Contextualization of Soft Skills in a Biotechnology Course with Project-Based Learning

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Abstract: A shortage in the science, technology, engineering, and mathematics (STEM) workforce has made it clear that STEM educators should adjust their teaching pedagogy to engage and retain students by improving student interest in STEM fields. Furthermore, in addition to discipline-based knowledge, students must learn the soft skills employers value to increase employability. Project-based learning (PBL), a student-centered teaching method in science labs, is a strategy that encourages students to create their projects while applying soft skills. This article demonstrates that integrating and implementing PBL in a biotechnology lab enhances knowledge and increases student retention and employment rates.

Keywords: project-based learning, biotechnology

Introduction

In September 2022, the White House issued an executive order on advancing Biotechnology and Biomanufacturing Innovation for a sustainable, safe, and secure American Bioeconomy to "train and support a diverse, skilled workforce and a next generation of leaders from diverse groups to advance biotechnology and biomanufacturing" [1]. It is known that the science, technology, engineering, and mathematics (STEM) workforce makes essential contributions to improving the nation's living standards, economic growth, and global competitiveness. However, economic projections predict a workforce shortage in the STEM fields to meet the demands in the labor market [2], which will have a high impact on the economy.

An analysis of the leading causes of this shortage indicates that younger generations are not pursuing careers in STEM compared to previous generations. Many factors contribute to the issue, including but not limited to access to higher education, high tuition, and decreased interest in the STEM disciplines [3]. These factors, especially the lack of interest in the STEM disciplines, have contributed to increased dropout rates among underserved minorities. It was also suggested that one of the reasons why students withdraw is that they find their classes boring and therefore become disengaged [4].

Additional studies have demonstrated that the best science training programs have a solid connection to industry and provide sufficient services to help engage adult students and complete the program [5]. Reports also indicate that successful programs offer adult learners (e.g., underrepresented and low-income students) access to essential services that remove barriers to entering and completing a training program. Hess et al. reported that programs with training developed with local employers' needs in mind and with their input result in improved employment opportunities and increased wages [6]. It has also been documented that successful interventions start with strong connections with employers [7]. However, very little detailed information is available about interventions that can make science programs in higher education more effective in training students for high-demand jobs while increasing program completion and job placement rates.

Traditionally, science labs have followed a protocol written in traditional lab manuals and mainly demanded discipline-specific knowledge. This method may not be suitable for science labs with the goal of training students for careers and better employability, where employers value skills such as communication, analytical thinking, and problem-solving [8]. Project-Based Learning (PBL), a student-centered instructional method, has been widely shown to successfully encourage students to direct their learning through inquiry and, at the same time, apply knowledge to develop real-world projects [9]. PBL strategies empower students to work together and develop their approach to scientific methods, where they begin with a clear objective; instructors facilitate and support the learning process. This strategy is effective for facilitating knowledge acquisition and retention [10]. In fact, Movahedzadeh et al. have reported that students in a biology course showed improvement in self-confidence and lab skills, in addition to high levels of satisfaction [11]. Another study by Yeh reported the effectiveness of PBL in retaining adult learners [12]. Further, using PBL, students acquire and develop soft skills, such as solving complex problems, thinking critically, analyzing, and evaluating information, working cooperatively, and communicating effectively [13, 14].

This study aims to explore the integration and implementation of PBL in a biotechnology laboratory setting and assess its potential impact on various important factors, including student retention rate, development of essential skills, and subsequent employment rates. Based on previous research and theoretical frameworks supporting the effectiveness of PBL, we hypothesize that incorporating this active learning approach into the biotechnology lab curriculum will yield positive outcomes in terms of student retention, skill acquisition, and employment prospects. The utilization of PBL is expected to enhance student engagement, critical thinking, problem-solving abilities, and teamwork skills, all of which are highly valued in the biotechnology industry, making the graduates potentially more competitive and marketable in the job market. Furthermore, this study holds significant potential for informing educational practices and curriculum development in biotechnology programs. The outcomes will provide compelling evidence for the integration of PBL in laboratory settings, serving as a valuable resource for educators and institutions seeking to enhance student learning experiences and improve post-graduation outcomes. Moreover, the findings may contribute to broader discussions on the effectiveness of active learning strategies in STEM education and serve as a catalyst for further research.

Methods

Experimental design

Data was collected over five semesters (two and a half years; 2019-2022) from 52 students (age range: 18-42 years old; average age: 25 years old; over 75% Hispanic - the main underrepresented group) to test the effectiveness of PBL strategy in biotechnology labs. In this 16-week training program, students learn discipline-based knowledge in the lecture and technical skills in the lab in the first eight weeks of the course. In the second eight weeks of the course, students continue with lectures while they apply acquired skills by designing lab projects with real-world applications.

