International Journal of Engineering Education Vol. 37, No. 6, pp. 1630–1642, 2021
Printed in Great Britain
0949-149X/91 $3.00+0.00

Creating Solutions Through Project-Based and Experiential Learning: A Case Study of the Concept Center*

MARY FOSS[1,2] and YUCHENG LIU[3]
[1] College of Engineering, Applied Science and Technology, Concept Center, Weber State University, Ogden, UT 84408, USA.
E-mail: maryfoss@weber.edu
[2] Department of Mechanical Engineering, Mississippi State University Mississippi State, MS 39762, USA. E-mail: mrf288@msstate.edu
[3] Department of Mechanical Engineering, South Dakota State University, Brookings, SD 57007, USA.

The modern engineering profession 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. 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. 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 community members and providing opportunities for students to gain needed skills in problem solving and project engineering. A summary of intrinsic benefits is presented in this paper with examples of past projects completed at the Concept Center by student interns. Additionally, key lessons learned from the operation and management of the Concept Center are provided.

Keywords: Project-based learning; student intern; Concept Center; lifelong learning; cross-functional teams

1. Introduction

Universities are challenged to respond to the needs of industry by preparing students with technical capabilities, intellectual development, and employability skills. This can be accomplished by broadening their understanding to encompass the economic, social, environmental, and international context of their activities [1]. This challenge is also integrated into the accreditation process of engineering programs in the United States [2]. One way to meet this challenge is by supplementing classroom learning with project-based learning (PBL).

PBL is a pedagogical approach where the learning centers around problems. The Concept Center at Weber State University is designed as a living laboratory for students to gain hands-on experience through PBL. The Concept Center strengthens the university's time-tested mission of teaching by expanding that mission to include the conversion of knowledge into solutions to real world problems. 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 sponsored projects. These responsibilities and duties include customer relations and communication, product design and development, and manufacturing. Our results from projects completed previously showed that in addition to gaining experience from participating in projects of different nature, students expanded their skills in computer aided design (CAD) software, additive manufacturing technology and other manufacturing methodologies. These student interns will complete their academic careers with skills that are in demand by potential employers. To accomplish this student learning, the Concept Center is organized into two components which represent the mission of the Center:

Education: The Concept Center is a proving ground for student interns to work on sponsored projects under the direction of faculty mentors. This hands-on experience allows student interns to be better prepared to meet the demands for 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, the student intern education is strengthened.

Research and Development: The Concept Center is a place where new knowledge, technology and capability are constantly being expanded. It can

* Accepted 26 June 2021.

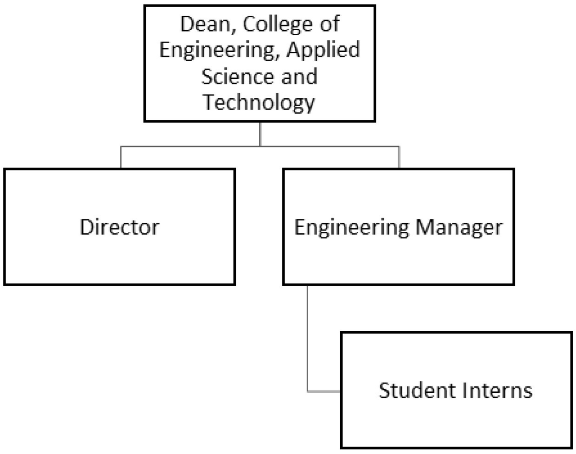


Fig. 1. Organization chart of the Concept Center.

meet a variety of different needs that industry will encounter during their research and development activities ranging from development research to product development. An organization chart that shows the hierarchy of the Concept Center is displayed in Fig. 1.

Engineering students need to be prepared with technical capabilities, intellectual development and skills in communication to be able to meet the requirements of industry [1]. Additionally, they need opportunities to hone those skills and incorporate a broader awareness of social, environmental, economic, and legal issues [1, 3]. Student interns employed at the Concept Center get hands-on learning experiences that suitably address these needs.

2. Background

PBL was developed in 1965 by the Faculty of Health Sciences of McMaster University. It is a learning approach in which students solve problems in small groups with the supervision of a tutor for each group [4]. The PBL process is student-driven, facilitated by the tutor and is based on an educational approach where the learning is driven by problems [5–8]. Learners are encouraged to pursue knowledge by asking questions. PBL has been regarded as a key strategy for creating independent thinkers and learners in the medical education community [9, 10].

Following the implementation of PBL in the education of medicine, it has since been expanded to other fields and is considered a solution to some of the issues facing today's engineering education. PBL was proved to be a successful approach and has been implemented into many engineering academic programs.

For example, the PBL learning approaches have appreciably facilitated the training in competencies related to interpersonal skills and technical aptitude, experience of solving real-world problems from an engineering perspective, and collaborative learning [6–9]. 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 [6, 8, 11, 12]. Liu's practice in introducing the PBL mode into the mechanical engineering classes showed that, by carefully selecting appropriate courses and integrating PBL into practical capstone experiences, students could supplement theoretical learning with hands-on experience and acquire a set of employability skills. Implementing PBL in course curriculum strikes a balance between achieving desired student learning outcomes and creating opportunities for enriching the student's educational experience [12–15].

Despite the progress made in integrating PBL into engineering coursework, there are, however, several major obstacles that hinder a seamless implementation of PBL into current engineering curriculum [16, 17]. First, students need foundational learning in theoretical principles before these principles can be applied. Textbook problem solving allows students to identify gaps in their content knowledge prior to application as well as provides the instructor an ability to assess the status of individual learning outcomes desired in the course. The time needed to mentor students in a project through PBL cannot squeeze current instructional time in some foundational courses. Second, most projects have associated costs that require careful planning and budgeting on the part of the instructor. These costs must be secured, allocated and budgeted in advance. If the project is sponsored by industry, the funding source can be the industry partner, but this would need to be renewed for each semester in which the course is taught. Integrating PBL into the curriculum thereby requires a recurring financial commitment that may not be feasible. Thirdly, not all projects fit within the timeline of an academic calendar. This may include a project with a deadline before pertinent topics are taught to the students or a project that may last for multiple years. To facilitate a successful PBL experience, the time requirements of the project need to match the academic time allocated for the relevant course(s). Lastly, large classrooms can be a challenge for projects that involve prototyping and fabrication. Access to suitable laboratory space and necessary equipment and/or technology may not be feasible for some courses. For example, a large class which cannot physically fit in a laboratory space won't allow everyone in that class to gain the hands-on experience of PBL.

