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Board 49: Project-based learning course co-designed with regional enterprises

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Project-Based Learning Course Co-designed with Regional Enterprises

Abstract

Project-based learning (PBL) courses in higher education require the instructor team to be highly resourceful, multi-disciplined, and inspiring. It also needs student teams to be proactive, collaborative, and good at inquiries. Designing and implementing PBL in a classroom can be challenging due to teaching staff shortage and insufficient knowledge of instructors. To address these challenges, we proposed a novel PBL course design methodology to involve local enterprises and entrepreneurs as course co-instructors, thereby compensating for the lack of industry participation in the current PBL course development efforts. The methodology consists of five main pillars: (1) inquiry-based problem solving using practical real-world problems; (2) active knowledge construction through a multidisciplinary team; (3) situated learning through meaningful social interaction with a community of practice; (4) guided investigation with scaffolded instructions on research methodology and technology; and (5) prototype demonstration with expert feedback. To test the effectiveness of the PBL course design methodology, we performed two experiments at Southern University of Science and Technology, a top research university in Shenzhen, China, in a form of a three-week summer school. Two-year data was collected including archival course data, interview data of students, faculty and industry partners, as well as student feedback surveys. We found that the proposed PBL curriculum involving industry mentors can significantly improve students' engineering design skills and effectiveness of learning.

Keywords

Project-based learning (PBL), New engineering education, University-Enterprise Cooperation.

Introduction

Project-based learning (PBL) is a student-centric teaching methodology that has gained increasing popularity in higher education worldwide. Differentiating from traditional teaching that imparts disciplinary knowledge to students, PBL is targeted to prepare students with the abilities to acquire knowledge and skills in an active, collaborative, and inquiry-based fashion that crosses subject boundaries [1]. It not only improves knowledge attainment and learner enthusiasm [2], but also trains students in skills and competencies that are required for their future careers, such as teamworking, interpersonal communication, problem-solving, interdisciplinary learning, and critical thinking [3], [4]. For instance, over two thirds of 2,500 graduates of Worcester Polytechnic Institute (WPI), which has been practicing a PBL curriculum since the 1970s, reported that PBL has "much" or "very much" impacted their ability to solve problems, function effectively in teams, and take responsibility for their own learning [5]. Employers of engineering graduates also revealed in interviews that students with PBL experiences exhibited stronger teamwork skills and interdisciplinary problem-solving abilities than their counterparts [3]. Therefore, PBL offers a compelling way to nurture students' real-world competencies as well as professional knowledge for their future career.

However, implementing PBL in a classroom is not as easy. Compared to the traditional lecture-exam style of teaching, it requires much more resources to assure the success of the course, including an instructor team equipped with professional knowledge, project management skills and pedagogical training, properly designed projects to fulfill the course objectives, funds to support the realization of the projects, devices and equipment, and networking efforts. For example, a first-year project-based engineering class at Massachusetts Institute of Technology (MIT) has a 2:1 student-faculty ratio with four professors, three teaching assistants, and one writing instructor; the completion of all student projects requires roughly 20 motors and a 16-feet-deep pool [6]. The highly resource-intensive nature of PBL poses considerable challenges to academic institutions that would like to embrace this pedagogical method in their curriculum design. These challenges include shortage of instructors, insufficient funds for course development and management, lack of experience in project design and pedagogical methods, and inadequate resources for project development [1], [6]. In addition, a lack of research efforts and systematic documentations of existing PBL practices also creates barriers for interested instructors.

Therefore, the goal of this paper is to propose a novel PBL design methodology to address the issues of teaching staff shortage and insufficient knowledge of instructors. We propose to involve local enterprises and entrepreneurs as course co-instructors, thereby compensating for the lack of industry participation in the current PBL course development efforts. We presented our innovative design framework for PBL and its implementation at Southern University of Science and Technology (SUSTech), a top research university in Shenzhen, China. A 3-week PBL program for undergraduate students was initiated during the summers of 2021 and 2022. The summer programs involved a total of 129 students, 5 course instructors, 20 industry mentors, and 20 academic mentors. The involved projects are proposed by industry sponsors, spanning cutting-edge technology and important social topics such as smart health, senior care, and robotics. The 3-week term of the projects is significantly shorter than a typical project life that ranges from seven weeks to an academic year. Each project was appointed with three designated mentors, including an international academic mentor who connects with the teams remotely, an industry mentor from the industrial project sponsor, and an onsite mentor who offers daily lectures on design thinking and provides face-to-face guidance to the project teams. The unique mentoring system laid a good foundation for the success of the PBL course. In this article, we will present the innovative PBL course design framework and discuss its efficacy as well as limitations. Our work fills the knowledge gap by providing a PBL design system that comprehensively mobilizes interdisciplinary knowledge and skills, and is tailored for Chinese post-secondary education.

