Creating Meaningful Experiences Through Extracurricular Project-Based Experiential Learning

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Abstract

Educators, employers, and students all understand the value of both taking part in extracurricular activities and the importance of integrating experiential learning into the engineering curriculum. Unfortunately, we know quite little about the impact that such extracurricular project-based experiential learning has on educating undergraduate students studying engineering. Informed by the literature in the fields of student engagement and experiential learning, this paper examines perceptions and experiences of nascent engineers to understand how these specific extracurricular activities contribute to their collegiate experience. Students who were taking part in extracurricular engineering projects while completing their four-year engineering degree at the University of Minnesota were included in this qualitative case study. Ten semi-structured hour long interviews (six males and four females) were conducted to collect the bulk of the data for the qualitative analysis. This data was supplemented with three observations and the collection and inspection of artifacts. Key findings include evidence that extracurricular projects serve as an especially impactful engagement activity for engineering students. Such projects also are effective tools for increasing self-efficacy and motivation, especially among women, and serve as a particularly valuable career preparation experience. Additionally, the organic design-build process students engage in outside the structure of a classroom parallels with Kolb’s model of experiential learning, suggesting a particularly suitable method for educating engineers in the design process. Going forward, engineering colleges and universities have multiple opportunities to enhance the participation rate and quality of their students’ access to extracurricular projects. This paper discusses these opportunities along with various challenges, while acknowledging that there is much unknown about the educational value of extracurricular project-based experiential learning. The work here hopes to help fill that gap in what may be a fast growing facet of an engineering student’s college experience. This paper is a condensed version of a completed dissertation for a 2016 Ed.D. Degree by the author.1

Introduction

In Educating Engineers, Sheppard, Macatangay, Colby, and Sullivan describe the new-century engineer emerging from the profound changes in technology. Engineers can no longer expect a linear environment, but rather a “network, web, or system.”2 No longer are the “number of variables … severely constrained, and … problems reduced to quantitative dimensions,” but systems are complex and “so heterogeneous that interdisciplinary interactive groups sharing perspectives and information are needed to create and control them.”2 In other words, the professional engineer cannot continue to be a “disengaged problem solver” and, likewise, the methods used to educate new engineers cannot consist of disengaged students working through linear, constrained, quantitative problems with single answers. A more complex, inter-connected world is emerging and science and engineering jobs are adapting along with the change, putting pressure on our educational systems to not only produce more students capable in science, technology, engineering, and math, but students who understand how their role impacts a
knowledge-driven, global economy. Understanding our students as citizen scientists and engineers is a powerful reframing for educators and our future graduates who we hope to be diverse, active, and engaged citizens solving problems of critical importance.²

This paper looks at the role extracurricular activities conducted in the midst of the national makerspace movement has on design thinking in engineering education. Educators have seen the excitement in students and the value-add that project-based extracurricular experiences like Solar Vehicle Project, Concrete Canoe, First Robotics, and a growing multitude of other activities bring to the student experience. However, there are many unanswered questions about the true effectiveness of these activities, who participates, and why students participate. We need to understand the value we are bringing to students’ educational experience and if we find that resources are worth investing, we must understand how to bring the experience to more students, do it effectively and in tandem with the regular curriculum, while ensuring that the collaborative, multi-disciplinary, and grass-roots nature of these groups is not eroded. An opportunity lies in this extracurricular project-based space to attract and better prepare students as new-century citizen engineers capable of solving the grand challenges this new century brings.

Reviewing the Literature

Student engagement theory pioneer Alexander Astin hypothesized that the more involved a student is socially and academically in college, the more he or she will learn due to increases in motivation and interaction with faculty, fellow students, and other campus activities.¹,²,³ Unfortunately Astin found that choosing an engineering major had “negative effects on a variety of satisfaction outcomes: faculty, quality of instruction, Student Life, opportunities to take interdisciplinary courses, … the overall college experience, … writing skills, listening skills, [and] Cultural Awareness.”³ He did find that engineering majors reported the highest growth in analytical and problem-solving skills, but those positive findings do not offset the missed opportunities for broad student growth and higher levels of overall satisfaction that lead to a growing number of citizen engineers prepared for our newly global, age of information.

Terenzini and Reason built upon the observations of Astin and found that the peer environment plays a deeply influential role in the learning and development of college students.⁴ Furthermore, out-of-class experiences can have substantial impacts on student outcomes. Strauss and Terenzini were able to show that graduating engineering students made gains in analytical skills and groups skills through out-of-class experiences.⁸ Yu and Simmons review of the relevant literature found that out-of-class activities had multiple positive influences in areas as diverse as cognitive development, communication skills, and leadership ability, among others.⁹

From another scholarly perspective, there is a litany of evidence that educationally purposeful activities where students assign validity to their own thoughts and begin constructing their own knowledge positively relates to academic outcomes and satisfaction.¹⁰,¹¹,¹² For young engineers, project-based learning is the typical structure for delivering such purposeful activities. Some scholars have found clear links between offering hands-on project learning and higher retention in the first year.¹³ Froyd, Wankat, and Smith argue that engineering education is in the midst of a shift toward a “renewed emphasis on design” and the application of “education, learning, and
social-behavioral sciences research,” which includes first-year project design courses and the application of project-based and cooperative learning in and outside-the-classroom. If such a shift is happening, it is crucial to better understand the role of extracurricular project-based experiential learning in the emerging engineering education environment.

At a basic level, project-based experiential learning refers to John Dewey’s longtime association with “learn by doing,” which succinctly (albeit poorly) summarizes Dewey’s canon of work on education. Dewey’s philosophy on education is best captured in his work, *Experience and Education* in which he declares “the only freedom that is of enduring importance is freedom of intelligence, that is to say, freedom of observation and of judgment exercised in behalf of purposes that are intrinsically worthwhile.” Project-based experiential learning aims to be intrinsically worthwhile by freeing the student through a process of creativity, curiosity, observation, and open decision-making that results in something tangible and relatable. In the literature, scholars also refer to project-centered learning, active learning, problem-based learning, team model-eliciting activities, and experiential and project-based learning separately. Although certainly important, if subtle, differences distinguish the terms, project-based experiential learning is the most appropriate term for this study, as it succinctly connotes “hands-on” through project and “practice” through experiential. The term allows for a broad understanding of the activity while still emphasizing the importance of learning by doing.