Despite these obstacles, students can still benefit from the PBL experience by completing internships through an on-campus PBL Center. A handful learning centers were created to facilitate the implementation of PBL. For example, seven Science, Technology, Engineering, and Mathematics (STEM) centers were created in Texas to deliver professional development activities on STEM education for teachers in district schools [18]. The primary mission of those STEM centers was to design and implement a PBL pedagogy helping to improve students' readiness for postsecondary majors and professions. Mercer University School of Medicine has a PBL curriculum with a strong community-based component and a small student body; the PBL curriculum is mainly implemented through the school's Peyton T. Anderson Learning Resources Center [19]. Samford University started a PBL center in 1998 to incorporate PBL into their undergraduate courses and documented the best models of PBL in their courses [20].

Unlike the previous PBL centers, the Concept Center at Weber State University is the first PBL center exclusively established for promoting the implementation of PBL in engineering education and the Center serves as a hub for various kinds of projects. A student internship with the Concept Center can be a great opportunity to achieve many advantages of PBL, such as 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. Through the Concept Center, PBL is incorporated into the academic experience without the constraints of curriculum.

3. Benefits of PBL Center

The Concept Center offers five benefits to the university, faculty, staff, students and the engaged industry or community partners. These benefits are (1) improving the ability to work in an interdisciplinary and cross-functional team; (2) providing an avenue to support and encourage lifelong learning; (3) supporting service responsibility; (4) facilitating student mentoring and; (5) advancing research and education within the university.

3.1 Team Work in Cross Functional Teams (CFTs)

The Concept Center functions as a hub for engineering projects and design works to be completed by faculty members and student interns across the university. Previous projects completed at the Concept Center led to a number CFTs formed between many academic units across the university, such as different departments in the College of EAST, the Hall Global Entrepreneurial Center, the Office of Sponsored Projects, the College of Nursing, the Department of Zoology, and the Department of Physics, etc. Equipped properly, the Concept Center has the needed infrastructure and design and prototyping capacity for researchers from across the university to come together and form an organizational partnership. Within an organizational setting, a CFT is a common-place and proven structure for businesses to increase competitiveness by leveraging unique skillsets among team members. To support the formation of CFTs, the Concept Center promotes a culture of teamwork by encouraging collaboration instead of competition. This culture is supported through discussing the value of teamwork, rewarding and recognizing teamwork, and modeling teamwork within the Concept Center. A culture of teamwork will encourage faculty members and student interns to work together and combine their skillsets to reach the best solution for the projects. By doing so, the Concept Center can capitalize on CFTs as what has been identified as the main factor in industry to obtain a competitive advantage. As demonstrated by Dinca and Voinescu, six important competitive advantages achieved through this team structure are speed, complexity, customer focus, organizational learning, and single point-of-contact [21].

For example, several recent projects completed at the Concept Center through CFTs include developing and prototyping tactile braille display hardware, devices for monitoring water and air quality, prosthetic guitar pic, and an intubation tool, as well as an aircraft corrosion study. These projects were sponsored either by industry partners or a faculty researcher and required the expertise of faculty members from different academic units. Unfortunately, due to non-disclosure agreements (NDAs) in many of these projects, only limited details can be shared here.

To successfully manage a CFT, it is important to understand the limitations of the CFT and possible reasons that cause failure of certain teams, such as governance, accountability, budgets, etc. [21]. One of the primary roles of the Concept Center is to incorporate this understanding by functioning as a project manager for CFT projects. The CFT projects are managed to be successful by clearly identifying responsibilities of each participating entity and documenting necessary accountability. Failing to establish and document roles of members on the CFT can lead to additional project cost and delay.

3.2 Lifelong Learning

One of the most important missions of any higher education institution is to nurture and promote a culture in the local community to foster lifelong learning. The benefits of lifelong learning to a community and an individual are immeasurable and that capacity can be developed through the Concept Center. Community members ranging from hobbyists to industry partners have clear paths to engage with the university by sponsoring projects via the Center. Some clients of the Concept Center may have little background in technology and design. Through working closely with these clients, the Concept Center will expose them to engineering fields and provide technical support and guidance toward patent application and/or prototype development. Lifelong learning is also promoted in faculty by exposing them to new and unique applications, challenges and technology related to their field of expertise. Student interns have opportunities to interact with customers from different industries and with varying backgrounds and to see the wide application of engineering principles encompassing the projects. Projects completed at the Concept Center also allow student interns and faculty to engage with the local community in a way that is relevant, current, and pertinent to the engineering disciplines. Lastly, student interns, faculty members and clients have an opportunity to continuously develop and evolve their skills in their fields of expertise and can acquire knowledge in areas they were not familiar with before. The result is that the benefits of lifelong learning are achieved for all parties that are involved [22].

