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Research Article

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Introduction

This inquiry is a case study which explores, explicates, and summarizes the recent shift to "whole-brained" engineering education for undergraduate-level students at the University of Dayton. This case study is primarily structured around the experiences and insights of an interviewee, Dr. Ken Bloemer, who is the Director of the Visioneering Center at the University of Dayton. The Visioneering Center is principally focused on promoting the progress of engineering education at the university. Voices from scholarly literature pertaining to this vision and other undergraduate engineering curricula are then used to reinforce the interviewee's views and give deeper insight into the various aspects of the changing engineering education format. This exploration includes the shift from strictly teaching the left brain—or the focus on logic, mathematics, and problem solving of engineering students—to more so cultivating the right brain—or a focus on creativity, artistic skills, and humanities—which is a recent phenomenon of engineering education at the undergraduate level (Bloemer, 2017). In an interview with Dr. Ken Bloemer regarding "whole-brained" engineering education at the University of Dayton, he states, "Engineering has traditionally done an exceptional job at educating the left brain- logic, problem solving- but companies are really desperate for engineers that are what I call "whole-brained"- those who have the creative side as well as the "engineering"- because it's the creativity that leads to innovation," (Bloemer, 2017). In addition, this piece divulges in the phenomenon of fieldwork shifting away from the image of the *lone engineer* (Bloemer, 2017) toward collaborative engineering (Bloemer, 2017), and the consequential engineering curriculum change that has come as a response to this shift. The study of pedagogy switch in engineering education can be seen in the *Transforming Undergraduate Education in Engineering* workshop report, a work collaboration between the National Science Foundation and the American Society for Engineering Education (2013):

> With support from the National Science Foundation (NSF), the American Society for Engineering Education (ASEE) has launched a series of meetings to develop a new strategy for undergraduate engineering education that meets the needs of industry in the 21st century. Transforming Undergraduate Education in Engineering aims to produce a clear understanding of the qualities engineering graduates should possess and to promote changes in curricula, pedagogy, and academic culture needed to instill those qualities in the coming generation of engineers. (p. 3)

The concept of *whole-brained engineering* is the integration of the "right brain" and the "left brain" into a single entity. The human brain is comprised of two hemispheres, or halves referred to as the "left" and "right" sides. Between these two halves is a section of millions of nerves that serves as a connection between the two sides. The following is a basic description of the integral aspects of the human brain's anatomy:

> The brain is composed of the cerebrum, cerebellum, and brainstem …The cerebrum is the largest part of the brain and is composed of right and left hemispheres. It performs higher functions like interpreting touch, vision, and hearing, as well as speech, reasoning, emotions, learning, and fine control of movement… The brain stem includes the midbrain, pons, and medulla...The folding of the cortex increases the brain's surface area allowing more neurons to fit inside the skull and enabling higher functions." (Mayfield Brain & Spine, 2008, par 6)

In 1981, Roger W. Sperry won a Nobel Prize in Physiology and Medicine for his work with split-brain research and his discovery in the functional specialization of the cerebral hemispheres. Sperry's work discovered the connection that the two hemispheres of the brain were linked between the cerebral commissure, which is hundreds of millions of nerve fibers that reside between the left and right brain hemispheres. "...Sperry found that, if these connections were severed, each cerebral hemisphere would retain its ability to learn, but that what had been learned by one hemisphere was not accessible to the other," (Nobelprize, 2014, par 3). This was revolutionary to science, which previously had the conception that the two hemispheres of the brain were completely integrated as one. Through Sperry's work, it was shown that the left hemisphere tends to favor logical analysis of details and mathematics, while the right hemisphere showed partiality in "interpreting auditory impressions and in (the) comprehension of music," (Nobelprize, 2014, par 4). Sperry's findings of the anatomical relationship between the two hemispheres of the brain were a fundamental discovery in medicine (Nobelprize, 2014, par 6).