Maria Montessori, famed educator of young children, said “the environment must be rich in motives which lend interest to activity and invite the child to conduct his own experience.” Although speaking of the development of pre-school aged children, the quote encapsulates the connection of interest leading to experience. Expanding on that idea, Kolb writes, “this perspective on learning is called ‘experiential’ for two reasons. The first is to tie it clearly to its intellectual origins in the work of Dewey, Lewin, and Piaget. The second reason is to emphasize the central role that experience plays in the learning process.” Kolb aligns Lewin’s model of action research, Dewey’s model of learning, and Piaget’s model of cognitive development into his own model of experiential learning that he described as “the process whereby knowledge is created through the transformation of experience.”

Figure 1, utilizing a recast and critiqued version of Kolb’s experiential learning model from Bergsteiner, Avery, & Neumann, illustrates four ways of experiencing: *Concrete Experience, Reflective Observation, Abstract Conceptualization,* and *Active Experimentation.* These four ways of experiencing iteratively interact with four distinct learning styles, *Diverging, Assimilating, Converging,* and *Accommodating.* Project-based experiential learning ideally harnesses a student’s natural interest and motivation to navigate an iterative path of evolving experiences, each of which enhance learning in different ways.
Implementation of the experiential learning model is commonly done through project-based learning. Blumenfeld et al. defined project-based learning as, “A comprehensive perspective focused on teaching by engaging students in investigation.” Within this framework, students pursue solutions to nontrivial problems by asking and refining questions, debating ideas, making predictions, designing plans and/or experiments, collecting and analyzing data, drawing conclusions, communicating their ideas and findings to others, asking new questions, and creating artifacts. Dutson, Todd, Magleby, and Sorensen described the relatively recent changes in engineering curricula that have brought back elements of engineering practice. After World War II, reacting to an increasingly complex technological environment, educators removed many of the traditional practical skills such as drawing and shop in favor of analytical training heavy in math and science. This newfound return to the basics was mainly achieved through senior capstone courses that implemented project-based learning as defined above.

Dym, Agogino, Eris, Frey, and Leifer discuss the role of project-based learning in design pedagogy for engineers detailing how it is the ideal outlet for the application of convergent-divergent thinking and exemplifies Kolb’s model of experiential learning. Furthermore, Harrisberger identified experiential learning as crucial to quality engineering education because “engineering was perceived as being responsible for the creation and application of more sophisticated devices utilizing the newest scientific discoveries.” The act of converting discovery into device is similar to the process of students taking the abstract concepts in their coursework and through evolving experiences in the lab or field, creating a project artifact. ABET suggests that “engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.” Sheppard writes that engineers “scope, generate, evaluate, and realize ideas,” providing similar language to Kolb. As mentioned above, Dym et al. describe design-thinking as iterations of divergent-convergent questioning and see divergent inquiry as lacking in engineering curricula. They then suggest a systems design approach to
engineering problem solving that includes four aspects parallel to Kolb’s model of experiential learning:

- Thinking About System Dynamics (Kolb’s Concrete Experience)
- Reasoning About Uncertainty (Kolb’s Reflective Observation)
- Making Estimates (Kolb’s Abstract Conceptualization)
- Conducting Experiments (Kolb’s Active Experimentation)

Dym, et al. go on to recommend project-based learning at the first-year level and making design pedagogy the top priority for educators.25

Finally, this paper looks at the concept of project-based experiential learning in the context of out-of-classroom experiences yielding extracurricular project-based experiential learning. As stated in the introduction, these types of activities have been happening formally and informally for decades through technology design competitions (Solar Vehicle Project, Concrete Canoe), outreach oriented project-build groups (Engineers Without Borders, Engineering World Health), and general design-and-build clubs that tend not to be nationally affiliated quite yet. We know surprisingly little about the impact these types of activities have on student development, despite the perception that they are growing in popularity among students, attractive to potential employers, and are by their nature, design and build engineering activities.

**Purpose**

The purpose of this study is to understand how extracurricular project-based experiential learning (EPBEL) contributes to engineering students’ college experiences. Perhaps in synergy with a national makerspace and open source movement, there is a perception that students are spending more time than ever designing and building outside the normal engineering course curriculum. Certainly not all students are spending significant time in design build extracurricular activities, but my experience tells me that a significant minority are and that the number is growing. I also hear from students and employers who tell me that participation in outside the classroom engineering projects is a very important factor in hiring decisions. Understanding the impact these particular activities have on student development is an important next step in examining the role extracurricular project-based experiential learning (EPBEL) can play in the future of engineering education.

This study is a qualitative case study drawing on perspectives of engineering students at a single large public Research One university. The questions for the study were developed to elicit comments regarding the learning experience of such projects, the design-build nature of the projects, the effect on engagement, the effect on self-efficacy, and how the projects prepared students for their professional careers. The research question guiding this study is, “How does extracurricular project-based experiential learning contribute to engineering students’ experiences?” To answer this overarching question, these following four exploratory queries help examine the underlying issues:

1. Why do students choose to participate in extracurricular project-based learning?
2. What do students perceive that they gain from participating in extracurricular project-based experiential learning?
3. What do students perceive as the necessary conditions to create a successful experience?
4. How do experiences with extracurricular project-based experiential learning differ among men and women?

Methodology

A case study consisting primarily of interviews with engineering students is chosen due to the bounded nature of this study and the desire to obtain data with exceptional depth. Kvale and Brinkman explain that “the qualitative research interview attempts to understand the world from the subjects’ points of view, to unfold the meaning of their experiences, to uncover their lived world prior to scientific explanations.”

To more fully understand the effect of extracurricular project-based experiential learning on students’ experiences, it is imperative to foster complex and open conversation that produces, as Merriam puts it, “an in-depth description and analysis of a bounded system.”

In this study, a bounded system is comprised of engineering students who use a particular makerspace designated for experiential learning projects.

