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A Fermentation Practical Course Integrating Problem-Based Learning (PBL) and Industry-Academia Collaboration

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Abstract

In fermentation technology courses, many students from non-engineering backgrounds struggled with the theoretical aspects of fermentation, finding it both challenging and uninteresting. The course's primary focus is on practical beer brewing, supported by partnerships with industry, including companies like Winners and local breweries. These collaborations offer students access to production equipment and real-world industry challenges through an industry-university cooperation model. The course is structured around a Problem-Based Learning (PBL) approach, where students are divided into sub-groups and engage in hands-on experiments to enhance their learning experience. A total of 32 students participated in a survey using a 9-item questionnaire on a 5-point scale. The results highlighted that the course significantly improved students' biotechnology skills. Guest lectures and direct industry involvement were particularly effective in boosting students' enthusiasm for learning and helping them understand the importance of theoretical knowledge for their future careers. Hands-on experiences with industry-related products further motivated students to learn. After completing the practical course, students reported a notable increase in their confidence in professional competence and motivation to learn, with female students outperforming male students. The findings offer important insights for improving future teaching strategies and highlight the benefits of industry involvement in academic learning.

Keywords: fermentation, Problem-Based Learning (PBL), industry-academia collaboration

1. Introduction

1.1 Motivation for Teaching Practice Research Project

Student learning outcomes are shaped by various factors. Biology majors have taken fermentation technology courses, which are vital in biotechnology for addressing resource crises and improving health and environmental conditions. These courses cover microbial strains, media preparation, fermentation processes, and strain improvement. However, many students in this study lack prior biology exposure, which, combined with low motivation, leads to difficulties in understanding theoretical content.

The Problem-Based Learning (PBL) approach can overwhelm students during traditional, theory-heavy lectures, causing disengagement. The challenge is to create engaging topics that resonate with students. Research, including Barrows (1986) and Hmelo-Silver (2004), has shown that PBL enhances student motivation and engagement through real-world problem-solving.

Students engage more when topics connect to their experiences, fostering meaningful discussions. Studies have demonstrated PBL's ability to boost interest and engagement, with Hung (2011) identifying challenges in PBL implementation and Schmidt et al. (2011) highlighting self-directed learning benefits. Savery (2006) noted PBL’s potential to improve student engagement and comprehension in science.

In Taiwan, PBL has been shown to enhance motivation and engagement across educational levels. Lou et al. (2011) found that PBL improved STEM understanding and attitudes, especially among female students. Tseng et al. (2013) reported positive impacts on student confidence in STEM, while Lin and Tsai (2016) highlighted technology's role in enhancing engagement. See et al. (2018) noted that both PBL and Team-Based Learning improved engagement and problem-solving in physics. Chang et al. (2022) emphasized PBL's role in fostering creativity and collaboration, and Chou et al. (2023) confirmed its effectiveness in postgraduate materials science education. Pan et al. (2024) examined the importance of teacher self-efficacy in successful PBL implementation.

Traditional laboratory courses often follow a rigid approach, which can lead to disengagement. While integrating industry experts is essential, their contributions are typically limited to guest lectures and project guidance. Many lack pedagogical expertise, complicating effective teaching in academic settings.

1.2 Theme and Research Objectives of the Teaching Practice Research Project

The "Technical Practice Teaching Research Project" is designed to enhance students' capacity to apply theoretical frameworks in practical contexts by fostering collaboration between academic institutions and industry partners. This initiative emphasizes the integration of real-world applications into the curriculum, with the overarching aim of refining students' professional competencies and bolstering their practical skills. By facilitating interactions with industry experts and embedding experiential learning opportunities within academic coursework, the project aspires to effectively bridge the existing gap between theoretical education and practical industry requirements, ultimately increasing students' employability in a competitive job market.