However, as more than three decades have passed since the initial discovery, more evidence has shown that the right brain does not solely supply the creative, creativity, artistic skills, and humanities side of an individual, nor does the left side solely contribute to one's logic, mathematics, and problem-solving skills. Both sides of the brain contribute to aspects of both creativity and logic:

> According to a 2013 study from the University of Utah, brain scans demonstrate that activity is similar on both sides of the brain regardless of one's personality. They looked at the brain scans of more than 1,000 young people between the ages of 7 and 29… No evidence of 'sidedness' was found. The authors concluded that the notion of some people being more left-brained or right-brained is more a figure of speech than an anatomically accurate description." (Schmerling, 2017, par 12)

Ironically, while there may be no substance behind a separate left brain and right brain, this theoretical separation of logic and creativity does play a large role in the shift to "whole-brained" engineering education. Engineering education traditionally has strong roots in what would be considered the left hemisphere, or specialization in logic and analysis. However, there has been a shift in the creativity hemisphere, or more of a focus on the right brain, in engineering education

(Bloemer, 2017). This deviation of undergraduate engineering education to a "whole-brain" focus indicates the usage of both hemispheres of the brain; the University of Dayton has been striving to create such a whole-brained engineering focus.

This article is constructed around an interview with Dr. Ken Bloemer, who is the Director of the Innovation Center at the University of Dayton. The main concept of "whole-brained" engineering and the following subtopics, Cultivating Creativity in the Classroom, Fostering Innovation Ideals in the Engineering Design Process, and Implementing Diversity of Thought into Engineering Team Dynamics stem from this interview. The main and subtopics and supported with information from academic literature reviews, academic journals, research regarding the topic, and curricula from other schools with undergraduate-level engineering programs.

Cultivating Creativity in the Classroom

Coinciding with the concept of "whole-brained" engineering, the encouragement of cultivating creativity in the classroom is a large aspect of the change in engineering education at the University of Dayton; in an interview with Dr. Ken Bloemer, he comments regarding the University of Dayton's commitment to developing this skill, "Our President, Eric Spina, at the University of Dayton, wants every student to take at least one course in creativity and innovation. I believe engineers, especially, need to take classes that are right brain expanding." To educate both students' analytical and creative capabilities, engineering education has tried to incorporate creativity and innovation-based classes into an otherwise math and science heavy standard curriculum. In a study completed by the National Science Foundation and the American Society for Engineering Education called *Transforming Undergraduate Education in Engineering* workshop report (2013), multiple participants were interviewed on what the fundamentals and prerequisites should be considered for engineering:

> One participant … addressed creativity and flexible thinking in engineering education and instruction in problem solving. The classroom instruction formula of one answer path per problem places boundaries on problem solving… pretty little perfect answers that don't require one to experiment with multiple methods in order

> to find the best solution are not adding value to the students' ability to assess a problem and determine a solution. (p. 13)

Rather than focusing on teaching students purely the fundamentals of engineering subject matter, the curriculum is now geared toward the utilization of creativity and alternative thought pathways. This concept of creative thought is clearly articulated by W. B. Stouffer, Jeffrey S. Russell, and Michael G. Oliva:

> The creative thought, then, is something that leads to the creative act or the creation of something new—an idea, theory, or physical product…Perhaps technical people prefer to be "innovative" rather than "creative." Regardless of what you call it, both innovation and creativity should lead one to the same end: to the exciting world of inventing and creating new knowledge, processes, and artifacts that push forward our science, technology, and art. (2004, p. 2, par 5)