3.3 Service Responsibility

Universities have a moral obligation to serve the communities in which they are located and make efforts to support and promote diversity and equality. This in turn needs to be passed down to the next generation of engineers to recognize the professional duty they have in serving their local communities. The Concept Center at Weber State University addresses this need by engaging in projects that are inherently service orientated. This has been done by funding events through the budget of the Center that are intended to foster and promote community engagement, outreach, or service. The Concept Center also involves in volunteering activities. Those activities include serving as volunteers in outreach events targeting underrepresented minorities. Moreover, student interns are encouraged to take on leadership roles in student chapters of professional organizations such the Society for the Advancement of Materials and Process Engineering (SAMPE) and Society of Manufacturing Engineers (SME). Additionally, the Concept Center has elected to complete many projects pro bono to demonstrate a commitment to service. Such projects include preparing and assembling student supply kits for PBL engineering outreach events. It deserves mentioning that the Concept Center has an operating budget provided by Weber State University to allow for the purchase of capital equipment and to pay the salary for faculty mentors and wages to student interns. The budget allows for one full-time salaried position that manages the Center. This individual selects appropriate projects and identifies needed faculty and student support for project completion. Funding for student interns work on projects and additional faculty members comes from the budget of the sponsored project

3.4 Mentoring

One of the most important benefits of the Concept Center is its inherent mentoring aspect. Student interns are tasked with various roles within an engineering project team under the guidance of at least one faculty mentor. As they progress in the project their skills in analysis, design, research, and problem-solving are further sharpened with the help of the faculty mentor. The benefits of the mentorship are mutual and developmental for both mentors and mentees alike. In that relationship, both parties have opportunities to improve communication and interpersonal skills, develop leadership and management qualities, reinforce study skills and subject-area knowledge, and increase confidence in abilities. In addition, each party will find opportunities to learn and to grow in the areas of creativity, leadership, and professional development [23]. It also deserves mentioning an explicit benefit to international students who may not have authorization to work in an industry setting while completing their education. These students can engage with the Concept Center as interns and gain valuable work experience to supplement their learning, thereby completing their education with experience and demonstrable skills.

3.5 Advancing Research and Teaching Within the University

Many successful projects completed through the Concept Center have resulted in significant advancements in research or teaching within Weber State University. In these projects, the clients are faculty or staff members of the University who were looking for solutions for their courses or research programs. These projects were previously mentioned in Section 3.1, which include designing and prototyping tactile braille display hardware, devices for monitoring water and air quality, and an intubation tool. A number of teaching aids have also been developed for various courses from these projects. A few examples of the developed teaching aids are Deming's Red Bead experiment for the course Quality Concepts and Statistics in the Manufacturing Systems Engineering (MSE) Department, I-beam molds for laboratory use in the course Reinforced Plastics/Advanced Composites in the MSE department, 3D printed self-assembling bacteria for Introductory Microbiology in the Microbiology Department, Leidenfrost effect blocks for several courses in the Physics Department, and a laser pointer assessment tool for the course Human Anatomy in the Zoology Department. Lastly, three senior project teams in the Mechanical Engineering Department engaged in an autonomous robot competition where each team had to design a robot that would follow a course and launch a projectile at a target from different pre-determined locations. The Concept Center designed and fabricated a table-height 9-foot by 10-foot flat seamless surface equipped with side barriers and target locations that could be easily stored compactly when not in-use.

4. Examples of Projects

A review of recent projects completed at the Concept Center of Weber State University is helpful to demonstrate the diversity and complexity of the projects that support the benefits of PBL as elaborated in Section 3. However, many projects completed at the Center cannot be fully described because they are subjected to NDAs. Four projects that do not subject to any NDA are presented here as examples to demonstrate the unique and diverse learning experiences achieved through PBL at the Center.

4.1 Solar Pavilion

The goal of the Solar Pavilion project was to design and fabricate two solar powered pavilions equipped with lighting and charging sources to power electronic devices. The primary goal of this project was to provide a safe and attractive place for students to convene, study, and work together outside. There were no such areas for students on the campus at that time and the cost of installation to run a new power line to a remote part of the campus was prohibitive and against the campus goals of sustainability. This project was selected by the Center because its scope covered important curriculum topics including project management, applied materials science, manufacturing processes, engineering design, and control systems. This project is closely related to ABET student outcomes 1, 2, 5, and 7 (Please refer to section 5 for ABET student outcomes).

This project was left uncompleted by a faculty member who left the university prior to its completion. The Concept Center agreed to complete the project with funding from the Office of Facilities Management. The project team was composed of 4 undergraduate student interns and 2 faculty mentors. After an initial review, the team quickly realized that most of the work that had been done previously was not usable. The original design included a mechanical structure that would be cost prohibitive to fabricate and might lead to safety issues.

Many projects in industry change hands due to various reasons. This makes it imperative for the new project team to stay open-minded about the best way to proceed. In the case of this project, a significant investment in hardware (batteries, structural steel, and power inverters) had been made by the previous team. It would be tempting for any team to design a solution by taking advantage of what has already been purchased but oftentimes, such decision can result in the project not meeting customer requirements. Previous decisions made in projects are based on information or technology that was current at that time and might no longer be the best option. In this project, the purchased batteries were nearly depleted; the structural steel was intended to protect the batteries but was not corrosion resistant; and the power inverters were undersized. When inheriting an uncompleted project from another team, the new team needs to review design rationale and verify if it is consistent with the customer needs. This type of learning experience is difficult to simulate in a classroom setting.

The evaluation of the original design also allowed the team to better identify the problem, which is another valuable learning experience intrinsic to PBL. The original design had an umbrella-like pavilion but did not include requirements for resistance to wind forces and snow load. The original design is shown in Fig. 2. As shown in that figure, batteries were designed to be stored in steel boxes under seats. However, structural analysis of the pavilion was missing. After reviewing the original project documentation, the team redefined major tasks for this project: (1) design and build a corrosion resistant structure that meets local building codes, (2) design and build a solar power station capable of charging portable electronic devices, and (3) design and build a structure with a solar-powered lighting source.

