Developing Creativity Through Project-Based Learning

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Engineering students must be prepared to enter a profession that is dynamic, filled with uncertainty and requires a technical background as well as interpersonal skills. The demands placed on modern engineers are to navigate competing priorities set by clients, regulating bodies, environmental groups, and the public at large to take decisive action to solve the problems faced by industry in new and oftentimes, unexpected ways. Of all the demands placed upon engineers, creative problem solving is quite possibly the most abstract as well as most critical in success. For engineering students to be prepared for the challenges they will face in their careers, they need to gain experience working in a dynamic environment to solve projects and problems that diverge from the theoretical realm and enter a practical landscape similar to what they will encounter in industry by developing experience and skills in creative problem solving. One way is through engaging with an on-campus project-based learning (PBL) center as a student intern. A PBL Center relies upon a pedagogical strategy where student learning centers around projects under the guidance of faculty mentors. The PBL Center also functions to allow industry and community partners to engage with faculty and student interns. The Concept Center at Weber State University is modeled after PBL pedagogy and functions to connect student interns employed at the center with sponsored projects. This paper discusses the application of PBL in the Concept Center to achieve a double mission of being an active community member by connecting academia with industry and providing opportunities for students to gain needed skills in creative problem solving. A summary of examples of past projects completed at the Concept Center by student interns that function to support the development of creative problem solving is presented.

I. Nomenclature

PBL = Project-Based Learning

II. Introduction

Engineering Education is continuously changing and improving. As noted by Felder, the format of learning via lecture-homework-quiz is an efficient way to present a lot of information in a condensed amount of time, however, though it functions well to impart facts to students, it does not necessarily prepare students to solve problems [1]. Furthermore, the Green Report published in 1994 by the American Society of Engineering Education (ASEE) was a call for change to respond to the revolutionary change that was taking place in technology. In this report, the authors challenged academic institutions to respond to the needs of industry by preparing students with technical capabilities and intellectual development but also with skills in communication, and broadening their understanding to encompass

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the economic, social, environmental, and international context of their activities [2]. This call was loud and clear and is now integrated into the accreditation process of engineering programs in the United States [3].

The concept of creativity is abstract as well as difficult to assess much less define. While researchers from behavioral psychology, social psychology, cognitive science, design research, innovation, philosophy and others might differ in an exact definition of what it is to be creative, there is more of a general agreement about traits and qualities that define a creative person. In Kazerounian and Foley's research, creativity is summarized as an intrinsic quality defined by the ability of a person to take chances; to make unique connections between ideas; to be flexible and imaginative; to question ways of doing things; and to be motivated, inquisitive as well as intuitive [4]. Recognizing the lack of scholarly research in the study of creativity in engineering education along with some alarming research by Wilde that showed that engineering education in fact can decrease creativity [4, 5], Kazerounian and Foley identified ten maxims of creativity in Education which are seamlessly addressed through the pedagogical framework of Project-Based Learning (PBL) through an on-campus internship such as the Concept Center at Weber State University.

III. Background

The Concept Center at Weber State University is designed as a living laboratory for students to gain experience through PBL. The Concept Center supplements the university's time-tested mission of teaching by expanding that mission to include the conversion of knowledge into solutions to real world problems thereby allowing students to apply the theoretical concepts they have learned. The Center employs undergraduate student interns from the College of Engineering, Applied Science and Technology (EAST) in a part-time capacity. Student interns are assigned roles and responsibilities on industry sponsored projects. These roles include customer relations and communication, product design and development, and manufacturing. In addition to gaining experience with a variety of projects, students develop and utilize learned skills in computer aided design (CAD) software, additive manufacturing technology and other manufacturing methodologies [6]. These graduates will complete their academic careers with skills that are in demand and relevant to today's job market. Achieving this goal requires two components which represent the mission of the Center:

Education:

The Concept Center is a proving ground for student interns to work on industry sponsored projects under the direction of faculty mentors. This hands-on experience allows student interns to graduate better prepared to meet the demands of the modern workforce by gaining more experience in communication, and broadening their understanding to encompass the economic, social, environmental, and international context of the engineering field.

Research and Development:

The Concept Center is a place where new knowledge, technology and capability are constantly being expanded. It can meet a variety of different needs that industry will encounter during their research and development activities ranging from traditional research to product development.

PBL was developed in 1965 by the Faculty of Health Sciences of McMaster University. It is an approach to learning in which students solve problems in small groups with the supervision of a tutor [7-9]. It has since been widely accepted in the education of medicine and is thought to be a solution to some of the issues facing today's engineering education and has been implemented in some settings. PBL is based on the educational approach where the problem is the starting point of the learning [10-14]. The PBL process is student-driven, and facilitated by the instructor. Learners are encouraged to pursue knowledge by asking questions. PBL is regarded as a key strategy for creating independent thinkers and learners in the medical education community [7-9].

