emphasized in a mechanical engineering curriculum is problem finding/defining. Problem finding/defining is used by industrial designers to either reevaluate a given, or define, a problem statement. Mechanical engineering students are often assigned a problem statement, and then begin solving, instead of having to formulate one on their own like industrial designers[45]. This is one of the differences between mechanical engineering and industrial design that has been highlighted in literature[46]. Teaching students to fully examine and formulate the problem statement for themselves will help them to gain a better understanding of the problem in question and in turn, perhaps result in a more innovative solution.

Problem finding/defining could be incorporated into mechanical engineering education in several ways. Educators could create questions and problem statements in ways that cause ambiguity. Felder [47] described five question styles (such as "Questions that require technical, as well as social and ethical analysis") that have been shown to help in fostering problem finding and creativity in the design process. These questions have been shown to foster creativity and innovative thinking in engineering courses and they are often cited in literature on the subject of problem finding/defining [47].

Creativity

Plucker et al [48] defined creativity as, "the ability to generate new ideas, or new associations between existing ideas" [48]. Creativity is valued and appreciated by mechanical engineering educators; however, few classes on the subject of creativity are actually offered [49]. Along with this scarcity of classes, few accepted ways to measure creativity within mechanical engineering education exist, making it to difficult for professors to not only teach creativity, but also to gauge if their methods are successful [50]. While creativity education does exist in some mechanical engineering programs, these programs remain the exception rather than the rule [21].

Furthermore, creative thinking allows people to see issues from several angles, instead of just one. Using this approach helps to bridge the gap between different fields of knowledge, change the ways things have always been done and create new ways to accomplish a common goal [51]. Increasing the amount of creative design education delivered to engineering students will increase the diversity and quantity of design solutions created by these students. The need to increase creativity education and research has been recognized and discussed by multiple influential bodies within engineering education such as the National Science Foundation (NSF), ABET and American Society of Engineering Education (ASEE)[19, 52, 53]. Polls have indicated that industry is looking for engineering graduates that have the ability to independently solve problems, generate multiple alternative solutions to said problem, are educated on the overall design process, and have the ability to utilize creative methods on the job[8, 54].

Lastly, extensive literature and research about creativity in design exists that could be applied to engineering design education from outside of the field of engineering [20]. Fields of study such as psychology, philosophy and cognitive science have been investigating creativity for decades and fields such as industrial design have been applying creative methods to the design process for some time as well[17]. Industrial designers are taught creative behaviors than can be applied during the design process. They are taught "tolerance to ambiguity, stimulus freedom, functional freedom, flexibility, risk taking, preference for disorder, delay of gratification and perseverance" [55].

Divergent Thinking

Engineers are perceived to be mostly convergent, or knowledge based, in their thought patterns and the classes that they are typically required to take utilize this type of thought process. The majority of classes, such as calculus, chemistry, physics and most engineering science courses, taken by engineering majors, deal with single solutions to problems. Design classes, such as capstone engineering design classes, present open-ended problems, but these classes typically comprise only a small portion of an average engineering education and do not occur until the end of a student's program of study [56].

Industrial designers take classes including topics of human factors, product design, marketing and drawing. These classes allow problems to have multiple solutions, which fits with industrial designers because of their divergent thought patterns. Brown stated that industrial designers are educated to try many ideas early on and change ideas often if a concept is not working out[31]. Using techniques such as brainstorming where the focus is on the quantity over quality of ideas are beneficial in the early stages of the design process [57]. By generating multiple possible solutions early on in the design process, students are allowed to make mistakes and different solutions can be investigated. This often leads to beneficial discoveries made from the mistakes[58]. Also, divergent thinking shows students that failure (that is, the failure of some ideas as compared to others) is acceptable.

In comparison, convergent thinking focuses on a single solution and uses only that solution. In the event the solution fails, a great deal of time may need to be spent on devising an alternative solution. Whereas in divergent thinking, when an idea fails one can simply move on to the next idea since it is likely that multiple solutions were discovered in the early stages of the design process.

Conclusion

National calls for more diversely educated engineers, have created the potential for exciting changes in engineering education. Incorporating methods from other disciplines and broadening engineering students' exposure to colleagues and faculty from other departments can lead to innovations in a wide array of fields.

As was shown above, it is possible to incorporate components of industrial design into mechanical engineering course work. Benefits may arise from the mixture of the two areas. Industrial design is one of the many diverse disciplines that mechanical engineers interact with frequently in industry. By incorporating industrial design techniques into mechanical engineering curricula, students could establish a solid working relationship both with the concepts of design and the professionals in the field while still in college. This may result in engineers having a deeper understanding of design and its process, as well as being better prepared for their future career. Or put differently, the aforementioned call could be answered.

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