This case study site is the University of Minnesota. According to the Carnegie Classification of Institutions of Higher Education, the University of Minnesota is a research university with very high research activity offering a range of majors and experiences for students through curricular and extracurricular courses and activities. Unusual among U.S. universities, the University of Minnesota’s College of Science and Engineering not only hosts the 12 engineering majors on campus but also is home to majors in the physical sciences. Students who identify as engineering majors and have completed at least one year at the University of Minnesota constituted the sample set. The requirement for one year is to ensure enough time to take part in an extracurricular experiential learning project. In addition, the College of Science and Engineering hosts 75 extracurricular student groups, of which a significant, but unknown number, offer project-based experiential learning.

Within this large sample set, students were assigned to a subset of 112 potential interview subjects by their association and access to the lone multi-disciplinary makerspace on campus available to engineering students. Students were contacted for semi-structured sixty minute interviews, with women being purposely oversampled, resulting in four women and six men as subjects. It was determined that after ten interviews, data saturation had occurred and thorough analysis commenced.

Beyond the guidance from the research question, the interview questions were derived from two interacting conceptual frameworks. The first is Terenzini and Reason’s framework of the College Experience grounding the study in the engagement literature and allowing for analysis and interpretation through that frame. The other framework is Kolb’s Experiential Learning Conceptual Model represented by Figure 1. This framework allows for analysis of the students’ perceptions of the learning through the EPBEL process and observations of their group interactions. To expand on the Kolb Model’s application for this study, it is important to
understand the parallels between the basic iterative engineering design approach and how Kolb models the advancement of learning through the navigation of the experiential learning iterative pathway. Relying on these models allows for understanding ways in which experiential learning contributes to knowledge and skills espoused as being critical for the new-century engineer.

The semi-structured interviews consisted of nine core questions and the interview data was supplemented by observations and artifact inspection. The semi-structured nature of the interviews allowed for multiple probing questions after each primary question and aided in producing a thick and rich dataset. The first question asked about the project(s) the student was working on and the second asked why he or she chose to participate in the extracurricular project(s). The next four questions asked the students to discuss how their learning, engagement, confidence, and career prospects are affected by the project(s). The seventh question asked them to describe, in detail, the project building process, while the last two questions had them reflect on the value of the experience and the support they received. After each interview, coding commenced using a constant comparative technique. Heuristic, discrete units of data was coded and categorized, initially through the note-taking process within the interviews and observations, and later through the transcripts, once available. Constant categorization refers to revising the categorization as coding continues and as new information is added. As Merriam details, this process starts out very inductive, but becomes more and more deductive as themes develop and categories crystalize until a saturation point is reached in the interview process. The analysis was in response to the research question at all times and as Merriam suggests: (a) was as sensitive to the data as possible; (b) was exhaustive; (c) was mutually exclusive; and (d) was conceptually congruent.  

Findings

As described above, data analysis consisted of the coding and categorization of the transcripts through a method of constant categorization. This method resulted in seven primary categories directly related to the larger research question and a bevy of themes under the umbrella of the seven overlying categories. The seven categories with their underlying themes developed by the sixth interview, retrospectively indicating that saturation had been reached. The remaining four interviews provided additional supporting data and allowed for a reasonable confirmation that few to no additional categories or even themes would be uncovered through additional interviews. The table below shows the frequency of responses for each primary category and underlying theme, as well as the frequency of description for various aspects of the design and build process that the subjects participated in.

<table>
<thead>
<tr>
<th>Categorization</th>
<th>Underlying Themes</th>
<th>Interview Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total (n=10)</td>
</tr>
<tr>
<td>Reasons for Participating</td>
<td>The Challenge and Intrigue of Application</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Teamwork and Mentorship</td>
<td>10</td>
</tr>
<tr>
<td>Category</td>
<td>Example</td>
<td></td>
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<tr>
<td>----------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>A Sense of Balance</td>
<td>6 2 4</td>
<td></td>
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<tr>
<td>Perceptions of Gain in Learning</td>
<td>The Acquisition and Use of Technical Skills 9 6 3</td>
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<tr>
<td></td>
<td>The Enhancement of Soft Skills 6 4 2</td>
<td></td>
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<tr>
<td></td>
<td>The Strengthening of Problem-Solving Skills 8 4 4</td>
<td></td>
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<tr>
<td>Perceptions of Gain in Engagement</td>
<td>Student Group and Peer Affinity 9 5 4</td>
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<td></td>
<td>Professional and Disciplinary Affiliation 10 6 4</td>
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<tr>
<td></td>
<td>Community Involvement and Spirit 5 3 2</td>
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<tr>
<td>Perceptions in Gain in Self-Efficacy</td>
<td>Social Confidence 8 4 4</td>
<td></td>
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<tr>
<td></td>
<td>Technical Confidence 7 5 2</td>
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<td></td>
<td>Creative Confidence 6 4 2</td>
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<td></td>
<td>Reduction of Inadequacy 6 2 4</td>
<td></td>
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<tr>
<td>Perceptions in Gain in Career Preparation</td>
<td>Resume and Interview Enhancement 8 5 3</td>
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<td></td>
<td>Project Management Experience 7 4 3</td>
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<td></td>
<td>Relevant Technical Skills 4 4 0</td>
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<tr>
<td>Value-Added Beyond the Classroom</td>
<td>10 6 4</td>
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<tr>
<td>Negative Impacts</td>
<td>6 4 2</td>
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<tr>
<td>Student Described Design Process</td>
<td>Brainstorm 9 5 4</td>
<td></td>
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<tr>
<td></td>
<td>Research 10 6 4</td>
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<td></td>
<td>Prototype 10 6 4</td>
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<td>Test 10 6 4</td>
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<td>Iterate 4 2 2</td>
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</tbody>
</table>

This data, when considered in light of Terenzini and Reason’s College Impact Model and Kolb’s experiential learning model, leads to the following four findings.7, 19

1. **EPBEL as an Impactful Engagement Activity**

Regarding student engagement, Tinto found that integration of the individual student is key while Astin illustrated that involvement, especially that which a student devotes plenty of physical and psychological energy to, is important for positive student outcomes for college graduates.30 6 Findings from the interviews show that EPBEL offers an accessible outlet for integration and involvement in various areas, including applying the engineering discipline, developing peer affinity, and connecting with the broader community.