The goal of educating engineers to be creatively literate is not only to challenge these future engineers, but to help them become more appealing to the future job market. In a case study completed by Research Associates, Inc. for part of an initiative called Liberal Education and America's Promise (Hart Research Associates, 2006), hundreds of employers and recent engineering graduates were interviewed and stated that in terms of intellectual and practical skills, 70% of the participants stated that "the ability to be innovative and think creatively" (p. 2) was crucial for the field of engineering, innovation being treated as a major part of engineering has only become popularized in recent years, and so the field has much room for improvement. Undergraduate and field education, therefore, has fashioned itself to fill this gap through renovations in pedagogy. This revolutionary school of thought of introducing creativity and innovation classes into basic curriculum has redefined what it means to be an engineer. Although this shift in undergraduate engineering curriculum at the University of Dayton is a relatively new deviation from traditional left brain targeted schooling the engineering program has already made the shift of offering more creative, problem-solving, and "artistic"-style classes in hopes to produce more capable, rounded, "whole-brained" engineers. To graduate from the University with a degree in engineering, students must complete at least a two-credit course in Engineering Innovation. According to the University, the Engineering Innovation class is described as,

> (For all) First-year multi-disciplinary innovation projects primarily geared towards skill development in the areas of requirements analysis, creativity, conceptual design, design and problem-solving processes, prototyping, teamwork, and project communications. Application to the development of a new product or technology meeting societal needs. This course is part of the Integrated Engineering Core for all engineering students." (University of Dayton, 2017)

In addition, the University of Dayton offers the nation's first academic certificate focused specifically on applied creativity. Sourced through a program called IACT, or the Institution of Applied Creativity, the University has drastically shifted their engineering education school of thought. Enforcing and offering such classes allows for individuals to become "whole-brained" engineers, skilled in both the needed analytical and problem-solving skills as well as the more creative and humanitarian side of engineering.

Fostering Innovation Ideals in Engineering Design Process

The innovation thought process has taken a particularly meticulous look at a major aspect of engineering: The Engineering Design Process. Creativity is a crucial aspect of the engineering design process. Without creativity in design there is no potential for innovation, where the implementation of creative ideas occurs (Mumford & Gustafson, 1988). As engineering education has rapidly evolved in recent years, so has this process of problem-solving. The standard use method of finding solutions to problems is typically "brainstorming", where one sits down and simply thinks of solutions to a problem. However, this standard method is limited, especially if one wants multiple new, novel ideas (Bigelow & Bloemer, 2017). There have been new "methods" of problem solving, which allow for one to use different pathways and outlooks in hopes of finding a good solution. These problem-solving methods are often considered various engineering "ideations" (a word created from combining the words "idea" and "generation"), or "tools". Three major examples that are now heavily encouraged to be used in engineering education include Painstorming, Biomimicry, and Biassociation. Painstorming is the process of uncovering the major issues and inconveniences of a product or situation to drive *breakthrough innovation* (Kaplan, 2013). A method of engineering innovation that also encourages thinking outside the box and using innovative thought to solve problems is Biomimicry. Biomimicry encourages engineering students and professionals alike to look to nature, “Biomimicry is an approach to innovation that seeks sustainable solutions to human challenges by emulating nature’s time-tested patterns and strategies,” (Biomimicry Institute, 2017, par 2). Finally, Biassociation utilizes what fellow innovators have created in the past so that one might be able to incorporate one idea into another, perhaps seemingly unrelated, design (Bigelow & Bloemer, 2017). The following excerpt from Seyyed Khandani’s *Education Transfer Plan* explicates the necessity of creativity and alternative thinking during the Engineering Design Process:

> Most engineering designs can be classified as inventions-devices or systems that are created by human effort and did not exist before or are improvements over existing devices or systems. Inventions, or designs, do not suddenly appear from nowhere. They are the result of bringing together technologies to meet human needs or to solve problems. Sometimes a design is the result of someone trying to do a task more quickly or efficiently. Design activity occurs over a period of time and requires a step-by-step methodology. (2005, p. 4)

