Cultivate the Problem Exploration Skills for Biomedical Innovation

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ABSTRACT

The majority of engineering students perceive themselves merely as problem solvers and are less concerned about finding a problem. However, the lack of ability to find a valuable problem from the real world is one of the major causes of invention failure. Problem finding is absent in most engineering curricula, even in design courses because most problems are still provided by a client or instructor. To address the need for training the next-generation of innovators, we developed an undergraduate elective, Biomedical Innovation, in which Industrial Engineering students teamed with medical students to identify authentic problems of clinical significance and propose engineering solutions. This course, which asks students to analyze the mechanism and scope of a problem—a skill highly desired for its potential in innovation and entrepreneurship—fills a unique curricular gap. The survey of learning experiences showed statistically significant differences between pre- and post-course scores in self-efficacies, which suggests that students saw improvement in the ratings of their learning in five target areas: (A) background research skills, (B) critical thinking and ideation, (C) project management and teamwork, (D) technical communication skills, and (E) interest in medical engineering.

1. Introduction

Current engineering education has well-established curricula that covers domain knowledge, mathematic skills, and engineering tools. Although education content and format have evolved, the general education goal and framework (formed in 19th century) has not substantially changed [1]. Essentially the primary objective is to prepare learners for the labor force of expertized industrial workers, in various types and levels. Traditionally, the focus of the development process for engineers has been limited to the solution generation stage [2]. Such an educational approach re-enforces the stereotype of engineers as simple executors of assigned tasks. Undoubtedly, *how to provide a solution* should be an essential component in engineering education; however, to neglect asking the right question in curricula and training will imperceptibly form a mindset of followers in students and ultimately impede their innovative and leadership abilities. Engineers are expected to develop new solutions for technical problems through an iterative decision-making process in which principles of science and mathematics are applied to generate a new artifact or method with a better performance [3]. Of equal value for engineers should be their ability to proactively anticipate potential problems before they materialize.

For all engineering projects, problem identification is the first and, arguably, the most critical step because it sets the foundation and direction for the research and development effort. Whether the problem is well understood and comprehensively evaluated often determines a project's success or failure. Furthermore, finding a valuable problem out of countless problems, largely presets the potential reward of engineering efforts. An effective problem definition clarifies the benefits and costs to help ensure that resources will be effectively utilized to address the most important issues. Ironically, this initial step of engineering development is often accomplished by administrative leaders or entrepreneurs who do not have engineering degrees [4].

Compared to problem solving, problem finding is an unfamiliar chore to many students [5] thus longer and more intensive training may be needed to change preferences for ideation in problem-finding. Reiter-Palmon et al. suggested that the problem construction ability, as partly metacognitive skill, may play an important role in merging varied information to create a consistent and feasible representation of the problem. Having the capability to view a problem from different angles, recognize numerous potential goals and objectives, and reconcile conflicting ones, can result in improved solutions [6]. Students who are exposed more frequently to problem-based learning (PBL) tend to exhibit a higher ability to frame problems. Teaching methods that stimulate prior knowledge and contextualize learning in scenarios akin to real-world situations are linked to the enhancement of students' capacity to comprehend and formulate problems. [7]. Lee et al. found that scientific knowledge was a predictor of problem finding performance in the ill-structured problem situation while divergent thinking positively predicted problem-finding performance in a moderately structured problem situation [8]. Their study also suggested expose students to a wide range of problem situations that vary in their degree of structure to enhance their problem-finding abilities [8]. Problems with different attributes may pose different formulation challenges. A team seeking transformative innovations, in which the problem is ill structured, will likely need different governance mechanisms from those pursuing incremental innovations [9]. Problem finding was found to be highly correlated with fluency and originality. Discovered problems elicited significantly more ideas than the presented problems and problem finding tasks facilitate people to be productive in generating ideas [10]. In summary, numerous studies have shown that tangible outcomes may start from finding a good problem. However, current theory of problem formulation assumes that the individuals assigned to formulate problems have access to the necessary information and knowledge [9]. How variations in the distribution of knowledge could impact the processes and governance of problem formulation remains unclear.

As engineering educators, how can we better prepare engineering students for innovation and leadership if we are not satisfied with merely training post-modern production line workers? There will be no simple solution to this question. Nonetheless, we believe that learning to identify a valuable problem through systemic analysis is a primary pillar that should be reinforced in current engineering education. This paper presents an undergraduate elective course for biomedical innovation. In this course, junior or senior Industrial Engineering (IE) students without biomedicine backgrounds will be asked to team with medical students to develop innovative solutions for clinical problems. Unlike conventional senior design or a capstone project, this course requires students to identify a problem in an authentic clinical setting and translate the clinical problem into an engineering project. Fifty percent of the credit for the final project will be based on the analysis of the problem and fifty percent of the credit will be based on the proposed solution in terms of novelty and technical rationale. This elective course is expected to encourage students to take ownership of their projects and enhance their development of critical thinking skills, independent research, teamwork, and technical communication in a multidisciplinary environment.