EPBEL offered a rich and diverse way for students to engage in their chosen discipline. Students were intrigued and challenged by projects they considered to be more related to the real-world
problems they would have to solve once they fully entered the workforce. They also saw it as a way to connect their burgeoning engineering skills with their passions, whether that be building interesting devices, learning particular skills, or helping people in the broader community.

For all students interviewed, developing connections to their peers was reported as important to their experience. Many saw it as the most important and valuable part. Their integration into this particular student community happened for various reasons. Some students were drawn to the interdisciplinary nature of EPBEL because their engineering courses were sub-discipline specific in regards to both topic and people. Others were drawn to the particular challenges and rewards of teamwork and mentorship. Sharing a passion—where students self-selected onto a team to exert large amounts of, as Astin would say, physical and psychological energy—was also important and positive for many of the students interviewed. This experience parallels that of learning communities set up as co-curricular environments where students studying similar fields live and learn together. EPBEL adds the additional element of shared passion for a specific task, which served to drive deep and quality involvement for the participating students.

For some of these students it was important that the energy was directed at helping the broader community. Here, one can especially see the overlap with service learning, as many of the student projects described involved some kind of interaction with stakeholders outside the university or had an aim to aid individuals in the local community or across the globe. Students engaged in the notion of utilizing their developing engineering skills in the service of others.

In total, providing the opportunity to make friends and integrate into a larger community that shared similar values sums up how EPBEL engaged students. One unique contribution from these findings is that EPBEL is an especially impactful engagement activity for students. Relatively speaking, there can be a high barrier of entry into the activity as the peer group expects non-trivial minimum levels of dedication that need to be balanced with a difficult curricular load. However, it is that higher barrier to entry that likely led to such high quality involvement and integration for students, which, in turn, provided an environment ripe for persistence, social development, and learning. This finding is consequential to policy makers looking at the implications for practice and will be discussed later in the paper.

2. EPBEL as an Effective Tool for Increasing Self-Efficacy and Motivation

EPBEL provides a particularly engaging experience for students, but another important question is how it develops self-efficacy. Bandura describes self-efficacy as the measure of “conviction that one can successfully execute the behavior required to produce the outcomes” desired. The Academic Pathways of People Learning Engineering Survey (APPLES) found that high levels of motivation and confidence are important indicators for success in engineering and that students who participate in extracurricular activities are more likely to have high levels of motivation and confidence. Is EPBEL simply providing a discipline related social experience or does this engagement go further and instill lasting confidence, motivation, and conviction related to engineering that will aid the student in her or his coursework and carry through beyond graduation? Although this study does not explicitly measure levels of motivation and
confidence, there is strong evidence from the interviews that students were highly motivated and perceived a growth in confidence as they navigated the EPBEL experience.

In regards to the evidence for increasing confidence, the findings show confidence growth in multiple areas. Students reported that they had an advantage in group activities occurring in their classes, because they were more likely to take the lead and had the additional experience and skills to push forward the process. Students also reported feeling more confident in communication and presentation due to EPBEL. Throughout the interviews, there was a tangible sense that these students and the students they worked with were confident that they could find answers to questions they had, take the lead when necessary, meet deadlines, and manage resources.

Technical and creative confidence was also reported to have been increased through EPBEL. Much of this growth can be traced to the accumulation of experiences in EPBEL. Students who had been at it for over two years exuded a confidence that they knew exactly how to get their projects staffed, funded, and built. EPBEL seemed to add the unique element of instilling a sense of independent accomplishment due to the project not being connected directly to curriculum or workplace requirements. This especially applied to the experienced students who were currently in leadership positions for their student groups, had been previously, or had seen successful projects go from ideas to working artifacts. EPBEL, similar to other extracurricular activities that rely entirely on student planning and effort, offers engineering education a particularly strong method to develop independence and entrepreneurship by building confidence through project successes.

It is possible that EPBEL is simply attracting highly motivated students rather than increasing motivation, but when coupled with the reported confidence gains, it stands to reason that they are interconnected. As Leslie, McClure, and Oaxaca found, increasing levels of self-concept—the belief that one has the ability and desire to do, in this case, engineering—leads to self-efficacy. Some of the student interviews illustrated this point by relating how they were hesitant to start doing EPBEL and that their participation level increased as time went on. As their confidence increased and they started to conceptualize themselves as engineers, their motivation increased as well. Women especially reported gains in confidence and self-concept that seemed to impact their motivation. EPBEL seemed to offer an outlet where the women could experiment with belonging, quickly learn that they were capable, and then go on to flourish. One became president of the largest project-based student group on campus, another started her own project-based student group, while the other two were deeply involved in a myriad of projects in which they were taking the lead. All four commonly expressed memories of doubt that they had to overcome and EPBEL played a large role in their changing sense of belonging. For the men, elements of increased confidence leading to motivation also was present, but the men were much less likely to express that they lacked confidence or didn’t belong. This study supports Leslie, McClure, and Oaxaca’s suggestions to build women’s confidence through accomplishment, peer reinforcement, and challenges and builds off of Kilgore, Yasuhara, Saleem, and Atman’s
conclusions that hands-on experiences for women help them build self-concept and ultimately self-efficacy.\textsuperscript{33,34}

Recalling the research that Sheppard et al. did in regards to intrinsic motivation and engineers, they showed that exposure to project-based learning correlated highly with increases in (a) intrinsic-psychological motivation for men and (b) intrinsic-behavioral motivation for men and women.\textsuperscript{32} Couple this with their results showing that students report self-directed learning, hands-on and applicable problem-solving, applying diverse knowledge, owning their experiences, and being challenged as their five most significant learning experiences, and it is not surprising that EPBEL proved to be quite successful at motivating the students in this study. The students interviewed for this study all reported putting in significant time to their projects, with many of them reporting multiple all-nighters. It is beyond the scope of the research design to fully differentiate what motivational types as described by Sheppard and her team were being affected and how, but the interviews seem to indicate that psychological, behavioral, social good, and mentor influence motivation increases happened for these students at varying levels.\textsuperscript{32}

EPBEL can be a very powerful tool for educators who want to provide pathways for students to independently increase their confidence and motivation related to engineering and other facets important to engineering like communication skills, working in teams, and broader civic engagement. Many of the interviewed students were looking for ways to have an impact but didn’t know how to effectively do that. EPBEL, like service-learning, offers an outlet to use their burgeoning skills in ways that feel impactful to them.\textsuperscript{35} Whether it be putting on a massive light-show that attracts thousands, making prosthetic hands for people in poor countries, reaching out to high school students considering careers in engineering, or building a device and competing against others across the U.S. or even the world, the EPBEL projects described by the interviewed students provided an avenue for meaningful impact and success. Alongside that impact and success, comes important growth in motivation and confidence, two essential elements to producing quality engineers.