The “old” process, prior to the transformation of engineering education school of thought, included a minimal amount of time dedicated to defining the problem and seeking out possible solutions, followed by a long period solely surrounding the testing and implementation stages. The new process essentially reverses the old process; the majority of time is now spent on defining and researching *exactly* what the problem entails (Bloemer, 2017). The old Engineering Design Process consists of the same steps as the new Engineering Design Process. These steps include Identifying the Problem, Exploring what has Previously Been Done, Design, Create, Try it out, and Make it Better (The Works Museum, 2016). However, the large differing factor between the “old” and “new” process is the time which is dedicated to the various sections of the Engineering Design Process, that of which is very similar to Albert Einstein’s strategy of problem-solving, “If I had an hour to solve a problem I'd spend 55 minutes thinking about the problem and 5 minutes thinking about solutions,” (Goodreads, 2017). When Dr. Ken Bloemer was asked, he said the following regarding the necessity of changing the engineering design process from its “old” format:

> Here's what typically happens with engineering teams that I put on… we get a problem given to us, and we spend a couple of hours brainstorming multiple solutions, and then we evaluate those solutions and pick the best and we go about making it happen. When, in reality, if we only spend a couple of hours and only use one tool of brainstorming, what's the likelihood, that in that small set of ideas that we have that there is a highly creative and innovative solution? Very small. … When I look at the Engineering design process, I would spend… half my time not just on idea generation, but on understanding and experiencing the problem… You should be living the problem, so you really get a deep understanding and then using multiple solution and ideation techniques.

The transformation of the Engineering Design Process and the "tools" of finding solutions not only has changed how engineers find solutions but also how sheds light as to how American engineering education has recently transformed. For example, in the previously mentioned Engineering Innovations class at the University of Dayton, students are taught the "new" Engineering Design Process and "ideation" (a hybrid of the phrase "idea generation") tools. The University of Dayton teaches students to think past the standard means of finding solutions and think outside the box, a new concept in engineering education. Through this change in engineering curriculum, students are encouraged to alter their thinking processes, utilizing both their analytical left brain and creative right brain, fulfilling the goal of creating better "whole-brained" engineers for the 21st century.

Implementing Diversity of Thought into Engineering Team Dynamics

In the shift of undergraduate engineering education at the University of Dayton, the structure of team dynamics has drastically changed. In our growing 21st century market "problems are too complex to be solved by individuals" and students are encouraged to utilize the whole brain (Bloemer, 2017). To comprehensively solve these problems, there must be a collection of individuals working together; there must be a team formed. Part of the criterion for the Accreditation Board for Engineering and Technology is the development of effective teamwork skills (ABET, 2017). "Recently, there has been much debate on the 'group size hypothesis' that larger groups are more robust or perform better than smaller ones"

(Klug & Bagrow, 2016, par 2). When Dr. Ken Bloemer was asked about the viability of one engineer working as their own "team" in order to solve a problem. He answered, "Long ago are the days of the 'lone engineer'". This fact can be seen at the undergraduate-level as well as the professional level. At the University of Dayton, students are required to work in groups to solve a task assigned to them in their required Engineering Innovations class. In these teams of four or more, they are given a problem statement and must collaborate to go through all of the stages of the "new" Engineering Design Process. In addition, these students are also required to later present their findings as a team. Companies are looking for future employees who can "play well in the sandbox", Dr. Ken Bloemer said, "consequently, engineering curriculum has thus changed the dynamics of their projects, calling for groups of individuals to work together in that crucial team format."

Diversity not only allows for teams to have more individuals applying their "brain power" to a problem, but people of diverse backgrounds offer different insight into a problem. "Without diversity, the life experiences we bring to an engineering problem are limited. Consequently, we may not find the best engineering solution," (Wulf, 2002, p. 2). Engineering is now rooted in teamwork and diversity of thought, and so engineering education programs are now creating classes structured around diverse individuals and group tasks. There is a formula that depicts this school of thought. It is represented by Eureka or stimulus, raised to the diversity of thought, divided by fear. Eureka stands for the moment when a problem is solved and is found by having a stimulus, or a provocative question. Eureka is "raised" to the power of diversity of thought, all divided by the "fear factor". The "fear factor" represents the fear of asking questions or full team participation, which hinders the success of a team's success (Bloemer, 2017). The factor pertinent from this "equation" is "diversity of thought". The diversity of thought and full team participation are crucial for a team to be successful. In addition to the diversity of thought serving as an integral aspect of team dynamics, teams must also be diverse regarding individual member personality traits. A standard to test what personality one aligns with or tends to show favor toward is the DISC model, "The DISC model provides a common language that people can use to better understand themselves and adapt their behaviors with others - within a work team, a sales relationship, a leadership position, or other relationships," (Harris, 2017). The following includes a basic description of what the personalities represented by the DISC testing method are from the DISC personality testing site and author Guy Harris (2017):