This project also offered valuable learning experiences to the participants in project management. Fabrication and installation of the solar pavilion required the Office of Facilities Management to dig footings. Due to the commitment of this office to other priorities, this portion of the project had a 6-

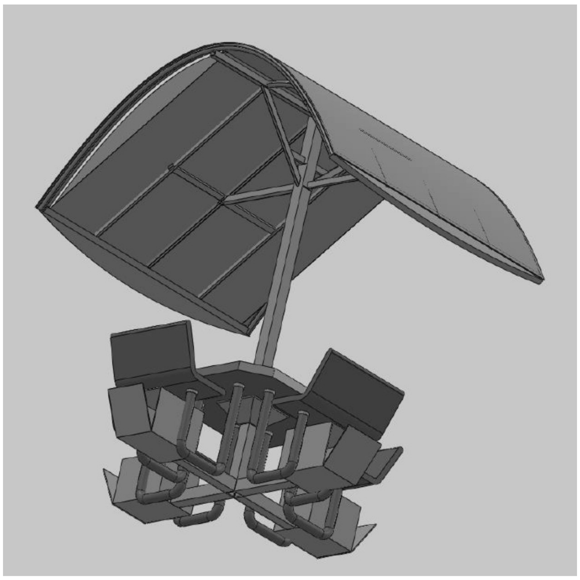


Fig. 2. Original computer-aided design of solar pavilion.

month lead-time, during which the progress on the project was stalled. During the lead-time, the team completed work on different concurrent projects while waiting for the completion of the footings. Student interns are typically assigned multiple project assignments to simulate what they would encounter in an industrial setting. This gives student interns experience in multi-tasking as well as managing multiple projects concurrently to build skills in project management.

At the completion of this project, two solar pavilions were installed on campus. Student interns gained hands-on experience in design and fabrication of the corrosion-resistant metal structures and accompanying solar power lighting and charging stations. In carrying out this project, they also developed skills in troubleshooting, teamwork, and problem solving. One completed solar pavilion with a student user is shown in Fig. 3. The pavilions have been in operation since June of 2019. The Concept Center has been monitoring their performance since then and has verified from student feedback that the solar powered pavilions function well in providing outdoor charging access for students. In recognition of the team's efforts, the project team was invited to a formal luncheon organized by the Office of Facilities Management.

4.2 Cadaver Storage System

The Zoology Department at Weber State University received two cadavers by donation for use as teaching aids. A faculty member in that department wanted to use these cadavers in undergraduate human anatomy courses but did not have a way to store them. Moreover, the department did not have a budget or funding access to purchase a

Fig. 3. Completed solar pavilion.

cadaver storage system. Laboratory grade cadaver storage systems are quite costly with a unit price as high as $15,000. The Zoology faculty member approached the Concept Center for help with a temporary and a long-term storage solution for the cadavers. A team including 4 student interns and 2 faculty mentors was formed to conduct this project. Based on the customer's requirements, the team began by dividing this project into two phases. The goal of the first phase was to provide a short-term solution for the summer term and the goal of the second phase was to develop a long-term solution for permanently storing the cadavers in the Zoology Department. Skills and knowledge required to complete this project include engineering design, materials science, manufacturing processes, statics, control systems, and FEA analysis. ABET student outcomes 1, 2, 3, 5, and 7 were addressed through completing this project.

The goal for phase 1 was identified as to create a temporary storage system that would eliminate required daily maintenance for the cadavers during the summer. The gurney that was in use required application of preservation fluids every day to prevent the cadavers from dehydrating and becoming damaged. Since the summer months were only a few weeks away when this project commenced, this became a unique opportunity for student interns to derive a temporary solution with a low budget and tight time constraint. Such a situation is one where creativity and problem solving become the most important skills. With these constraints, the team came up with a temporary solution that would only cost about $100 for the summer term. A custom fabricated wooden storage container with a polymer impermeable liner was built for the phase 1. This container functioned perfectly through the summer of 2019 and did not require any maintenance treatment during that time. The customer, a zoology faculty member, expressed satisfaction with the wooden storage container delivered by the project team.

In phase 2, the team was given enough time to design a cadaver storage system to permanently meet the need of the Zoology Department by following a systematic engineering design process [12–14]. Design requirements of this project were first identified after reviewing defects of existing commercial products. The team found that existing products on the market are less ideal for intermittent usage by faculty and students. In commercial cadaver storage systems, 1% phenoxyethanol is used as a wetting agent and is delivered through either manual spray or immersion tank. Manual spraying requires constant maintenance and would take considerable time of the instructor. Immersion tanks are a compromise between long-term storage and teaching versatility. In addition to their high price, immersion tanks require the removal of the cadaver from the immersion tank 24 hours prior to usage to allow for preservation fluids to drain from the cadaver. Additionally, immersion tanks are bulky in size and extremely heavy. To eliminate those defects, the design requirements were defined as: (1) the cadaver storage system should have the ability to combine an automated fluid spray and recycling system with the current cadaver gurney tables, (2) the cadaver storage system should be easily moved and (3) each cadaver storage system should cost less than $6,000.

The team presented a design that modifies the existing cadaver gurney table by adding an automatic spray system supplied by a recirculating reservoir. This spray system is controlled by a timer with a manual override, eliminating the need for the instructor's manual maintenance and fluid drain time. Additionally, by eliminating the large immersion tank, the storage system is more compact. The modified gurney table design simplifies the wetting efforts while retaining the automated tilt and elevation functions of the gurney table for ease of teaching. The total cost for designing and fabricating two such storage systems was $11,050. The cost requirement of this project is therefore met.

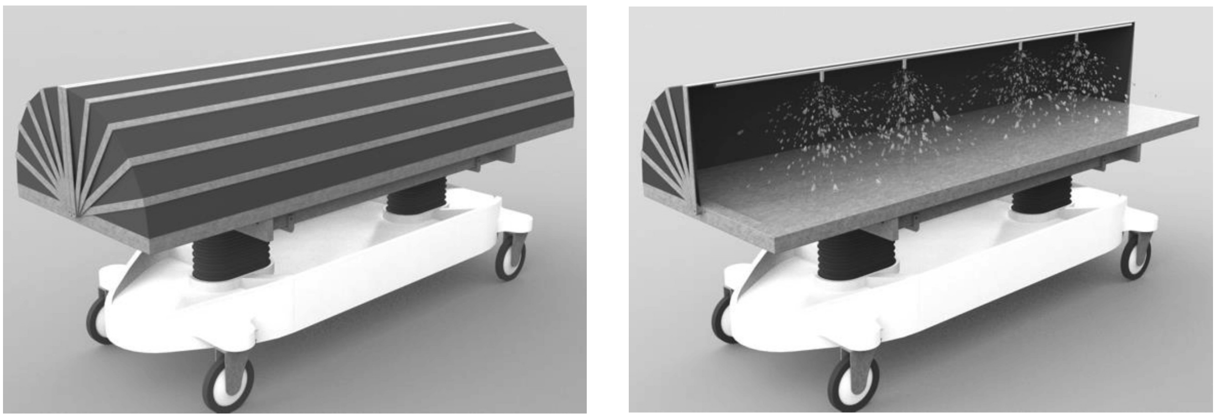
CAD models of this design and its automatic spray system are displayed in Figs. 4a and 4b, respectively. The difference in cost over the purchase of a system on the market largely is due to the utilization of an existing cadaver gurney. In addition to its low cost, the designed spray system features a significant weight reduction compared with the immersion tank. This design also eliminated the need for expensive structural materials capable of handling the loading and environmental requirements of an immersion tank.