3. EPBEL as Career Preparation

It became clear through the interview process that students felt they had an advantage in the job hiring process for internships and post graduate jobs due to their EPBEL experiences. Generally, these advantages do not stem from direct technical experience gained from the projects, although that does happen, but from the more general skills students pick up such as working in teams, project management, communication, and independence. The findings indicate that employers are very keen to hire students with EPBEL experiences. Contemplating the discussion from the previous two sub-sections on engagement and self-efficacy, it follows that if employers want to hire highly engaged, confident, and motivated students, an accurate marker for those types of students is a well-articulated EPBEL experience.

4. The EPBEL Learning Process
Learn by doing. This simple yet lasting paraphrase of John Dewey and others’ work continues to resonate with educators and the general public today. Defining “doing” is key in the phrase and probably why Dewey likely never uttered his philosophy on education quite so succinctly. Instead Dewey saw freedom as key to learning by doing, writing, “the only freedom that is of enduring importance is freedom of intelligence, that is to say, freedom of observation and of judgment exercised in behalf of purposes that are intrinsically worthwhile.”

For the learning to happen, the doing must have value and its value derives from the freedom to observe, reflect, judge, experiment, research, create, and dream (among others). At its core, extracurricular project-based experiential learning is one of the purest exercises in doing, in the Dewey sense, that nascent engineers do at college. There is no requirement to take part, hence the extracurricular nature. If one does decide to take part, there is rarely direct or even indirect guidance from staff or faculty. The projects may be constrained by time, resources, and skill, but never by imagination or curricular and grade pressures. This study sought to understand how this freedom to build whatever, whenever, in the EPBEL context resulted in a tangible learning process. Kolb’s model of experiential learning seemed to offer the likeliest parallel to the EPBEL experience and the interviews and observations backed up that assertion.

In deconstructing student responses to questions on taking a project from idea to working device, the process described by each was remarkably similar despite no structured guidance as one

![Figure 2: The Experiential Learning Model and the Engineering Design Process](image-url)
would see in a course. Perhaps the engineering design process has already been ingrained through their courses, or engineering projects simply lend themselves to this type of process, but regardless, there was continuity of process across the descriptions from the ten interviewed students. Overall, the process fit into four stages moving from brainstorming to researching to prototyping to testing. Figure 2 correlates this finding with Kolb’s model of experiential learning and the engineering design process that Dym et al. emphasize as key experiences that new-century engineering students need.19,22,25

Breaking down the process individually, EPBEL projects usually start in the brainstorming stage, a divergent thinking stage, where students tend to be their most creative, building on their previous experiences to imagine the outer limits of what they can accomplish. In this stage the students contemplated what to build or what problem to solve; or if part of an iterative cycle, thought about how to improve a previous design by starting over with a new design. Some of the ideas to emerge from this stage among the students interviewed for this study include fire that dances to music, very inexpensive blood glucose monitors for citizens of poor countries, a hovercraft that shoots t-shirts, and a wind turbine that could be fixed by uneducated poor people in remote non-electrified regions of the world. This stage aligns with Kolb’s reflective observation stage and what Dym and his colleagues describe as reasoning about uncertainty. As Kolb’s experiential learning theory generally posits, EPBEL students, even though their projects generally started in this stage, did not come to it as blank slates. Instead they built upon their previous experiences. In EPBEL, the teams usually consisted of diverse members in terms of experience enabling for modeling and mentoring to occur. In practice, this is very much a group social activity for EPBEL students where excitement was built for ideas, and whiteboards and sticky notes played a prominent role.

After this divergent stage, EPBEL groups would move into assimilating their various requirements for their project and devise a plan to research what they needed to know. This stage tended to be more independent and involved reading papers, sketching rudimentary models, consulting with experts, and understanding how an individual solution fits into a larger system, among other abstractions. Kolb refers to this as abstract conceptualization while Dym et al. (2005) discuss making estimates. This stage often served as a reality check, necessitating revisiting what can be accomplished. After the research was gathered, priorities were set in terms of what is most important to accomplish and what methods or designs were most likely to align with those priorities. The research stage in EPBEL was often repeated throughout the entire process as problems or opportunities emerged. However, some of the interviewees did correlate project success with solid preparation in the research stage.

Once there was consensus that enough was known, real convergent learning started to occur as students took what they knew and set out to build a working prototype, a proof of concept. Kolb calls this active experimentation and Dym et al. refer to as conducting experiments.19,25 This part of the process tended to be more group oriented than the research stage, but generally still involved a fair amount of independent work if there were multiple parts to a project. This is also the stage where resources were important, especially access to appropriate materials, tools,
space, and storage. It was the most hands-on stage and perhaps the stage that caused many of the
all-nighters mentioned by some of the study subjects. Sometimes the prototype was a simpler
version of the future finalized device, a true proof of concept, while other times it was the first
iteration of the final device. Regardless, students were taking the ideas from the brainstorming
stage and the knowledge from the research stage and creating an artifact.

All this active experimentation set the students up for the testing stage, where they immersed
themselves in the concrete experience, as Kolb calls it, of turning a prototype into a fully
functioning and finished device. Dym and his colleagues refer to thinking about system
dynamics, as students now had to poke and prod what they had created, ensure its various parts
worked together, and consider if it fully met the goals they had in mind when they were in the
brainstorming stage. This is a slight move away from the convergent thinking they engaged in
during the prototyping stage and is what Kolb referred to as the accommodator learning style.
Here EPBEL students started to wonder what could or needed to be improved, how it was going
to work in different environments, and how it could work even better. Sometimes this prompted
an iterative move back to the brainstorming stage for a new design if enough dedication
remained in the group or new motivated students had cycled in. Other times, groups simply
tinkered and perhaps decided they had achieved their goals. Although not asked of the
interviewees or indicated in the findings, the testing phase of the process was probably most
student’s first interaction with EPBEL, but not as members of the student group or a particular
project. When recruiting for their project-oriented student groups, demos of current projects
played a major role, as they enticed students to test their devices. It is this concrete experience
that preceded further commitment and future participation in a brainstorming session for a new
project or a new design on an old project.