2. **Methods**

Our elective course had three distinctive qualities: (1) unfamiliar domain, (2) multidisciplinary teamwork, and (3) problem finding. The first unique aspect was that biomedical product design is beyond the traditional IE curriculum. None of the enrolled IE students had received formal training in biological science or biomedical engineering, yet they were required to work with medical students to solve healthcare or biomedical problems. The lack of experience forced students to leave their comfort zone. We believed that the stress of being inexperienced combined with a desire for academic success would stimulate self-motivation and encourage creativity.

The second unique aspect was the multidisciplinary teamwork. Each engineering team must include at least one medical student from Texas Tech University Health Sciences Center. The medical student joined the team through the Sling Health Network, a national student organization for medical innovation. Students were expected to learn through practice to translate customer requirements to engineering specifications and effectively communicate with non-engineers on technical issues.

The third unique aspect of this elective was that it required students to manage the problem topic selection phase. To aid in the stimulation for self-motivation, students were taught to collect, analyze, and screen real-world problems through discussion, on-site interviews, and literature reviews with medical students and healthcare professionals. They took responsibility for every decision in the development project—beginning with the selection of the project topic.

The lectures covered four modules, including domain knowledge, problem identification, ideation, and communication. The domain knowledge module introduced the basics of material, function, design, and manufacturing of medical devices. The problem identification module focused on the research methodology for scanning the important unmet clinical needs with quantitative analyses. Teams were required to determine their project topics and clearly define the expected outcomes with measurable milestones. The ideation module focused on the toolbox for design and product development. Students learned a structured process of creative thinking for novel solutions and critical review for revision and improvement. The communication module equipped students with techniques of project management and conflict management in research and development (R&D) teams. In addition, students learned professional presentation and technical writing. The specific topics are summarized in **Table 1**.

Table 1. Contents covered by Biomedical Innovation

Domain Knowledge	Research Methodology	Ideation Tools	Technical Communication
• Medical Device Basics • Human Physiology Basics • Bioelectronics • Biomaterials • Biofabrication	• Strategy Development • Qualitative Data Collection • Literature Review • Market Analysis • Stakeholder Analysis • Voice of Customers	• Design Planning • Brainstorming • Quality Function Deployment • TRIZ Basics • Biomimetic Design	• Research Team Management • Conflict Management • Technical Presentation • Technical Writing

By the end of the course, each team completed an R&D proposal to address the problem they identified. The rubrics of the proposal were based on the following five criteria: (1) Value proposition, (2) Market analysis, (3) Gap analysis, (4) Novelty of the Solution, and (5) Feasibility of the Solution. In addition, each team was required to describe their proposal in a 10-min business presentation. The business presentation was assessed based on the design of the slides (including structure, content, and graphic design) and the talk.

A self-efficacy survey was conducted before and after the course. The survey asked students to evaluate their current level of confidence in certain types of skill/knowledge, such as "perform effective background research and investigation for medical problem" or "Manage time-sensitive work through effective prioritizing, scheduling, and tracking." The survey used the Likert scale where 1 refers to "the lowest confidence" and 5 refers to "the highest confidence". The survey comprised 19 statements that covered four skills: (1) problem analysis, (2) critical thinking and ideation, (3) project management and teamwork, and (4) technical communication. In addition, a course evaluation was administered during the final week of the course to evaluate the effectiveness of this pedagogical strategy. The survey used the Likert scale where 1 refers to "strongly disagree" and 5 refers to "strongly agree". The sample size of the survey was 24 and the response rate was 79.2% (19/24).

3. Results and Discussion

This course was implemented in the fall 2022 with the enrollment of 24 IE students. 54.2% of the class included underrepresented students, seven (29.2%) of which were female. Nine medical students joined the course projects, resulting in a total of six project teams. One of the teams presented the proposal at the Innovation Hub of Texas Tech University and won the Start-Up Ideation Competition Award of $2500.

The results of the self-efficacy assessment before and after the course are presented in **Figure 1**. All four skills saw significant improvement, in which the skill of project management and teamwork received the highest level of confidence, and the skills of problem analysis was the most enhanced skill through the training of this course.