Students were grouped into diverse teams of 3-4 members to design the projects. They were then asked to propose a project relevant to them and their communities. Examples of projects that the students designed were "production and characterization of green nanoparticles," "testing immunoglobulins in saliva," and "reducing bioburden in wastewater." Students were asked to formulate a hypothesis and then propose their experimental design to begin the process. After iterative discussions to optimize the experimental procedure, students conducted the experiments by applying the lab skills learned in the first eight weeks of the semester. Techniques used included enzyme-linked immunoassay (ELISA), polymerase chain reaction (PCR), spectrophotometry, etc. The group projects engaged students and encouraged the use of soft skills as they collaborated to complete projects in a timely and professional manner through guided facilitation by the instructor. At the end of the semester, students were asked to prepare a research poster on their findings. The posters, presented at a poster exhibition organized by the instructor, provided students with the opportunity to showcase their work to industry partners, peers, family, and community members.

In addition to the integration of the PBL, industry partners were invited to the class to speak about job opportunities and required skills. The instructor also had the opportunity to work with the students to prepare their resumes and conduct mock interviews. Actual interviews were set up with the industry partners before the semester ended on campus.

Assessment of student outcomes

A comprehensive survey was administered to assess student outcomes at the conclusion of each semester. The surveys encompassed various aspects such as critical thinking skills, teamwork abilities, motivation to learn, enhanced communication, effective time management, a sense of accomplishment, and improved problem-solving capabilities. The survey questions utilized in the assessment were carefully selected from a diverse range of general surveys to ensure comprehensive coverage of the specific needs and requirements of the PBL design for this particular project. By drawing upon a variety of survey sources, the questions were designed to capture the multifaceted aspects of student learning and to identify the specific areas where PBL could effectively address those needs. This approach ensured that the survey instrument was robust and aligned with the goals of implementing PBL and its impact on student development and achievement.

In addition, after each semester, detailed records were gathered to obtain accurate student attendance and retention rates. Furthermore, as part of the assessment process, students were also given the opportunity to express their preferences regarding the instructional approach. Specifically, they were asked to provide feedback on their preference for PBL as opposed to traditional laboratory exercises. This additional input from students allowed for a more holistic understanding of their learning experiences and provided valuable insights into the effectiveness and impact of different instructional methods.

Results

Fifty-two students were surveyed with 100% return on responses. The survey questions rated their critical thinking skills, teamwork, motivation to learn, improved communications, time management, sense of accomplishment, and enhanced problem-solving skills. Students were asked to reflect on the criteria above at the end of the semester and report how much they enhanced each skill. The majority of students reported that they have improved "exceptionally" in all criteria, and fewer students reported their improvement as good or fair (Figure 1).

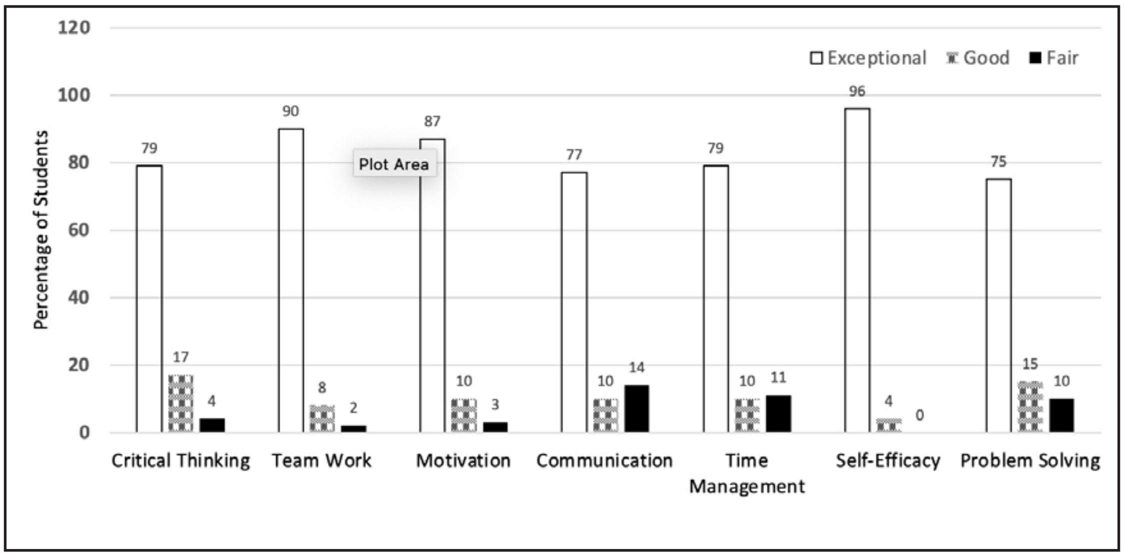

Fig. 1. Skill sets of students developed during PBL included critical thinking, teamwork, motivation, effective communication, time management, sense of accomplishment reported as self-efficacy, and problem-solving skills. The numbers represent the percentage of students grouped as exceptional, good, and fair. As shown, 75% of students (n=52) rated exceptional improvement in all criteria.

Furthermore, 94% of the students indicated their preference with PBL over their previous traditional science labs. Additionally, as shown in Figure 2, the "perfect attendance" data was 89%, and the "student retention" rate was 94%.