One final note on the iterative nature of this building and learning process. Kolb writes, “ideas
are not fixed and immutable elements of thought but are formed and re-formed through
experience.” An engineered device is not so different. Its final build state is not pre-
determined, but formed and re-formed through the entirety of the iterative build process. If
learning itself is accomplished through a cyclical process moving from concrete experience, to
reflective observation, to abstract conceptualization to active experimentation, and back to
concrete experience; then it stands to reason that an educational activity that starts with testing
and moves to brainstorming and then to research and then to prototyping before starting over, is
uniquely suited to educate engineers, as it mimics both experiential learning and the engineering
design process. This is not a new finding, as many have connected the two, even if not
explicitly. What this study contributes to our understanding of engineering education is that
encouraging the extracurricular nature of project-based experiential learning enhances the value
of the project building experience even further. Inherent in EPBEL is a high level of freedom for
the students, helping greatly to foster, as Dewey says, “purposes that are intrinsically
worthwhile.” The purposes and the projects studied here were wide-open and generated by the
students, or at least the students self-selected into on-going projects. Thus, EPBEL can be
thought of as always functioning in an environment of free choice—an environment Maria
Montessori would endorse because, paraphrasing her, it is rich in motives which lend interest to activity and invite students to conduct their own experience.21

**Limitations of the Study Findings**

Despite strong findings for extracurricular project-based experiential learning providing impactful engagement, increasing self-efficacy, preparing students well for careers in engineering, and being an effective learning process, there are many limitations to this study’s methods.

Regarding the research methods, the key limitation is the sampling method. Utilizing one campus makerspace to identify a sample does not capture all student participating in EPBEL. Within that sample there is likely selection bias. Twenty-six students were asked in total to sit down for an interview to get to ten interviewees. Those that agreed to participate may have had a different experience than those who refused to participate or did not respond. It can be argued that those who chose to participate were more highly engaged students overall and that their EPBEL experiences were affecting them more positively than the median case. Furthermore, students who participate in EPBEL at all also self-select into such experiences, casting further doubt on what the actual impact would be on a typical engineering major. These limitations are important to consider when thinking about the transferability of study findings across all engineering students. However, as a qualitative study, generalizability is not the goal, but rather understanding individual interpretations of experiences and what meaning individuals are attributing to those experiences.

**Discussion**

If this is the information age—an age driven by empowered individuals better able to connect to others, access knowledge, and tailor an environment best suited for her or him—then it is no surprise that makerspaces are appearing in multiple contexts all over the world. With the knowledge at their fingertips, a handful of creative, imaginative, and motivated individuals are designing and producing devices and ideas that were once limited to the selectively trained, operating in industrial oriented laboratories or corporate offices, solving problems in a linear and variable constrained environment. Now, citizens and consumers are also part of this new knowledge-based economy, and it takes a new-century engineer to navigate an interconnected, heterogeneous, and multi-dimensional society. Therefore, institutions of higher education must adapt to this new reality, not just by adjusting the technology and knowledge present in the classroom, but adjusting the way students interact with technology, knowledge, and most importantly, each other. Extracurricular project-based experiential learning offers multiple opportunities for expanding the tools with which we educate engineering students but is also limited by a number of challenges. This final section explores those opportunities and challenges.

*Opportunity: Foster Meaningful Experiences*
As reported earlier, Astin found that engineering majors were, in many ways, the least satisfied students upon graduation, despite often having the best and most lucrative job opportunities.\(^6\) These students were less satisfied with their student life experiences, interdisciplinary experiences, cultural awareness, instruction and other facets. It is not difficult to understand why this is the case. Engineering students typically take the most difficult courses while taking the most required courses, leaving less time to have the quintessential college experience. Courses are generally technical in nature and, although improving, there is little integration of larger societal or pedagogical context such as considering the natural environment, the teaching of communication or design, or working with the larger community. As illustrated by the interview subjects, some students are finding their own outlets for this additional context through extracurricular activities that retain a discipline connection. This study shows how successful EPBEL can be at creating highly-engaged, confident, and motivated students. Considering strategies for getting more students involved in EPBEL can be a powerful path forward to foster more meaningful experiences for engineering majors.

**Opportunity: Expand the Pathway**

Bandura defined self-efficacy as the measure of “conviction that one can successfully execute the behavior required to produce the outcomes [desired].”\(^{31}\) Facing a STEM student shortage, it is more important than ever for the engineering discipline to open itself up to all potential students. If EPBEL can be successful in creating more meaningful experiences for students, then there is potential to attract students that haven’t historically looked at engineering. Rather than an image of engineering as merely a staid application of math and science, potential students will see current students participating in a discipline of hands-on design innovating solutions for the world. This may be especially effective for under-represented minorities and women who have to first develop the self-concept that they belong in engineering. This study produced evidence that women who participate in EPBEL report gains in confidence and self-concept that impact their motivation to continue as engineers. EPBEL is a potentially powerful tool in promoting the hands-on community focused nature of engineering, thereby attracting a more diverse set of students that participate in their own meaningful and confidence building extracurricular engineering projects.

**Opportunity: Connect Outside the University**

Closely related to the concept of expanding the pathway for a diverse set of future engineers, EPBEL offers a natural conduit for pre-college outreach. Student led and student built projects, that were the artifacts for this study, provide a relatable window for young people to see the potential of engineering and their own potential as engineers. Engineering programs that coordinate connections between local primary and secondary schools and extracurricular student projects can foster a local outreach environment that creates excitement and a clear pathway for youth. Mentorship can also grow out of such connections and EPBEL students only enhance their own sense of community engagement and spirit.
Having a strong culture of EPBEL can also provide the flexibility and boldness among students to find and enter national and world competitions. Multiple students in this study were involved in design competitions or design projects that involved a public-facing event. Government agencies, non-profits, and industry all sponsor design competitions meant to increase interest and experience in engineering design. Building off previous project experiences and knowing that the resources exist, encourages students to engage with the larger engineering community who are also putting in resources to cultivate an exciting design and build culture across the nation. Extracurricular projects, whether part of a competition or not, can potentially attract industry sponsorship and mentorship as companies see value in students solving problems relevant to their technologies, students using their devices, or being able to evaluate and recruit students in a relevant context.