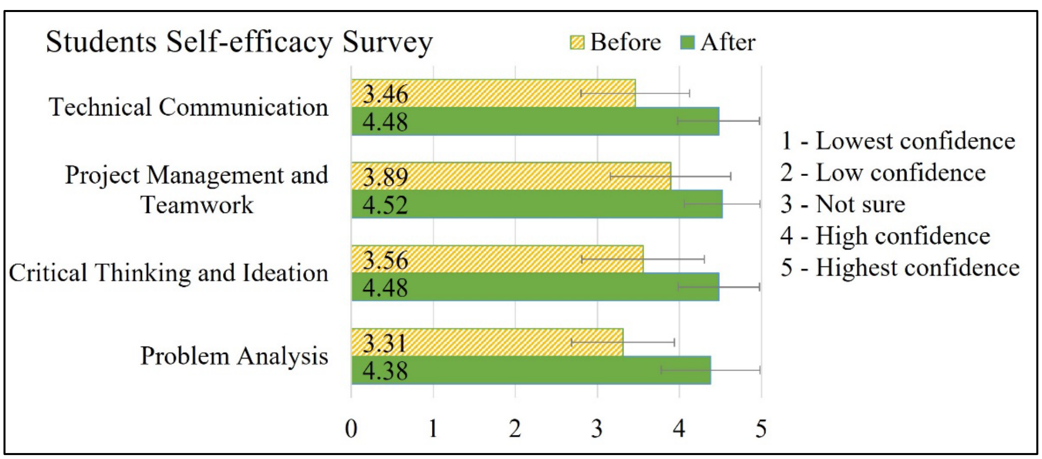

Figure 1. Self-efficacy before and after taking the course.

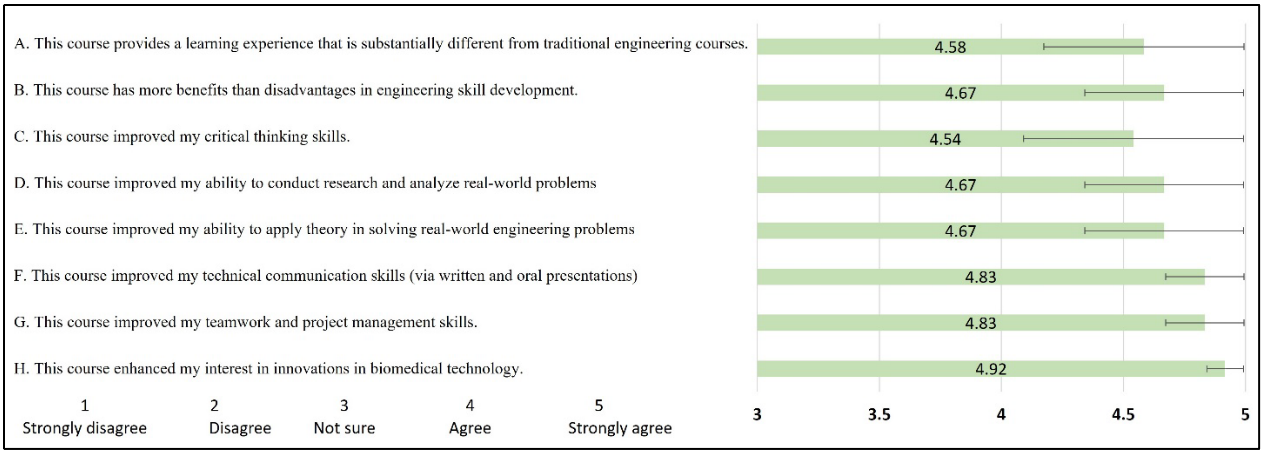

Figure 2. Course evaluation.

Figure 2 shows the course evaluation results. Question H, "This course enhanced my interest in innovations in biomedical technology" received the highest average score (4.92). Such a response average score from IE students demonstrates that students without biomedical engineering backgrounds were innovative in an unfamiliar problem area. Furthermore, students overwhelmingly perceived the real-world challenge of the course provided a quality learning experience that improved their skills in engineering development, critical thinking, analysis, project management, and technical communication.

This in-process study presents preliminary data that support the hypothesis that learning to identify a valuable problem in an unfamiliar area through systemic analysis promotes students' self-efficacy in research capability and facilitate ideation for solutions. None of the participants received clinical or biomedical engineering training yet most of them effectively worked with medical students by matching their expertise and interest to clinical problems and developing novel solutions from outsiders' perspectives. This is consistent with the findings from prior studies [10] that problem finding plays a key role in producing tangible outcomes. Problem finding tasks are more interesting, engaging, as well as ill-structured, eliciting free associations of ideas [11]. Rubenstein et al. found that students who planned to use more elaboration strategies tended to identify more potential problems and the number of problem identification strategies significantly correlated with problem-solving fluency and problem-solving flexibility [12]. This finding has practical implications for educators of mature students, as it suggests that they should incorporate exercises that promote problem finding skills into their teaching practices.