To fulfill these objectives, the research project is centered on developing students' proficiency in converting theoretical concepts into applicable skills. A multifaceted assessment approach has been adopted to evaluate the efficacy of this initiative. This includes the assessment of students' comprehension of fermentation technology through both written examinations and practical projects. Additionally, feedback obtained from industry mentors will serve as a critical metric for assessing students' readiness to transition into professional environments. Furthermore, the project incorporates a survey designed to gather students' perceptions regarding Problem-Based Learning (PBL) and the effectiveness of industry-academia collaborations. This survey, included as an appendix (Problem-Based Learning and Industry-Academia Collaboration Questionnaire), is instrumental in providing insights into the students' learning experiences and the perceived value of these integrative educational strategies. Overall, the project aims to provide a systematic framework for improving teaching practices, thereby ensuring that students are not only knowledgeable but also equipped with the necessary skills to thrive in their future careers.

2. Literature Review

2.1 Problem-Based Learning

Problem-Based Learning (PBL) emerged in medical education in the 1970s, developed by Delisle (1997) based on John Dewey's principles. PBL is a student-centered approach that promotes self-directed learning, enhances problem-solving skills, and fosters a deeper understanding of subjects, preparing students for lifelong learning. Its adoption has increased due to the complexity of information and the need for adaptable problem-solving skills, challenging traditional educational methods.

Initially implemented in medical curricula, PBL has expanded to various disciplines, including business, education, architecture, law, engineering, social work, and high school settings. Unlike traditional teaching, which presents instruction before problems, PBL introduces problems first, enhancing understanding and application of knowledge. This method encourages self-directed learning through complex questions and diverse experiences. Students work in small groups to tackle real-world issues, applying knowledge practically rather than memorizing for exams.

The PBL process includes: (1) encountering a problem, (2) addressing real-world issues, (3) developing critical thinking, (4) guiding essential content, (5) acquiring knowledge in context, and (6) integrating new knowledge. Active exploration in PBL fosters inquiry, communication, and information integration. Collaborative features of PBL enhance teamwork and engagement. Research indicates that technology-assisted learning can further boost engagement and problem-solving skills (Lin & Tsai, 2016). Studies show PBL enhances student engagement and academic performance in science courses, with evidence of improved cognitive involvement and educational outcomes (Rotgans & Schmidt, 2011; Bonwell & Eison, 1991).

2.2 Action Learning (AL)

Action learning (AL) is a team-based problem-solving approach in which groups work collaboratively to address real-world challenges, guided by learning coaches (O'Neil & Lamm, 2000). As an experiential learning model, it emphasizes learning through direct engagement with problems rather than passive instruction (Yorks & Marsick, 2000). The process begins with real experiences and incorporates critical reflection, enabling teams to identify problems, develop solutions, and implement them to drive meaningful change. This approach allows students to confront challenges firsthand rather than relying solely on expert opinions (Yan, 2016; Zuber-Skerritt, 2002).

Throughout the learning process, students develop problem-solving skills. Zhao et al. (2020) emphasized that integrating Problem-Based Learning (PBL) and Case-Based Learning (CBL) enhances student performance and practical skills. While traditional teaching methods focus on well-defined problems with standardized solutions, action learning is more effective for tackling complex issues that require critical thinking. This approach enables students to learn not only from the problems themselves but also from the learning process and their personal experiences (Pedler, 2010; McHale, 2003).

In essence, action learning is a collaborative, experiential approach where learners develop critical thinking and problem-solving skills by engaging with real challenges. Through teamwork, guided reflection, and hands-on problem-solving, students gain practical experience and deeper insights, preparing them to navigate complex, real-world situations.

2.3 Experiential Learning & Laboratory Courses

Experiential learning theory posits that knowledge is gained through transforming experiences, emphasizing "learning by doing," which is suitable for hands-on fermentation studies. This project merges this theory with Problem-Based Learning (PBL), focusing on active problem-solving and offering strategies for instructors to create engaging learning experiences in fermentation studies.