Alumni engagement with current students is a final fruitful opportunity provided by EPBEL. Alumni returning to campus are often personally excited by the concept of students taking their extra time to engineer extracurricular projects. For colleges and universities, these meaningful alumni experiences—ranging from seeing student project artifacts to mentoring projects—are excellent methods to foster the type of alumni engagement that leads to significant giving.

One concrete avenue for implementation is tapping into the funding and excitement around the language of grand challenges. Grand challenge funding and support opportunities are already available at many institutions and the National Academy of Engineering also has a set of 14 engineering grand challenges. Grand challenges seek to frame problems in broad, inclusive, and recognizable terms that inspire cooperation and action. EPBEL is ideally suited as an educational activity to tackle the grand challenges of our times, due to the interdisciplinary and malleable structure of the technique. If combined with committed faculty and courses to initiate excitement and projects, EPBEL could excel at helping students connect to the outside world and build meaningful experiences.

**Opportunity: Fostering Entrepreneurship**

Wagner writes that the way to create talented innovators is to develop a learning culture with the values of “collaboration; multidisciplinary learning; thoughtful risk-taking, trial and error; creating; and intrinsic motivation: play, passion, and purpose.” This study found all of those elements present in EPBEL. Colleges and universities can enhance EPBEL by offering support for taking a product to market, through connections with business students, technology commercialization resources, and access to venture capitalists. EPBEL and the makerspaces in which such learning takes place are natural incubators for young innovators and efforts should be made to connect existing campus entrepreneurial education and support to these students.

**Opportunity: Enhancing the Regular Curriculum**

Sheppard, Macatangay, Colby, and Sullivan found that the engineering curriculum is overcrowded, theoretically heavy, pedagogically stale, and highly structured; or as Duderstadt
EPBEL offers the opportunity to put some of the joy back into the young engineer’s journey through their program, replacing theory with practice and structure with freedom. In addition and as demonstrated in this study, EPBEL provides students with an outlet to apply what they have just learned in class. At colleges of engineering across the nation much effort has been put into introducing project design experiences in the freshmen year and implementing multiple week project-oriented lessons into entry level courses. EPBEL allows for students to build on these early experiences, continuing to enhance their design and build skills until they reach the typical capstone design courses found in the senior year.

For this study, the interviewees also indicated that their EPBEL experiences added value beyond what they could get from their courses. They suggested that meaningful project building was missing from the curriculum altogether and that EPBEL filled in that hole. Some felt that labs, even when project oriented, had single paths to solutions, instead of multifaceted approaches to a working answer in an interdisciplinary context. Others liked the added complexity and length of extracurricular projects. In addition, the EPBEL learning process, as stated earlier, is uniquely suited for educating young engineers. If supported well, the evidence points toward EPBEL enhancing, rather than hindering, the engineering curriculum, that some experts believe would be improved by a shake-up.

**Challenge: Scalability**

Extracurricular project-based experiential learning was a great experience for the students interviewed for this study. However, they represented a small subset of all students studying engineering. There is a strong possibility that extracurricular activities appeal to only a portion of students and since, by the nature of it being extracurricular there is no way to compel students to participate, EPBEL’s impact will always be limited. The success of EPBEL as a strategy worthy of investment largely turns on the challenges of scalability and is worth exploring both in future research and in practice.

**Challenge: Space and Resources**

The challenge of providing enough space, funding, materials, and tools in a safe environment is straightforward. In order for EPBEL to scale appropriately and for students to be successful, there must be makerspaces available and they must be available at times corresponding with when students have time and want to build. Professionally staffing an 18-24 hour a day facility is likely prohibitively expensive, so colleges and universities will need to be creative in addressing this particular challenge. It is likely that student paid and unpaid labor will be heavily depended on and that access will need to be largely unsupervised.

**Challenge: White Male Privilege**

White males make up the disproportionate share of engineering students and due to higher levels of self-concept and self-efficacy, they are generally more motivated and confident to jump into
unstructured projects. They may have more experience with the tools and materials used as well, opening the gap in readiness between white males and others even further. The challenge for EPBEL is how to attract and include women and underrepresented men into these experiences that have traditionally been the domain of white men in the United States. Navigating this challenge successfully becomes crucial to taking advantage of the opportunity to expand the pathway, as mentioned above.

Challenge: The Organization

Higher education institutions are hard-to-change organizations, often with long histories, that are subject to complex and intractable governance. The engineering curriculum resembles an obstacle course. Revisiting Terenzin and Reason’s College Impact Model, these two referenced statements represent barriers for effective EPBEL implementation related to the organizational context of the university, both institutionally and disciplinarily. Considering that there is likely to be (a) skepticism to the scalability of EPBEL; (b) concern that it requires investment and resources not generally allocated for unproven new educational endeavors; and (c) uncertainty regarding whether it will help at all with increasing the diversity of the student body, resistance to organizational change that allows for a sustainable and scalable version of EPBEL may be quite strong.