The PBL learning approaches have resulted in the facilitation of training in competencies related to interpersonal skills and technical aptitude, experience of solving real-world problems from an engineering perspective, and collaborative learning [16-18]. One author (Liu) has successfully integrated the PBL mode in his senior mechanical engineering classes such as mechanical systems design and vibrations and controls through introducing more than 20 projects from industry partners, university research centers, and a state agency [10, 12, 14, 15].

IV. The Ten Maxims of Creativity in Education and PBL

Kazerounian and Foley identified ten maxims of creativity based upon a large body of literature on creativity as well as their own experience to assess the ability of engineering education to meet these needs [4]. This list was created by Kazerounian and Foley as a starting point of a compilation and culminating result that educators can refer

to. This section will demonstrate that PBL is a useful tool in addressing each of these maxims by providing examples from the Concept Center. Many of the projects discussed are subject to non-disclosure agreements (NDAs) with the customer, so limited details can be shared here.

A. Keep an Open Mind

Creativity can be taught by learning to see things in a new light. Often, the best answer is not the most obvious. In one project, the Concept Center was working with a company that needed a solution to improve the aesthetic aspects of a latch system for their product. The Concept Center initially worked to completely redesign the product and pursued three different design concepts each significantly resulting in a more complicated and expensive solution. Eventually, the team reexamined the goals of the project and reframed it to create and design a housing to obscure the unattractive latch system. This proved to be a simple and inexpensive solution that the customer could mass-produce. By keeping an open mind on the project, the team was easily able to abandon the overall direction of the project and refocus on other alternative solutions.

B. Ambiguity is Good

For Foss, this maxim is probably the most challenging for engineering students. Students are used to being fed problems with neatly defined constraints as well as given variables. Problems encountered in industry tend to instead be not well-defined and inherently ambiguous. Many students are uncomfortable spending time defining the problem and tend to want to start working on the solution whether the problem is adequately defined or not. Student interns are intentionally tasked with a vague problem which needs to be better developed and defined before a solution can be identified. This process allows for the opportunity of discovery and innovation as it slows down the pace in the early stages of the problem definition and allows students to research and collect information before focusing on the solution. In one example, a customer approached the Concept Center to make an athletic tape dispenser product for a student that only had one arm. The product needed to accommodate multiple rolls of athletic tape as well as have the ability to cut the tape at custom lengths with one-handed operation. The Concept Center began by looking for solutions that could meet the customer requirements and created a simple and low-cost prototype that was belt-mounted and used a cutting wheel and slider as well as an easy quick-release mechanism for changing and replacing tape rolls. Though, initially this project was defined with very limited requirements from the customer, the ambiguity allowed for the team to fully understand and explore the functional requirements and create a simple and inexpensive solution.

C. Iterative Process that Includes Idea Incubation

Creativity can occur in stages and time must be allowed for the process to be complete. Allowing a project to sit on a "back burner", can lead to more creative solutions. However, for obvious reasons, idleness is not encouraged. For this reason, student interns at the Concept Center are often assigned multiple projects. Not only does this simulate the work environment he or she will experience in industry, but it also allows for the delay in task progress that results in benefiting creativity [19]. Multiple projects not only function to aid students in developing skills in project management and multi-tasking, but also allows for idea incubation.

D. Reward Creativity

With positive reinforcement and reward, creative and innovate solution can be recognized. This creates an environment which allows for students to strive for and target innovation as an objective. With any problem considered in PBL, there is no right answer, but rather a series of options that need to be carefully considered and evaluated to select the best of all the possible answers. Rewards that have been offered at the Concept Center include everything from recognition in the form of a luncheon to a gift card and in one instance a $1,000 scholarship. It is also worth noting the intangible reward of creativity of experience and resume building for student interns. Student interns have reported back to Concept Center management that their experience with PBL has allowed them to discuss unique and interesting examples during the interview process of their job search. Former student interns ascribe their experience with the Concept Center as beneficial in making them stand out to potential employers.

E. Lead by Example

In Taylor's work on climate for creativity, he described the observation of a colleague, "As I am hearing these things and as I reflect upon people who have done something that has truly reshaped the world, nearly all of them have gotten outside of existing organizations to do so" [20]. Taylor then mused that perhaps traditional and conventional organizations as a model might in fact be functioning to hinder creative scientific work. It is possible that the common thread that links organizations together in their ineffective efforts to spur creativity is not leading by example nor believing that a creative solution exists. A culture in which ideas are quickly dismissed will greatly hinder the

brainstorming process. Foss is known to use the history of the 4-minute mile as an example of the power of what people can do if they believe they can do it [21]. To reap the benefits of PBL in creating innovative solutions, it is imperative that an environment is created where leaders 'practice what they preach,' believe in the process, and lead by example.