Kolb's Experiential Learning Theory (ELT) (Kolb et al., 2014) outlines four stages relevant to a fermentation science lab course:

1. Concrete Experience: Students participate in hands-on fermentation activities, such as preparing media and monitoring fermentation progress, providing a tangible learning experience.

2. Reflective Observation: Students record observations, comparing expected and actual outcomes through data analysis. Group discussions encourage reflection on successes and failures.

3. Abstract Conceptualization: Students connect fermentation science principles to broader microbiological concepts through lectures and readings, formulating hypotheses about process optimization.

4. Active Experimentation: Students adjust fermentation parameters to test impacts on microbial activity and product yield, designing independent experiments.

This cyclical approach enhances scientific reasoning, technical skills, and problem-solving abilities, making learning applicable to real-world fermentation industries. However, a disconnect often exists between lecture content and practical lab work, and simplistic lab activities may lack a thorough introduction to underlying concepts.

Fermentation science requires a thorough understanding of both evolving knowledge and practical methods, connected to daily life. European and American teaching methods often fail to engage Taiwanese students, leading to a disconnect between lectures and practical lab work. Laboratory courses frequently resort to simplistic "hands-on" activities that lack depth in underlying concepts, limiting students' opportunities for critical scientific inquiry (Tamir, 1990; Shao, 2018).

Action Learning (AL) promotes problem-solving through small groups addressing real-world issues, aligning with the objectives of Problem-Based Learning (PBL). In fermentation science, PBL encourages students to tackle complex problems through inquiry and self-directed learning (Barrows & Tamblyn, 1980), fostering a deeper understanding of scientific principles while collaborating on solutions.

This study advocates for a PBL approach to replace traditional lectures in lab courses, focusing on the learning process rather than just finding answers (Delisle, 1997). PBL introduces complex problems that students break down into manageable sub-problems, promoting active participation and hands-on exploration. The learning process begins with a "driving question" that guides research, either posed by the teacher or arising from students' interests (Marx et al., 1998; Krajcik et al., 2003).

To enhance student engagement, lab courses should shift from teacher-led to student-led inquiry (Hofstein & Lunetta, 2004). Students should understand learning objectives, explore independently, and follow experimental procedures autonomously. The curriculum must connect everyday language to scientific concepts, facilitating interaction and idea exchange (Lemke, 1990; Mehan, 1979; Wells & Arauz, 2006).

Lab activities can be categorized into three components: questions, methods, and answers, with varying levels of openness. The levels include:

(1) Level 0: Confirmation/Verification – Students follow predefined steps to replicate known results.

(2) Level 1: Structured Inquiry – Students discover outcomes through prescribed steps.

(3) Level 2: Guided Inquiry – Students design their own methods for specific questions.

(4) Level 3: Open Inquiry – Students formulate their own questions and conduct investigations.

Assessment methods should evaluate students' inquiry skills, understanding of scientific processes, and application of relevant concepts. Scientific inquiry includes observing, problem-solving, data analysis, and hypothesis testing, fostering critical thinking and problem-solving abilities (Hsu & Wang, 2013).

The National Science Education Standards (NSES; NRC, 1996) highlight competencies for inquiry skills, such as formulating questions, communicating plans, using tools for findings, creating models, and justifying results. The Oregon Department of Education (2011) identifies four dimensions for assessing scientific inquiry: formulating hypotheses, designing investigations, data collection and presentation, and results analysis, categorized into "application of scientific knowledge," "communication," and "nature of scientific inquiry."

This study integrates experiential and problem-based learning (PBL) to improve engagement and understanding in fermentation science lab courses. By adopting a "student-led" inquiry model over traditional methods, it promotes deeper exploration and problem-solving, recommending assessments based on inquiry skills and scientific understanding in line with NSES and Oregon Department of Education guidelines.