Much recent research addresses the need to improve engineering education. For example, [13-15] discuss how to enrich and broaden engineering education so that students will be technically grounded and better prepared to work in a global economy with interdisciplinary skills as well as have an appreciation for life-long learning. Techniques such as active learning, collaborative learning, team-based learning, problem-based learning, and flipped classrooms have been promoted as effective ways to support different learning styles and promote more interaction in the classroom [16,17]. Committee meetings such as those reported in [18] call for educational innovations that have significant impact through implementation of proven practices. Adoption of such techniques are rare as implementation of such pedagogical practices are time-consuming and not usually recognized or rewarded in the academy.

Studies on change strategies for engineering education have concluded that STEM change agents have primarily focused on the individual level, with a lack of attention to systems and environment [19, 20]. The development of a shared vision for implementation of new teaching methods was the area identified as most critical. Besterfield-Sacre et al. [21] build on [22] to recommend professional development for faculty to learn about innovative teaching methods, with a corresponding rewards system and new structures, positions, and policies to support innovation. Finelli, et al. [23] provide additional recommendations for the implementation of educational innovation by faculty and administrators. The report in [24,25] emphasizes the importance of real-world experience in education, reporting on 29 programs that have successfully infused real-world experience into the curriculum. This course explores the use of real-world experience at a deeper level within the curriculum, with students engaged in team-oriented instructional methods.

In recent years, strong interest has gained traction for the incorporation of project-based learning (PBL) in a variety of different engineering disciplines, e.g. [26-33]. These previous efforts can inform proposed curriculum. However, few prior efforts have occurred to implement PBL throughout an entire engineering curriculum. One exception is the Iron Range Engineering (IRE) program, which started in 2010 and uses 100% PBL with no formal courses in the final two years of the curriculum leading to the BS in Engineering at Minnesota State University-Mankato [34], thus serving as a partial model for our proposed program. While evaluation studies of the IRE program outcomes are ongoing, initial results suggest a high potential for success [34, 35].

PBL is based on the concept of "constructivist learning," which relies on the student's ability to utilize previous knowledge and skills as well as attribute value to the project at hand, thus constructing their own education [36]. Students are more likely to experience program integration, retention, and complete graduation in engineering if they engage in constructivist learning because they will (1) perceive knowledge and skills gained and (2) develop positive affect via actively understanding and internalizing core concepts. The experience of these outcomes will result in increased enrollment and student retention through student recognition of the authenticity of engineering education. Enrollment and retention of underrepresented groups such as women and minorities should also increase since research has indicated that constructivist classrooms are places of great success for them [37]. Meanwhile, PBL allows students with different backgrounds to work on the same problem, in which they model the thinking and problem-solving process within their own discipline, but at the same time see problems from others' perspectives [38]. The interdisciplinary environment creates intellectual advantages by creating a dynamic and interactive learning environment that inspires new research ideas and intellectual partnerships among faculty [39].

It is important to consider some limitations when interpreting the results of our preliminary study. One such limitation is the moderate sample size, and the students are all majoring in IE. The study did not include a diverse range of participants. It should also be noted that this senior elective may have survivorship bias. Approximately three-quarters of the class were senior students, and the rest of the class were junior students. Although the medical field is new to them, all of them had built a solid foundation of IE, which enabled them to take challenges by applying their skills to a new field. The success of this course does not guarantee the effectiveness of this learning model to entry-level engineering students who lack sufficient training in a specialty and confidence in engineering skills. Future work will expand the scope of this study and include engineering students with various backgrounds by actively promoting this course in all engineering departments to have a diverse student body.

4. Conclusion

This paper presents a novel upper-division elective for biomedical innovation in IE for undergraduate students who had not previously experienced biomedical engineering courses. Students were unfamiliar with the domain and collaborated with medical students to (1) determine a valuable medical problem to work and (2) develop an engineering solution. This nontraditional PBL experience enhanced students' sense of ownership to their projects and motivated students to innovate. Course evaluation feedback from learners confirmed that students' abilities for problem analysis, ideation, teamwork, and communication in a multidisciplinary environment improved. This course provides a training template for PBL outside the comfort zone to equip engineering students with requisite skills and mindset for innovation and leadership.

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