F. Learning to Fail

Fear of failure can be paralyzing and functions to greatly hinder what anyone can accomplish. At the Concept Center, student interns make frequent errors in design and analysis and assumptions. However, rather than using these errors as reason for discipline, instead they can be reframed to allow for a deeper understanding of the topic which can in turn lead to innovation. If students understand why their concept does not work, they can be better able to identify other concepts that might work. Many students have not had the opportunity yet to build the resiliency needed to move beyond failure and see it as merely a pathway to their end goal, so it is important to communicate with them that many of the greatest accomplishments throughout history are a direct result of failure [22]. In one example, a student intern selected a circulating pump intended to circulate a specialized fluid. The pump was tested upon arrival and found to be inadequately sized. In this example, allowing the student to make a low-risk mistake can function as an incredible learning opportunity. The pump was inexpensive and could be returned but allowed for the student to grow in understanding of fluid systems as well as become more thorough in selecting components for an assembly. Learning to fail is a skill like any other and ultimately allows for engineers to make mistakes and learn from those mistakes without becoming debilitated by the error.

G. Encouraging Risk

Encouraging sensible risk taking for student interns to pursue ideas that are not likely to be successful is something that must be intentional in a PBL Center. Often, student interns have a limited understanding and experience with technology and there is a gap between what is believed is possible and what has historically been possible. The Concept Center has mentored students that have proposed solutions to problems that would likely defy laws of science. However, with proper coaching, these ideas can often evolve into something else that is innovate as well as possible. By allowing students to take risks with their time and research they can go down paths that would not have been considered and potentially identify a new and innovate way of examining the problem. In one example a customer tasked the Concept Center with designing a system that could melt snow from a driveway. The customer described frustration with shoveling snow and identified a marketing opportunity for a product that would not involve demolition and instead could be installed on the surface of an existing driveway. The student intern team initially considered a very complicated hydraulic system. Intuitively, the Concept Center management believed the economics of such a project would be prohibitive but encouraged investigating this project nevertheless. Ultimately, the team identified several potential methodologies and built a scaled prototype based upon roof melt heating technology. The prototype was delivered to the customer for testing. While the results of the testing were unsatisfactory, the customer was satisfied with the initial prototype and is currently engaging with the Concept Center to look at design revisions.

H. Search for Multiple Answers

Classical tools in brainstorming can be used to generate creative solutions. The Concept Center structures projects so that students work in teams. Teams dedicate the early stages of projects in brainstorming multiple solutions. In one example, in the early stages of the COVID-19 pandemic, all in-person intern work was halted and the Concept Center transitioned into a virtual work environment. As a result, much of the hands-on and fabrication aspects of the Center were put on hold and attention was redirected to projects that could be done remotely. One such project that the student intern teams elected to complete was to identify current technology that could be used to clean and disinfect surfaces and environments. By brainstorming and understanding the unique environments of Weber State University and the needs of various computer labs, metal cutting lab, welding lab, and other large work places, the students were able to search for multiple solutions divided by applications such as the heating, ventilation and air conditioning (HVAC) system, impervious and non-impervious surfaces as well as potential designs for no-touch handles into the buildings and classrooms. By utilizing the brainstorming process, they were able to identify many recommendations to the multi-faceted problem and document them in a report.

I. Internal Motivation

Creativity is supported through PBL when students are interested in the project and motivated by the challenge of the project. The Concept Center addresses this by aligning projects with the personal interest of the interns when possible. For example, one such intern has a background in the Navy working on a submarine and has a passion for nuclear power generation. While there were no current sponsored projects available to assign to him related to nuclear

power, he was instead assigned a project in renewable energy examining the use of solar power for emergency use in marine applications. While ultimately, the conclusion of his work was that size requirements of solar power were prohibitive for the application, this served to be a good way for him to expand his interest in alternative energies and build upon his interest in nuclear power.

J. Ownership of Learning

Students are better able to explore creative and innovative solutions when they have control over the project and a sense of ownership. This personal investment in the project can allow them to develop a sense of pride as well as satisfaction in the tangible aspects of their work. In one example, a student intern worked directly with the customer on a project to build a cadaver storage system. The customer was a faculty member of Weber State University and built a relationship and rapport with the student and invited him to attend and present his work at a conference [6]. The student was very engaged with this project due to the level of ownership he had that resulted from him being the primary point of contact with the customer. As a result, he was not only able to design a cost-effective solution to the problem but also develop a sense of pride in the work he was doing.

V. Conclusion

The modern engineering profession is hinged upon creative problem solving. To prepare students for careers in engineering, they need more experience and opportunities to learn outside of the classroom and develop skills and confidence in creative thinking. A PBL Center is one way to better prepare students for the demands placed on modern professionals to navigate sometimes competing priorities set by clients, regulating bodies, environmental groups, and the public at large. The wide variety of projects that student interns are exposed to illustrates the ability of a PBL Center to achieve its mission and address the 10 maxims of creativity. A PBL Center connects academia with industry and provides an opportunity for students to gain needed skills in creative problem solving.

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