Literature Review

Project-based learning (PBL) and problem-based learning (P_mBL) methods are in essence founded upon the same set of principles of learning: the learning process is incentivized by an ill-structured problem, and the construction of knowledge occurs in learners' attempt to solve the problem [7], [9]. Though sometimes used interchangeably, a key difference between PBL and P_mBL is that PBL culminates in a concrete product to solve the problem by definition, whereas P_mBL does not necessarily involve the production of an artifact [1], [7], [9]. PBL typically involves a real-world, open-ended problem that drives a series of learning activities, in which small groups of students apply multi-disciplinary knowledge and skills in the development of a tangible product that solves the problem, as well as a written and/or verbal report that documents the work process [6]-[8]. The problem serves as an incentive for students to embark on the selfdirected learning process and is often introduced by external partners of the institution. The transformation from teacher-centered conventional learning to student-centered PBL presents a range of benefits as well as challenges to multiple stakeholders: students, faculty members, academic institutions, and industry partners. Despite extensive research on PBL's impact on workplace readiness, attitudes towards PBL, and specific implementation cases [9], there is limited literature exploring the challenges of PBL implementation, its current limitations, and potential solutions to address these issues. Several unique challenges and deficiencies in PBL applications are discussed as follows.

Challenges related to Instructors

In a PBL model, instructors are often faced with difficulties when adapting to their new roles as facilitators rather than lecturers, mastering multidisciplinary knowledge and skills regarding project content and PBL methods, and balancing between the workload of providing timely, professional guidance and teamwork support [10]. As PBL encourages students to actively acquire concepts and new skills, instructors need to transit from an authoritative to a facilitative role in the classroom. Faculty members are responsible for the supervision and guidance on student-centered project work, allowing student groups to control their own learning pace, sequence, and content [7]. The successful implementation of PBL thus requires instructors to create a learning environment that promotes collaboration, inquiry, and challenge [3]. Moreover, since the development of solutions to a real-world problem extends beyond traditional subject boundaries, it is essential for instructors to scaffold students' learning along the project process. Faculty advisors are expected to possess interdisciplinary knowledge that meets the demand for necessary instruction and guidance pertinent to the project [6]. Yet, instructors may find it challenging to meet these requirements. For example, [7] reviewed 22 articles of PBL course implementations and identified a number of challenges reported by faculty members, including student motivation, group dynamics, integration of supplementary material with the project, and aligning the instructor's specialized area with the field of the project.

Besides the appropriate pedagogical methods and content knowledge that PBL demands, some instructors have struggled with the time-consuming preparations for PBL projects, the monitoring and assessment of individual student performance, and the lack of time to fulfill curriculum requirements [3], [10]. At the same time, students have reported the lack of guidance and help from supervisors [10]. In practice, more faculty and staff for each project may facilitate the success of PBL implementation. According to [7], half of the 22 reviewed courses revealed that classes with up to 30 students were supervised by one or two instructors, with project groups typically consisting of three to five students. Two course descriptions explicitly reported that groups of three to four students received faculty guidance 20% to 25% of the estimated total working time [7]. This format was deemed feasible for engineering projects based on its longevity and positive outcomes. For example, a first-year engineering PBL class at Massachusetts Institute of Technology (MIT) of 13 students was supervised by two professors, four teaching assistants, two instructors from the writing center, and a coordinator from the public service center, creating a 1.4:1 student-faculty ratio. Another class with 17 students was supervised by four professors, three teaching assistants, and one writing instructor, creating a student-faculty ratio of 2.1:1 [11]. However, many institutions cannot guarantee such a low student-faculty ratio to facilitate a smooth transition to a PBL model.