The designed cadaver storage system is currently being fabricated but the project has already produced several positive outcomes:

1. The CFT (including faculty mentors and student interns from departments of Zoology, Mechanical Engineering, and Manufacturing Systems Engineering) was awarded a grant of $11,050 from the University to fabricate the cadaver storage system.
2. Major work and main results of this project have been presented at the 2019 Human Anatomy and Physiology Society (HAPS) conference by a student intern.
3. One student intern highlighted this project experience on his resume and received a full-time job offer upon graduation from a laboratory equipment company as a design engineer.

4.3 Public Art Project

A unique project with a goal of creating a public art sculpture for a faculty member from the Visual Arts Department was undertaken by the Concept Center. In conjunction with the College of EAST, the faculty artist assisted in hosting a summer camp titled "The Art and Science of Metalwork" for



(a) (b)

Fig. 4. (a) A CAD model of the cadaver storage system. (b) A CAD model of the automatic spray system.

Fig. 5. Completed haiku fence [25].

high-school aged girls [24]. The Concept Center decided to sponsor this project because it would develop student interns' manufacturing skills and the project itself is closely related to ABET student outcomes 3 and 4.

During this summer camp, 16 high-school aged girls spent three days on-campus learning about welding and metalwork. They completed a total of six projects during the camp. One of those projects was for each girl to write a Haiku poem. The text of these poems would later be cut into pickets for a fence for a public art project displayed at the Bountiful Davis Art Center in Bountiful, Utah (Fig. 5). Utilizing CAD tools, two student interns at the Concept Center designed panels with poems on them. The developed CAD models were then imported into a computer numerically controlled (CNC) waterjet cutter for making the haiku fence pickets. Student interns learned how to program and operate this waterjet cutter to fabricate the pickets from participating in this project.

Besides this public art project, student interns were assigned with several other tasks in support of other camp projects, which included materials preparation, assisting the girls in welding technique, and maintenance of the metal inert gas (MIG) welders such as replacing damaged contact tips. Student interns were also trained on programming and operation of the CNC plasma cutting table and gas settings on the MIG welders.

4.4 Mold for Mannequin Shoulder Teaching Aid

One of many ways the PBL Center supports the university is through recognizing and supporting the university's mission of teaching. The Concept Center has completed many projects of developing teaching aids for faculty members to use in their classes. One such project was the development of a mold for a mannequin shoulder insert. A faculty member from the Department of Zoology wanted a mold that could be used to make gel shoulder inserts for a mannequin for a continuing medical education (CME) accredited class for the Ogden Surgical-Medical Society's 2018 annual meeting. The gel shoulder inserts would be used in a technical training course for attendees led by a faculty member from the University. The mold was designed to allow attendees who are doctors, nurse practitioners, and physician assistants to practice injecting corticosteroids into various joints of the shoulder that are prone to damage. In this technical training course, CME students could visually see the location where the dye was delivered to simulate an injection of medicine on a real shoulder. The faculty member approached the Concept Center and asked help for fabricating such a mold. The mold would allow him to produce the shoulder inserts and eliminate the need of purchasing one from a third-party vendor. Mold making skills and knowledge in material properties learned from classes were required to conduct this project and the scope of work rightly address ABET student outcomes 1 and 2.

The Concept Center formed a small team of one student intern and one faculty mentor to carry out this project. Using the mannequin provided by the Zoology faculty, the team made a reusable silicon mold. Fig. 6 shows the mold made in progress for the mannequin shoulder. The student intern acquired a skillset in making the mold from this

Fig. 6. Mannequin shoulder mold teaching aid in progress.

project and the final mold prototype only costed $180. This mold allowed for the fabrication of multiple shoulder inserts for the students who attend the CME class to practice repeatedly. A similar product on the market is a single-use arthroscopic shoulder with a unit price of $255.

5. ABET Student Learning Outcomes

1. An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2. An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3. An ability to communicate effectively with a range of audiences.
4. An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5. An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6. An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.
7. An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

6. Lessons Learned in Identifying Appropriate Projects

Successful projects have several key qualities in common which are important to recognize when evaluating whether a potential project should be taken on and will ultimately lead to a beneficial experience for the student interns, faculty mentors, and customers. Projects must be evaluated in the context of the mission of the Center while considering the capacity of the student interns and faculty mentors affiliated with the Center. In general, an approach of under-promising and over-delivering is a safe way to communicate capabilities, resulting outputs, and timeframes with the customers. Key factors to consider are highlighted below:

6.1 Intrinsic Learning to Student Interns and Faculty

Before moving forward with any project, one question that needs to be answered is will the project bring valuable learning opportunities? Several projects have not progressed beyond the initial customer meetings because they would not promote student learning. One such project was to fabricate metal lawn signs to promote an event. This project was not chosen by the Center because it did not have a design component and would offer limited opportunities for teamwork, collaboration, design, experimentation, or acquisition of new knowledge to the student interns and faculty. Projects that are undertaken by the Concept Center should present a strong design, research, or fabrication challenge and not be primarily assembly work.