Perhaps the most immediate and important organizational challenge lies with engineering faculty. If institutions are to maximize the potential of EPBEL, curriculum changes must occur. Right now, some engineering students have difficulty finding the time to engage in activities outside the classroom, no matter their value. To really take advantage of extracurricular projects, engineering faculty will need to rethink the status quo in their educational techniques. There is reason to believe that EPBEL would be able to be scaled and delivered to many more students if faculty shift some of their attention from delivering technical knowledge in lectures to supporting project-based learning inside and outside the classroom. The support would entail a few facets. The one likely to meet the least resistance is including project-based learning in the classroom. Faculty know the value here through the literature and their own personal experiences, while most engineering programs have already implemented project oriented course early in the curriculum and the vast majority require it in senior capstone projects at the end of the program. The more challenging organizational change will be making the choice to eliminate the total number of required courses to free up room for a more varied experience outside the classroom. Faculty time can be redirected to providing mentorship and consultation on specific projects, and toward the development of a structured program that entices students to participate in projects outside the classroom and gives them the necessary support to have an educational and impactful experience. If engineering educators can alter how they think about the value that extracurricular projects offer, engineering programs can possibly deliver a more engaging and valuable experience that will attract a more varied kind of student attracted to the full range of what a new-century engineer does.
**Recommendations for Implementation**

Opportunities to enhance the education of engineers exist for a properly supported and encouraged culture of extracurricular project-based experiential learning, but much is still unknown. This study has shown that at least for a self-selected subset of engineering students at the University of Minnesota, there is high educational value in extracurricular project-based experiential learning. It provides high levels of discipline specific engagement, increases self-efficacy, prepares students for their careers, and provides a learning process that uniquely fits the engineering design and build process. Based on these findings, it is worth the time of practitioners to experiment with strategies that provide the proper resources and cultivates the lasting culture that allows for EPBEL to scale to a level of participation that creates a broad impact.

To implement EPBEL at a basic level, colleges and universities need to consider the following elements. The most important element is the proper space for students to build and store their projects. This type of space is critical, both from a resource standpoint for successful projects and as a centerpiece for a culture of experimentation, innovation, and teamwork. Funding is the next critical element to ensure that students do not feel an additional financial burden to buy the materials necessary to complete a project. Also important is the fostering of strong and supported student groups, as student groups often provide the structure and organization that attracts students into EPBEL and sustains projects. These first three elements are the minimum necessary components for a working EPBEL infrastructure, but are not enough to make EPBEL much more than a small component of the engineering educational experience.

In order for EPBEL to make a broad impact, the following additional elements should also be considered. Often space is allotted to single-project build groups. Ideally, space should be expansive, centrally-located, and shared across multiple entry points into EPBEL. Those entry points may be through established student groups, projects related to a course or competition, or independent projects, but efforts would be made for all these project groups to interact in common space. This type of organization has the added benefit of being resource efficient. Efforts should also be made to make projects interdisciplinary, not just across engineering disciplines, but across the entire scope of a particular campus. Faculty participation is another element that should be fostered and can be done in multiple ways. Faculty can encourage project building in their courses and even provide the class assignment that leads to a first prototype that is then developed further through EPBEL. They can also serve as active advisors on projects or as consultants to assist with difficult problems. Though it would be important to maintain the independent nature of EPBEL, certain projects should become eligible to be turned into meaningful credits for students if additional requirements are met. As mentioned earlier, the most impactful step would be a fully engaged faculty that is willing to reduce course requirements in exchange for fully developed outside the classroom project experiences.

Other services are also important, including education on entrepreneurship and technology transfer, information on additional build resources on and off campus, assistance with purchasing, and trainings for various tools. In order for these additional services to be
communicated and developed, a robust system of administration must be supported that includes the ability to provide technical services, maintain communication and marketing, and develop the elements that will grow and sustain a lasting EPBEL culture. Also important are meaningful connections to the university, local community, and the wider world, through design shows, outreach events, and service projects. EPBEL can connect with industry and alumni through mentorship, judging, and sponsored projects. Underlying all of these elements is a concerted effort to encourage students to engage in EPBEL from the moment they step on campus while specifically targeting the underrepresented.

Avenues for Future Research

Beyond experimentation on campus, there are multiple avenues of additional research that will provide key information for practitioners. In particular, there are opportunities to design surveys that find the participation rate of engineering students in EPBEL and look for differences in satisfaction, engagement, self-efficacy, and performance, among others. Understanding the current landscape of EPBEL across the nation is also important, so comparative research that provided information on the different EPBEL opportunities available at different engineering schools would inform the current levels of penetration and support. Another consideration is the particular nature of project oriented student groups, so research that looked at their structures and practices and proposed a taxonomy would be of particular interest. In order to scale EPBEL to a large proportion of engineering students, research that looks at why students choose or do not choose to take part in extracurricular project building would provide important implications for implementation. Relatedly, understanding the particular effectiveness of EPBEL with populations that are currently underrepresented in engineering is important information for decision makers. Finally, understanding the impact EPBEL participation has on job prospects would provide excellent evidence for the investment or non-investment in EPBEL.

Conclusion

For those tasked with educating the next generation of engineering students, there are two critical concerns, (a) that not enough students will choose engineering as a career due to demographic changes and other factors, and (b) that students are not being properly trained for the complexities and challenges of the information age. A new-century engineer is needed who has a more diverse background and has the ability to not just engage with the constrained problem in front of him or her, but to engage as a citizen engineer who understands how their role impacts a knowledge-driven, global economy. It is within this context that this study explores how extracurricular project-based experiential learning contributes to engineering students’ experiences, looking for an understanding of how this unexplored area of higher education could impact the important concerns above and provide a unique and potentially very effective method for teaching design in engineering.

The findings were clear that EPBEL contributes positively to student experiences, showing particular promise in providing impactful engagement, increasing self-efficacy, preparing students for their careers, and providing an effective learning process, steeped in the design process that is particularly well-suited for nascent engineers. There are multiple opportunities for practitioners to encourage and implement EPBEL experiences in ways that contribute to the
crafting of a new-century engineer who is adept with people, undaunted by complexity, and understands the global context of their actions.

Perhaps what EPBEL is really providing is the opportunity for faculty, staff, and administration to get out of the way and let students’ natural curiosity and motivation take over without the typical constraints of the classroom. In fact, student project teams often meet in campus makerspaces, a sort of anti-classroom where knowledge is gained through experience and there are no textbooks or experts to guide you. EPBEL can in no way be a replacement for what is learned in the classroom, but it can be the supplement for what the classroom cannot achieve and the antidote for the sometimes suffocating structure the classroom must provide to function. This is not meant to imply a hands-off approach, but rather an approach that provides the basic scaffolding from the institution for students to find, as Dewey wrote, “purposes that are intrinsically worthwhile.”15 If we find the proper balance, there is potential to enhance experiences for students and prepare a generation of diverse and broad thinking engineers—new-century engineers.

References