Lack of Industry Involvement

Industry's participation in PBL projects remains limited despite the numerous advantages of industry-university collaboration. The most apparent benefit that companies can gain through the collaboration is that they can keep the prototype, artifact, or design that students developed either as a direct solution to their problem or for future testing and experimentation [12]. This collaboration would also effectively outsource the work, saving time and human resources for non-urgent strategical problems that will be addressed should the company have more manpower [12]-[13]. Throughout the development of a project, companies may observe, evaluate, and train prospective employees; on the other hand, the university-industry collaboration is a chance for companies to advertise their brand, culture, products, and career opportunities to students [13]. Additionally, engaging with faculty members and students can provide companies with innovative ideas from academia that advance their understanding of knowledge [12], [14]. A study of 2,600 firms in Denmark found that one-third of the companies that collaborated on innovative activities with Aalborg University (AAU), which implements a PBL engineering curriculum, continued to collaborate with the same university for at least two consecutive periods [15]. This ongoing collaboration indicates satisfactory partnerships in PBL courses.

In spite of the numerous benefits of industry-university collaboration on PBL courses to the industry partners, prior literature has identified a lack of industry and community involvement in PBL [10]. Obstacles in the initiation and persistence of industry-university collaboration include: (1) incompatible or unrealistic expectations for project outcomes; (2) at least one party's inability to offer essential resources for the projects, such as funding, time, staff, and equipment; (3) inefficient communication between universities and industry partners; (4) legal restrictions, insufficient governmental support, and unfavorable market conditions for partnerships; (5) the lack of geographic proximity between the partners [10], [12], [16]. Honest communications between both parties and a careful selection process prior to collaboration can contribute to the successful implementation of a PBL curriculum [16].

Methods

For this pilot study, a three-week program is offered at SUSTech, a top research university in China during summer 2021 and 2022. Upon completion of the program, students are expected to: (1) execute design process from problem conceptualization to prototyping using a diverse set of strategies; (2) conduct systematic research on the problem to identify suitable design strategies; (3) practice as a motivated professional designer with ethic, discipline, leadership and responsibility; (4) communicate ideas effectively with oral and written communication assisted by digital tools; and (5) apply technical knowledge and skills to generate new ideas and evaluate feasibility of the design concepts with prototypes at different complexity level.

To achieve these objectives in a short three-week program, the PBL curriculum for product design has five main pillars: (1) inquiry-based problem solving using practical real-world problems; (2) active knowledge construction through a multidisciplinary team; (3) situated learning through meaningful social interaction with a community of practice; (4) guided investigation with scaffolded instructions on research methodology and technology; and (5) prototype demonstration with expert feedback.

The first step to develop the course content is to solicitate project ideas from industry partners including university collaborators, established enterprise and start-up companies in local industrial parks. Companies with practical problems to be solved in product design are provided with instructions regarding the scope and timeline of the curriculum. The design problem to be addressed should be open-ended in both problem space and solution space to provide students with the maximum flexibility during the design process. To be specific, project proposals should provide sufficient information regarding the background of the problem for students to define the problem space and does not adhering to any preferred solution. On the other hand, the problems being solved should have practical real-world impact that can not only contribute to the company but also benefit a broader range of members in the society. For example, the Future Senior Care project aims to explore possible solutions to improve the quality of life for the elderly through product, community, and service design. Centered around the core problem, students can generate follow up questions to decompose the problem as inquiries to pursue during the design process.

As a second step, multidisciplinary teams of students are formed. This is conducted by sourcing both undergraduate and graduate students at all years from over 20 different majors and programs (e.g., mechanical engineering, biomedical engineering, robotics, physics, statistics and data science, financial engineering, etc.), as well as several selected outstanding high-school students. In contrast to conventional discipline-specific design courses, the multidisciplinary design process can benefit from diverse pool of ideas during problem-solving. Sourcing students across multiple departments/schools can be achieved during summer/winter breaks with university level support or cross department joint effort as in [19]. Clashing of ideas from different perspectives can provide a more comprehensive picture of the problem and generate novel ideas with shared knowledge as team members learn from each other. Active knowledge construction can be achieved more efficiently as team members' expertise can complement each other to establish a more advanced baseline when searching for information that would help to solve the problem. On the other hand, multidisciplinary teams need to overcome several challenges to be successful. The two main challenges include efficient communication and respect between team members expertise to ensure idea contributions are valued in a balanced manner. This can be more difficult when students in different years and background are placed into the same team. To facilitate this process, the curriculum begins with an icebreaker event (e.g. spaghetti tower construction) to boost team bonding. Moreover, each team is paired with a teaching assistant who closely works with the team throughout the program. The instructors also actively join student discussions in a casual manner with emphasis on promoting active participation of all team members by designating leadership roles for different aspects of the project based on expertise and interest.