6.2 Incremental Stretch of Skillset or Capability

The Concept Center must evaluate the stretch required on existing skillsets or existing infrastructure and equipment for completion of projects. By considering if the skills required for the project are attainable or if the complexity of the project is beyond the scope that can be handled by the faculty and student interns, projects can be evaluated as suitable or unsuitable. This is a very subjective measurement but should be taken before starting a project. For instance, the Concept Center did not take on a material characterization project for a medical device company because the requirement of conducting this project surpassed the capacity of the Center. This project involved testing material samples and providing resulting data that would be used for a medical device submission change to the Food and Drug Administration (FDA). However, since the Center is not an ISO 9001 certified laboratory, the data generated from the Center would not be considered valid and therefore not be usable, so the project was not undertaken.

6.3 Well Defined Scope of Work

A project with a vaguely defined scope and deliverables is difficult to conduct and can result in unsatisfactory results that fail to meet the customer needs. At the initiation of each project, there must be a clearly defined statement of work that details work that will be completed, along with deadlines and costs. This document needs to be reviewed and approved by both the Concept Center and the client so that it will serve as a legally binding agreement. Many conflicts and misunderstandings can be avoided by properly and explicitly defining the project's scope of work and specifying responsibilities, deliverables, and tasks that will be completed during the project period.

6.4 Flexible Time Constraint

Projects with tight time constraints can be a recipe for disaster. When determining the project duration, the team needs to account for the extra time needed to provide quality mentoring in addition to allowing for unexpected situations that result in delay. One such project that did not proceed past the scoping phase was an industry partner looking for help with hardware design for an aircraft. In this project, the customer required full-time employment and required the project to be completed in two months, which is unrealistic for a student project managed by the Concept Center, and therefore this project was declined.

6.5 Customer's Ability to Recognize the Value of Learning

It is most helpful if customers approach the Concept Center with an understanding of the value of PBL to the students and a supportive and cooperative attitude. In one example, a customer refused to provide engineering drawings of a prototype and only wanted the Center to fabricate mass quantities of the product off a CAD file. Without reviewing the geometric dimensioning and tolerance (GD&T) requirements of the product, the faculty and student interns would not be able to evaluate the suitability of candidate manufacturing methodologies. This customer did not even allow student interns to review the design and manufacturing plan, which is customary in the planning phase of a project and offers a valuable learning opportunity for student interns. Engaging with this type of customer is not recommended.

6.6 Feasibility

It is quite common for the Center to receive many proposals presenting infeasible projects. Some customers assume that a project can be completed by student interns without associated costs. Other customers think that engineering design and analysis does not require a certain amount of labor time. There are still a few customers who have unreasonable ideas about fundamental laws of science. Many projects failed to progress beyond initial meetings because the customers imagined that there should be no costs associated with the work on design, research and prototyping. Other projects could not be carried out because the science background of the customers was so flawed that their ideas violated laws of physics and could never be turned to realities. In one example, faculty engaged with the Center were exploring a project with a local industry partner. After completing three meetings and two tours of facilities, the industry partner insisted that student interns would be working for free, which is not the format for projects at the Concept Center unless there is a clear service component of the project. To avoid significant time invested into these kinds of projects, it is sagacious to utilize a project application form as a screening tool. This form will be completed by potential customers and should include information such as the description of the project, customer requirements including cost, time, materials, and other specifications. If available, the customer can supplement the application form with engineering drawings. This form will become a starting point for the Center to assess the suitability and feasibility of the project. It also can form a baseline for additional questions raised toward the project to finalize its scope and required deliverables. If the project appears to meet the requirements described in sections 5.1 to 5.5, the Center will arrange an initial project meeting with the customer.

In the initial meeting, a discussion of an estimated budget for the project is appropriate in addition to reviewing customer expectations. In some cases, the customer may not have a technical background and may have not done any vetting of the project in terms of practicality or may assume there is no cost associated with the project. In these instances, it is very likely that misunderstanding between two parties appears. Customer meetings should be summarized with meeting minutes where details of the discussion and future plans or actions are explicitly stated. These meeting minutes should be shared with the project team and the customer. It is also imperative that the communication back to the customer about failing to accept the project is with utmost respect.

It should be noted that the Concept Center has had several experiences in which customers failed to answer follow-up questions related to their project. If the customer is not responsive in the early stages, this may be a sure indication that the project should not be accepted. In this case, it is still important to close the communication to the customer with an explanation why the project is no longer under consideration.

7. Lessons Learned in Student Intern Management

To ensure project success and build a positive reputation for the Center and the University, it is critical that a competent team of capable faculty members and student interns is formed for each project. Key factors to consider in forming such a project team and the resulting organizational structure are highlighted in following subsections.

7.1 New Student Interns are Employed in a Project-Based Capacity

The Concept Center employs student interns for each new project based on the alignment between the project requirements and the students' background. This project-based hiring helps to engage students with the Center without a long-term commitment. For example, to fabricate the cadaver storage system in phase 2, the team needed a stainless-steel welder. Since the MSE Department has a program with emphasis on welding engineering, the team contacted that department and successfully hired a student from the department with professional welding experience. The MSE student joined the project team during the fabrication phase and then resumed his outside employment after completing his task in that project.

There are situations in which it can become quickly apparent that an intern will not be successful in the project team. In one example, a new student intern was assigned a project task and given a deadline for completion. The intern failed to do any work and did not show up to the Center. To keep project schedules moving, it may be necessary to reassign projects to different students and remove students from project teams. However, considering the many experiences a PBL center can offer, formal intern dismissal should be avoided if possible. The project-based hiring is also a way of simulating a 90-day probationary period that new employees would normally have in their company, which makes the formal dismissal of a student intern unnecessary. Dismissing an intern should only happen in extreme cases of gross negligence or due to illegal behaviors.

7.2 Proven Interns are Employed in a Continuous Capacity

Some of the most notable gains that can be attained through PBL are achieved with continued mentoring. Student interns that have demonstrated their ability to learn, engage, and function in a team can be employed with a regular weekly schedule in a continuous capacity and be assigned multiple projects with long timelines. The regularly scheduled hours can be designed to accommodate the student's course load and could vary from 10 to up to 30 hours per week and extend through semester breaks. These student interns are funded through the budget of the center. This continuous involvement allows for student interns to build working relationships with their faculty mentors and with other student interns and get involved in a diverse number of projects and multiple project teams. For example, one such student intern was employed through the Concept Center for two years. Throughout this time, he worked on a total of 14 different projects. The hours he worked were set on a schedule that was designed to accommodate his course load and were increased during semester breaks. This format allowed for continued mentoring until his completion of his degree program and entry into industry.