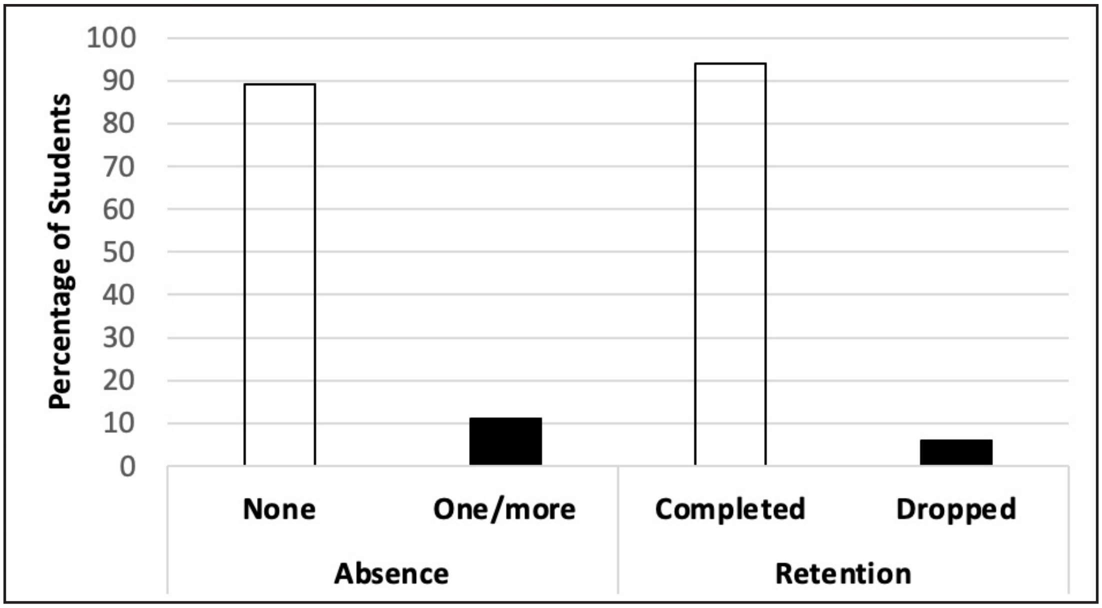

Fig. 2. Effect of PBL on attendance and retention of students in the class. The absence reported was 1-3 during the semester. Retention reflects the percentage of students with completion of the course. (n=52)

Implementing PBL fostered a more dynamic and interactive relationship between students and instructors, facilitating a thorough evaluation of individual students' skills and enabling better preparation for interviews with industry partners. This approach enhanced retention rates and resulted in a notable improvement in students' skill sets. Furthermore, the employment rate following each semester remained consistently high, with a minimum of 90% of students securing employment within two and a half years. Remarkably, even during the challenging times of the pandemic, the employment rate surged to an exceptional 100%. This remarkable achievement speaks to the effectiveness of the PBL approach in equipping students with the necessary knowledge and practical skills sought by employers, ensuring their successful transition into the professional world.

Discussion

Project-based learning is an active learning strategy that has been demonstrated to increase student motivation and self-efficacy [15]. Self-efficacy is a key element of the social cognitive theory that appears to be an important variable because it affects students' motivation and learning [16]. Consistent with results published by Shin, in our study, the self-reflection outcomes on contextualized skill set (critical thinking, teamwork, motivation, improved communication, time management, sense of accomplishment, and problem-solving) were also rated mostly exceptional by the students indicating a sense of enhanced self-efficacy and motivation [15]. In addition to the inclusion of some survey questions adapted from Shin [15] and incorporating feedback from industry partners gathered during advisory board meetings, it is essential to emphasize the limitations of the survey used in this study and the critical need to assess the reliability and validity of the survey in future studies.

PBL also created an opportunity for students to collaboratively engage in a time-limited science experiment and be able to communicate and provide feedback to their team members. Basic knowledge and skills are identified to be essential by employers [17], which our industry partners also emphasized. In fact, according to the National Association of Colleges and Employers, soft skills, in particular critical thinking skills, are the top priority for an employer to hire someone [18].

Motivation and retention were additional factors rated very high in our study. Our results support the findings of Beier et al., where utility value of PBL in STEM courses was examined [19]. They found that PBL in at least one course affects the utility value of participating in STEM courses and STEM career aspirations. In addition to gaining skills required by employers, our findings show that PBL strategies enhance the students' interest in the sciences, which also resulted in a very high employment rate. Our placement has been above 90% within two and a half years. Due to a shortage of workers in STEM, community colleges are being called on to address the persistence of minorities in the STEM fields [3]. Palmer and Wood further report a low number of underrepresented minorities in these fields [3]. The community colleges with primarily enrolled underrepresented minorities are in a great position to train students in STEM disciplines. They can make a meaningful impact on student interest, as well as retention, in the sciences.

Conclusion

Project-based learning in the college science labs provides students the opportunity to approach coursework with curiosity and motivation for the sciences in a collaborative, team-based approach. This strategy will result in skills valued by the employers and hence an improved job placement rate. This study demonstrates that the PBL approach addresses the skills gap in science labs, providing a bridge from classroom to career. In addition, this approach will enhance the interest of underrepresented minorities in STEM disciplines, which may lead to closing the equity gap.

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Disclosures. The authors declare no conflicts of interest.

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