Third, a community of practice (CoP) is formed with an international team of experts as a situated learning experience for the students. The CoP model typically includes five layers of participation including core group, active group, an occasional group, a peripheral group, and a transactional group as in [19]. In this case, the multidisciplinary team of students are the core group for the project. The course instructor and the teaching assistants assigned to each team can be considered as the active group that interact with the students throughout the program to provide various resources. For the occasional group, an international academic mentor at Ph.D. level with matching background interacts with the team for an hour every day virtually online to provide guidance on technology and research methodology. In the peripheral group, industry mentors from the project sponsor company provide details on the specific problem to be addressed and meet with students weekly for progress updates. Several domain experts are also available to the teams for on-demand consultation during problem solving. The transactional group is composed of sponsoring company leadership and potential product user who only participate in the initial problem definition and final prototype demonstration stage. As will be demonstrated later in the results section, interaction with academic mentors and industry mentors help students to know more about the actual practice in their future career and expand their horizons with the diverse background of their mentors in both company and academic research institutions. Mentors can also serve as role models to motivate the students and share their experience on ethical and responsible practice when solving open-ended design problems. However, formulation of such a cross-organizational community of practice for product design education is unprecedented and rare in Chinese higher education with the large number of resources required.

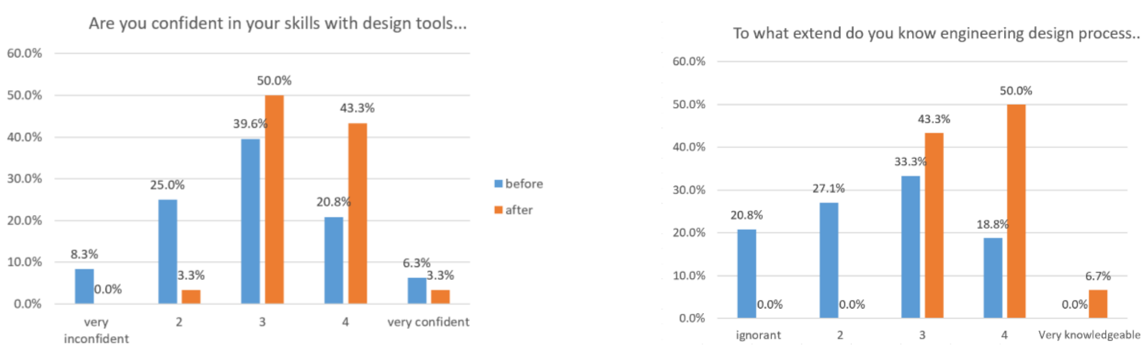
Next, to provide scaffolded guidance to the students, instructions on design methodologies and technical knowledge are provided. Synchronized with the progress of the projects, basic principles of the five primary stages for the design thinking process are presented in lectures, including Empathize, Define, Ideate, Prototype and Test. Within each stage, both theoretical concepts and selected examples are presented in the morning session and students practice immediately in the afternoon lab session with fresh memory and guidance from both instructors and teaching assistants. One important role that the instructors play during interaction with the team is to balance the level of effort spent on exploration of potential design strategies and time spent on design selection with prototype verification. In other words, students are encouraged to be open-minded when navigating through both the problem space and the solution space, but need to consider practical limitation on time and resources to narrow down the options and reach a final solution. To avoid getting stuck by limited technical competency or ignorance of the state-of-the-art technology, on-demand technical consultation sessions are provided by experts in relevant fields. In addition, to facilitate effective teamwork and idea exchange, instructions for online project management tools such as Trello and cloud drives are provided. Tutorials on multi-media technology for presentation, design idea/data visualization, video production, and only portfolio are also introduced in optional workshops.