7.3 Professional Development for Students

The Concept Center is committed to promote the professional development of the student interns. Major activities include supporting the students to attend conferences, expos, and other events relevant to their field of study. For example, the student interns have attended the Wasatch Front Materials Expo, Society for the Advancement of Materials and Process Engineering (SAMPE) monthly meetings, The Composites and Advanced Materials Expo (CAMX), and Western States International Council on Systems Engineering (INCOSE) conference. Student interns are also encouraged to take on internships provided by industry partners and other companies. For example, one intern employed by the Center was offered a summer internship by a laboratory equipment company in another city. With the overall goal of supporting students to advance in their careers after graduation, the student intern was welcomed to return to the Concept Center at the completion of the summer internship when the semester commenced.

7.4 Facilitate Recruitment of Student Interns

One challenge that a PBL center faces is to recruit top students for the projects. The high-ranked students often have other opportunities with internships from local industry employers. At most universities, the stipend paid to undergraduate students is not competitive with what is offered by industry employers. To recruit more high-ranked student interns, it is critical to explain to them the benefits of the project experience to their careers and assign them project tasks that best match their interests and which they can take advantage of in pursuing their career goals.

7.5 Allow for Individualized Mentorship

Student interns can benefit the most from the PBL center through the mentoring relationship. From a mentoring standpoint, each student will have varying and individual needs. One student may need instructions on research methodologies. Another student may need guidance in interpersonal and communication skills. It is the responsibility of the mentor to assess the needs of each student intern and guide them accordingly. The role that the mentor plays should be tailored for each student intern. Each mentor should meet with student interns individually, document their goals of development, and discuss ways of assessing their progress.

Faculty mentors should utilize failure of the student interns as opportunities for their growth. Positive learning experiences often result from failures if those failures are managed delicately. For example, one student intern sought to take all credit for project work and neglected to recognize the roles of other team members. It should be the responsibility of the mentor to use this as a lesson to educate the student intern to understand the negative influence on team culture from such behavior. Through these practices, the student interns will grow professionally and be better prepared for their careers.

The number of student interns that the Concept Center can support is greatly influenced by the number of mentors available as well as the number of projects, scope of the projects, and operating budget. Potential projects should not be undertaken without adequate mentors with appropriate backgrounds and expertise. To ensure quality mentoring, the mentor must spend a considerable amount of time with each student intern while managing the project toward its completion. Full-time faculty mentors affiliated with the Concept Center feel that they can successfully manage up to 5 direct reports. Capacity of each mentor must be considered when assigning student interns to this mentor to ensure that each student intern will have a positive experience from working in the project team and from the mentorship program.

8. Conclusion

The modern engineering profession is dynamic and constantly changing. To be better prepared for engineering careers, students nowadays need more experience and opportunities to learn outside of the classroom. A PBL center like the Concept Center is an effective way to educate and train current students for the demands placed on modern professionals to navigate competing priorities set by clients, regulating bodies, environmental groups, and the public at large. It also can function as a platform to engage industry partners and community members with faculty and student interns through mutually beneficial R&D activities. This paper shares the experience of the Concept Center at Weber State University in establishing PBL learning models. The benefits of a PBL center to the students, faculty members, and the institution are fully demonstrated. Examples of past projects are reviewed, and lessons learned from those projects are discussed. By overcoming the challenges posed by the institution, the customers, and the projects themselves, the Concept Center is making progress toward its mission of connecting academia with industry and community sponsors. Projects completed demonstrate the ability of the Concept Center to address the expressed needs of the projects while providing excellent opportunities for student interns to gain crucial problem solving and employability skills.

Acknowledgements – This paper is authored based upon projects completed at the Concept Center at Weber State University located in the College of EAST. The authors would like to express their gratitude for the help and support from the following student interns, faculty members, and staff: Thomas Odenwalder, Brandon Burke, Taylor Foss, Dr. David Ferro, James Taylor, Justin Knighton, Patrick Thomas, Gina Naisbitt, George Comber, Jason Manley, Jeff Strahan; and industry and community sponsors: Hill Airforce Base, Murphy Door, ATK, Hydropur, GSC Foundries, Dr. Brian Chung, and SES Engineering.

References

1. *The Green Report: Engineering education for a changing world*, American Society of Engineering Education, Washington DC, 1994.
2. *Criteria for Accrediting Engineering Programs*, Engineering Accreditation Commission of the Accreditation Board of Engineering and Technology, ABET, Baltimore, Maryland, 2001.
3. J. Mills and D. Treagust, Engineering Education – Is Problem-Based or Project-Based Learning the Answer? *Australian Journal of Engineering Education*, **3**(8), pp. 2–16, 2003.
4. G. Schmidt, Foundations of problem-based learning: some explanatory notes, *Medical Education*, **27**(5), pp. 422–432, 1993.
5. E. Graaff and A. Kolmos, Characteristics of Problem-Based Learning, *International Journal of Engineering Education*, **19**(5), pp. 657–662, 2003.
6. Y.-C. Liu, Renovation of a mechanical engineering senior design class to an industry-tied and team-oriented course, *European Journal of Engineering Education*, **42**(6), pp. 800–811, 2017.
7. Y.-C. Liu, A. Artigue, J. Sommers and T. Chambers, Theo Jansen project in engineering design course and a design example, *European Journal of Engineering Education*, **36**(2), pp. 187–198, 2011.
8. Y.-C. Liu and Y.-Q. Dou, Design of an industry-tied and team-oriented course for mechanical engineering seniors, *Proceedings of ASEE SE Section Annual Conference*, University of Florida, Gainesville, FL, April 12–14, 2015.
9. S. Bell, Project-Based Learning for the 21st Century: Skills for the Future, *The Clearing House*, **83**(2), pp. 39–43, 2010.
10. J. Uziak, A project-based learning approach in an engineering curriculum, *Global Journal of Engineering Education*, **18**(2), pp. 119–123, 2016.
11. Y.-C. Liu, F. Baker, W.-P. He and W. Lai, Development, assessment and evaluation of laboratory experimentation for a mechanical vibrations and controls course, *International Journal of Mechanical Engineering Education*, **47**(4), pp. 315–337, 2019.
12. Y.-C. Liu and F. Baker, Development of vibration and control system through student projects, *Proceedings of ASEE SE Section Annual Conference*, North Carolina State University, Raleigh, NC, USA, March 10–12, 2019.
13. Y.-C. Liu, V. Meghat and B. Machen, Design and prototyping of a debris clean and collection system for a cylinder block assembly conveying line following an engineering systems design approach, *International Journal of Design Engineering*, **8**(1), pp. 1–18, 2018.