> People who have both Outgoing and Task-oriented traits often exhibit dominant and direct behaviors. They usually focus on results, problem-solving, and the bottom-line. People who have both Outgoing and People-oriented traits often exhibit inspiring and interactive behaviors. They usually focus on interacting with people, having fun, and/or creating excitement. People who have both Reserved and People-oriented traits often exhibit supportive and steady behaviors. They usually focus preserving relationships and on creating or maintaining peace and harmony. People who have both Reserved and Task-oriented traits often exhibit cautious and careful behaviors. They usually focus on facts, rules, and correctness. (p.1)

This method of evaluating personalities for team dynamics has proven effective in creating ideal group interaction. According to a study called "The Effect of Personality Type on Team Performance in Engineering Materials Term Projects" completed by Kim, Jang, and Jae Shin (2008), where multiple groups of varying conglomerations of personality tests were arranged, "effective leadership and diverse personalities are the key factors to maximize project outcomes" (p. 9). The usage of personality tests is now seen in undergraduate levels. At the University of Dayton, individuals in the first-year Engineering Innovation class are required to take the DISC personality test to be placed in a diverse group dynamic. The diversity of engineers in a teamwork scenario is a metaphysical representation of "whole-brained" engineering-- students of various strengths and weaknesses work together to create a better, better well rounded and "whole" team dynamic. By now instilling in students that a team must have multiple members and should be diverse in both thought and personality, engineering education at the undergraduate level at the University of Dayton prepares students to be better prepared for the complex, diverse, and interdependent world of modern engineering.

Discussion

In this case study concerning "Whole-Brained" Engineering Education for undergraduate-level students, Dr. Ken Bloemer, the Director of the Visioneering Center at the University of Dayton, provided valuable information regarding this field. Voices from scholarly literature pertaining to the conversation and other undergraduate engineering curricula were then used to reinforce and give deeper insight into the various aspects of the changing engineering education format. The major change in pedagogy can be seen in the transferring from isolated left brain engineering education to the well-rounded whole-brained engineering education approach, which marries both aspects of logic and creativity. This main topic created three subtopics, namely Cultivating Creativity in the Classroom, Fostering Innovation Ideals in the Engineering Design Process, and Implementing Diversity of Thought into Engineering Team Dynamics stem from this interview. These aspects of the new engineering education curriculum, particularly at the University of Dayton, reflects the changing needs of the ever-advancing 21st century market and the consequential questions that have grown in perplexity. However, there are still questions that should be answered in further research. One such question is: What does this transformation of undergraduate engineering education mean for the future of engineering design? As interviewee Dr. Ken Bloemer stated, we are far from the peak of engineering innovation. As engineering education has changed, there has been opportunity to recognize where engineering education at the undergraduate level could be strengthened even further. In addition to this question, a following question should include: How does this change of engineering education impact engineering student success? Again, there is simply not enough data at this point to conclude how the radical shift of engineering education to a "whole-brained" focus has impacted the success of engineering students who later enter the professional field. However, "... there is a lot more awareness of the need of engineers who are able to think outside the proverbial box," Bloemer said. It is expected that the future American needs and market will change, as America has shown to be dynamic as it has had its share of triumphs and collapses throughout history. Therefore, the needs of engineering students at the undergraduate level will likely change, but to what degree is uncertain. Nonetheless, the current 21st-century engineering education curriculum has proven itself successful in adapting, and radically transforming so.

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