In the end, two rounds of design reviews are organized. For the mid-term design review conducted during the second week, the focus is placed on finalizing the problem space exploration. Students are expected to clearly define the problem and showcase their research results on the problem significance and prior solutions in relevant fields. Potential design ideas should also be presented for industry sponsors and invited experts in the fields to provide constructive feedback. To verify assumptions and select between various potential solutions, students are encouraged to develop low fidelity prototypes and iterate quickly through the ideas they intend to explore. The final design review focuses on the solution space exploration and design idea selection process. Company leaders, professors and industry experts are invited as judges to rate the performance of the design teams. Prototype demonstration is expected during the design presentation to validate the feasibility of the proposed design. Moreover, technical communication skills are also evaluated for public speaking skills and effective usage multi-media technology. Therefore, the curriculum design forms a cross-organizational community of practice and provides the students with abundant resources for project-based learning experience.

Results and Discussion

We collected student feedback surveys before and after the summer program to evaluate student growth. The survey was developed to capture the effectiveness of the program design and aims to answer the following questions: (1) How does the PBL-based program impact student skills for engineering design? (2) How does the collaborative education between university and industry improve students' capabilities? And (3) how would the interdisciplinary team and diverse community of mentors, sponsors, and teammates help with opening students' mindset? The results are shown in Figs 1-5.

As can be seen in Fig. 1, student's confidence levels in skills with design tools and engineering design process has both been significantly improved. The percentage of students who reported a high level of confidence in design tools (i.e., rating >3 in a 5 Likert scale) increased from 66.7% to 96.6%, and all the students reported they are the knowledgeable with the engineering design process after the program, while in contrast, only 52.1% of the students reported knowledgeable before the program. However, it is noteworthy that there was a decrease in the percentage of students who reported feeling very confident in their skills with design tools. This drop could be attributed to the fact that the students were exposed to real-life open-ended problems with high levels of difficulty for the first time during the summer program. Unlike the problems in a traditional PBL class, where problems are abstracted by the instructors and students only need to find the solution of the problems, the problems students faced in the summer school are all derived from real-life applications, they are more complex, open-ended, vaguely defined, and involves much more uncertainty. Students need to define the problem and understand the users before looking for the solutions. As a result, some over-confident students may have had a more realistic assessment after working on these challenging problems.



(a) (b)

Fig. 1 Evaluation of student skills for engineering design in terms of (a) confidence in using design tools and (b) knowledge in engineering design process

The collaborative education between university and industry leverages the educational resources in universities and the real-life practices and experiences in industry. Survey results indicated that 93.33% of the students believed that involving industrial sponsored open-ended problems helped with the design thinking process (as shown in Fig. 2). These problems addressed challenging and pressing issues faced by enterprises, balanced with innovation, cutting-edge research, and openness, which meets the needs of students with diverse interest and background. Through solving these problems, students are provided with a unique opportunity to practice and develop a range of skills (i.e., engineering skills, design thinking process and systems thinking methods, creativity, critical thinking, and strategic thinking) in a short three-week time.

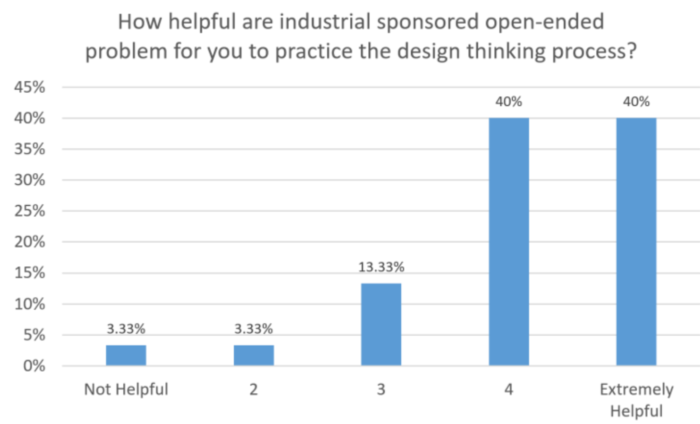


Fig. 2 Evaluation of the effectiveness of industrial sponsored open-ended problems on practicing design thinking process

The diverse and multidisciplinary environment provided by the program has proven very effective in opening students' mindset. According to the survey, 96.67% of the students reported that the multidisciplinary team and cross-organizational community of mentors is advantageous in their design projects (Figs. 3-4). The top three highest ranked values of the program, as reported by students, are learning from industry mentors, making friends in the program, as well as learning from academic mentors (Fig. 5). During the intense three-week training, the first barrier students faced was to collaborate with a team of students with diverse backgrounds, interests, and grade years, both online and in-person. This requires students to quickly learn and master team capabilities, to take initiatives and be bold, be able to motivate and inspire others, as well as to plan ahead and allocate resources and time smartly. The unique mentoring system with academic, industry, and onsite mentors addressed the challenge commonly faced by PBL mentors, where the three mentors serve as the three pillars to support student success in the project. In addition, the diverse background of the mentors can provide students with diverse insights into their projects using thorough examples rooted from real-world applications.