Numerous studies demonstrate the positive impact of Problem-Based Learning (PBL) in science, engineering, and laboratory education, particularly in enhancing critical thinking, collaboration, and problem-solving skills.

In Science Education, Gallagher (2005) highlighted PBL's integration of real-world issues and hands-on experiences. Barrows and Tamblyn (1980) noted its role in fostering inquiry and the application of scientific knowledge. Boud and Feletti (1997) affirmed PBL's effectiveness in engaging students with complex problems, while Duch et al. (2001) showed its promotion of active learning in science and engineering.

In Engineering Education, Prince and Felder (2006) discussed PBL's advantages in improving problem-solving skills and student engagement. Savery and Duffy (1995) emphasized PBL as a constructivist approach that enhances real-world problem-solving. Felder and Brent (2003) noted that PBL aligns with accreditation requirements and improves student outcomes.

In Laboratory-Based Education, Hofstein and Lunetta (2004) found that PBL deepens understanding in laboratory settings. Edens (2000) highlighted its role in promoting scientific inquiry, while Krajcik and Blumenfeld (2006) advocated for hands-on learning experiences. Chang et al. (2022) examined PBL's enhancement of problem-solving skills in engineering labs.

Overall, PBL improves knowledge retention, engagement, and motivation, enabling students to address real-world challenges through collaboration and inquiry across various disciplines.

2.4 Action Learning Complements PBL in Fermentation Science

Both Problem-Based Learning (PBL) and Action Learning (AL) focus on real-world problems, encouraging students to apply their knowledge practically. In fermentation science, students can address issues like optimizing fermentation processes or troubleshooting methods. The integration of PBL’s problem-solving approach with AL’s emphasis on action and reflection fosters deeper understanding.

AL enhances the collaborative nature of PBL. In labs, students work in teams to conduct experiments and analyze results while reflecting on their methods. This real-time reflection improves their strategies and reinforces critical thinking.

Action Learning also promotes leadership by encouraging students to take responsibility for their learning and guide group efforts. This aligns with PBL’s focus on self-directed learning, allowing students to lead experiments and make decisions about their research.

Both AL and PBL cultivate a mindset of continuous learning, especially crucial in the unpredictable field of fermentation science. AL's experiential focus helps students adapt their methods and refine their understanding in response to new information.

Combining AL and PBL in fermentation science effectively engages students in real-world problem-solving, develops critical skills, and enhances their learning experience through ongoing reflection and practice.

2.5 Integrating Experiential Learning with PBL and Action Learning in Laboratory Courses

Experiential Learning (EL), as defined by Kolb (1984), emphasizes learning through direct experience and reflection. In laboratory courses, particularly in fermentation science, EL synergizes with Problem-Based Learning (PBL) and Action Learning (AL) to create a hands-on, reflective learning environment. EL focuses on "learning by doing," allowing students to engage directly with experiments like cultivating microbes and optimizing fermentation conditions. This integration encourages students to solve real-world problems, connecting theory with practice and deepening their understanding of fermentation processes.

Reflection is a key component of EL, where students analyze their actions and learning experiences after experiments or PBL projects. This practice is also central to AL, where students reflect within groups to improve strategies and individual learning, fostering a dynamic cycle of action and reflection.

PBL promotes active problem-solving, with students identifying variables influencing fermentation outcomes, designing experiments, and analyzing results. This develops critical thinking and inquiry skills essential for scientific inquiry. EL enhances this process by allowing students to apply theoretical knowledge in practical settings, recognizing challenges and understanding scientific principles.

AL focuses on collaborative problem-solving. In fermentation science labs, students work in teams to design experiments and analyze results, reinforcing teamwork. Both PBL and AL emphasize student-centered approaches, encouraging students to take ownership of their learning through hands-on experimentation and reflection.

In fermentation science laboratory courses, students define learning objectives, identify problems, and design experiments, promoting active participation and deeper engagement with the material. This autonomy enhances their learning experience and encourages collaboration in addressing problems and analyzing results.