14. Y.-C. Liu, V. Meghat and B. Machen, Design and prototyping of an in-situ robot to clean a cylinder head conveying line following an engineering systems design approach, *International Journal of Design Engineering*, **7**(2), pp. 106–122, 2017.
15. Y.-C. Liu, J. A. Batte, Z. H. Collins, J. N. Bateman, J. Atkins, M. Davis, D. Salley, C. L. Bethel, J. E. Ball and C. Archibald, Mechanical design, prototyping, and validation of a Martian robot mining system, *SAE International Journal of Passenger Cars – Mechanical Systems*, **10**(1), pp. 1289–1297, 2017.
16. J. Perrenet, P. Bouhuijs and J Smits, The Suitability of problem-based learning for engineering education: theory and practice, *Teaching in Higher Education*, **5**(3), pp. 345–358, 2000.
17. I. Rios, A. Cazorla, J. Diaz-Puente and J. Yague, Project-based learning in engineering higher education: two decades of teaching competences in real environments, *Procedia Social and Behavioral Sciences*, **2**(2), pp. 1368–1378, 2010.
18. S. Han, B. Yalvac, M. M. Capraro and R. M. Capraro, In-service teachers' implementation and understanding of STEM project based learning, *Eurasia Journal of Mathematics, Science & Technology Education*, **11**(1), pp. 63–76, 2015.
19. J. H. Labeause, LibQUAL+^{TM} in a problem-based learning (PBL) medical school, *Journal of Library Administration*, **40**(3–4), pp. 59–72, 2004.
20. S. Ahlfeldt, S. Mehta and T. Sellnow, Measurement and analysis of student engagement in university classes where varying levels of PBL methods of instruction are in use, *Higher Education Research & Development*, **24**(1), pp. 5–20, 2005.
21. L. Dinca and C. Voinescu, Cross-functional teams and their role in increasing competitiveness of the organizational partnerships, *Proceedings of European Integration Realities and Perspectives*, **7**, pp. 453–459, 2012.
22. M. Laal and P. Salamanti, Lifelong learning; why do we need it, *Procedia – Social and Behavioral Sciences*, **31**, pp. 399–403, 2012.
23. W. Hart, In focus/mentoring nurturing relationships provide many benefits", *Leadership in Action*, **29**(1), pp. 17–20, 2009.
24. M. Cortez, *Weber State's Girls Welding Camp harnesses 'power of lightning*, https://www.deseret.com/2018/7/12/20648917/weber-state-s-girls-welding-camp-harnesses-power-of-lightning#emily-curtis-welds-during-girls-welding-camp-the-art-science-of-metal-work-at-weber-state-university-in-ogden-on-tuesday-july-10-2018, Accessed April 15, 2020.
25. J. Manley, *Haiku Fence Detail*, https://www.jasonmanley.com/?attachment_id=631, Accessed April 15, 2020.

Yucheng Liu, PhD, PE is a Professor in the Department of Mechanical Engineering (ME) at Mississippi State University (MSU), he currently serves as Graduate Coordinator in that department and holds the Jack Hatcher Chair in Engineering Entrepreneurship in the Bagley College of Engineering. Prior to joining MSU in 2014, Dr. Liu was an Assistant Professor of the ME Department at the University of Louisiana at Lafayette (UL Lafayette). Dr. Liu received his PhD degree from the University of Louisville in 2005 and bachelor's degree from the Hefei University of Technology in 1997, both in Mechanical Engineering. Dr. Liu's research has historically focused on the areas of multiscale material modeling and simulation, high strain rate performance of materials, vehicle systems design and analysis, and hydropower and wave energy technology. His current research interests and activities center on gaining a better understanding of the process-structure-property-performance relations of structural materials through advanced multiscale theoretical framework and integrated computational and experimental methods. To date, Dr. Liu has published about 230 peer reviewed publications, including more than 120 peer reviewed journal articles, and received 2 patents. He has been the PI and co-PI for over 40 research projects funded by NSF, DOD, DOE, NASA, FAA, Louisiana Board of Regents, and industry with a total amount over $15.5M. Dr. Liu was elected a Fellow of ASME in 2017, a Fellow of SAE in 2019, and received the SAE Forest R. McFarland Award in 2020. Dr. Liu is a Professional Engineer registered in Ohio State and also holds active membership in ASEE and AAAS. Dr. Liu will become the Mechanical Engineering Department Head at South Dakota State University in July 2021.

Mary Foss is Director of the Concept Center at Weber State University and Assistant Professor in the Manufacturing and Systems Engineering Department. Prior to joining Weber State University, she worked in the Pharmaceutical and Medical Device Industry as a department manager and leader in quality systems. Her current research interests and activities center on gaining a better understanding of methods to achieve learning outcomes through integration of PBL in various outreach activities in local communities and in the classroom setting. Mary Foss earned a Bachelor's degree in Biomedical Engineering from Arizona State University and a Master's degree in Pharmaceutical Manufacturing Engineering from Stevens Institute of Technology. She is currently pursuing her PhD in Mechanical Engineering from Mississippi State University.