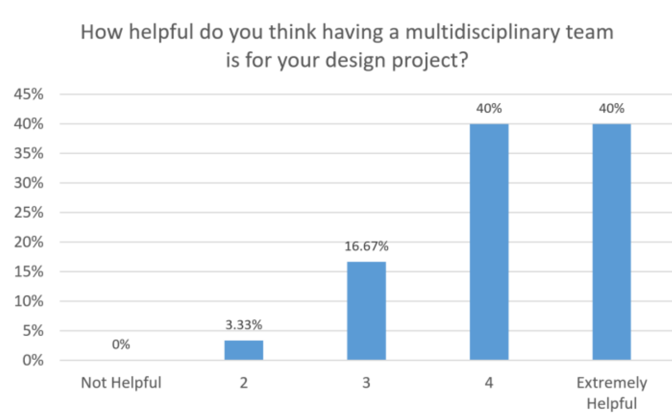


Fig. 3 Evaluation of the effectiveness of multidisciplinary team on the learning process

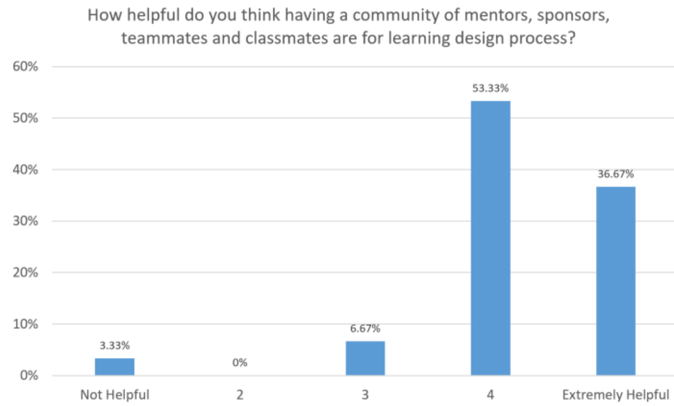


Fig. 4 Evaluation of the effectiveness of diverse background of mentors on the learning process

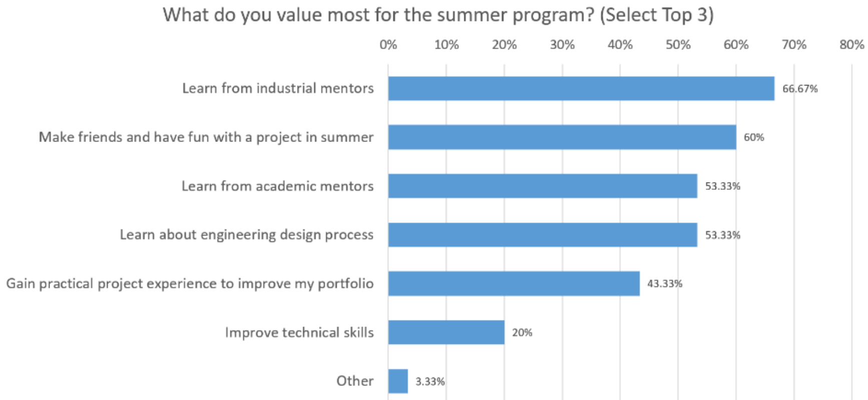


Fig. 5 Values of the program, ranked by students

Conclusion

The authors have proposed a PBL curriculum that involves collaborating with multiple industry partners, using real-life open-ended problems, and working in a multidisciplinary team setting to train students with a broad range of abilities and improve their engineering design skills. The proposed program is a comprehensive practice in a highly intense and complex environment for design thinking-based new engineering education. The results of this project indicated that the PBL curriculum can significantly improve students' engineering design skills, and the multidisciplinary team (including the diverse background within student groups and the community of mentors) could significantly improve students' learning. Despite the prosperous results of this program, there are still challenges that need to be addressed for the program's long-term success. Specifically, the authors plan to focus on solving issues such as formulating and utilizing the community of practice, and sustaining the program's operation within budget constraints in their future works.

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