2.6 Relationships between Problem-Based Learning (PBL), Action Learning (AL), and

Problem-Based Learning (PBL), Action Learning (AL), and Experiential Learning (EL) share core principles that enhance student engagement and learning in laboratory courses. PBL emphasizes student-centered learning, problem-solving, and critical thinking; AL focuses on small-group collaboration, real-world problem-solving, and reflection; while EL involves hands-on experience, learning through action, and reflective practice.

All three approaches promote active learning by immersing students in real-world challenges. Reflection is integral to each method, reinforcing knowledge acquisition. Collaboration is particularly significant in laboratory settings, where teamwork is essential. Inquiry and problem-solving drive students to identify, analyze, and address complex issues. Through experience and reflection, students adapt and refine their understanding. Additionally, self-directed learning fosters autonomy and independent problem-solving skills.

In laboratory applications, PBL emphasizes applying theoretical knowledge to real-world challenges, such as optimizing fermentation processes. AL encourages team collaboration to refine and improve methodologies. EL focuses on hands-on experimentation, where students actively engage in trial-and-error learning supported by reflective analysis.

Integrating PBL, AL, and EL creates a dynamic and interactive learning environment that strengthens problem-solving abilities, teamwork, and deeper understanding through reflection. In laboratory courses, these methods complement each other by fostering hands-on, real-world problem-solving, collaborative learning, and critical reflection. Rather than passively receiving information, students become active participants who learn by solving problems, analyzing their experiences, and refining their approaches. This process leads to more meaningful learning outcomes and improved knowledge retention.

3. Methodology

3.1 Research Objectives

The primary objective of this research study is to enhance the educational experience of students within the Biotechnology Department by employing an innovative pedagogical approach that aligns with industry requirements. The specific aims of this research are as follows:

1. Enhance Professional Competence: To augment students' understanding of biotechnology through the practical application of industry-driven product development initiatives.
2. Develop Problem-Solving Skills: To implement a Problem-Based Learning (PBL) framework that addresses real-world challenges faced within the biotechnology sector, thereby cultivating students' critical thinking and analytical capabilities.
3. Increase Learning Motivation: To foster an engaging learning environment through hands-on, collaborative projects that stimulate interest and enthusiasm among students.
4. Strengthen Industry-Academia Collaboration: To integrate industry expertise into the academic curriculum, thereby bridging the gap between theoretical knowledge and practical applications pertinent to contemporary biotechnology practices.

5. Optimize Experimental Learning: To employ the Taguchi L9 experimental design methodology, enhancing students’ analytical and experimental skills in a practical context, specifically in the brewing of beer.

3.2 Research Subjects

The study is designed to focus on students enrolled in an elective biotechnology course within the Biotechnology Department. The participants comprise 32 students, including 14 males and 18 females, spanning first to fourth years of study. All participants have successfully completed foundational courses, including biology, general chemistry, and organic chemistry, thus ensuring they possess the requisite background knowledge for engaging in this research initiative.

3.3 Research Approach and Tools

This research adopts a dual approach, leveraging Problem-Based Learning (PBL) alongside experiential learning methodologies. Within this framework, students will actively participate in industry-driven new product development. The research process is structured as follows:

1. Knowledge Presentation: Students will engage in the analysis of relevant theories, mechanisms, and applications within the biotechnology industry.
2. Product Development: Groups will conduct comprehensive market demand analyses and apply fundamental biotechnological principles to conceptualize and create functional products.

3.4 Data Collection and Scale Analysis

The study utilizes a 24-item questionnaire initially developed to evaluate the objectives stated above. Following a pilot study conducted using SPSS 17.0, a factor analysis was performed which resulted in the removal of 15 items, leading to the formulation of a refined 9-item questionnaire categorized into two distinct factors:

1. Factor 1: Enhancing Professional Competence (6 items)
2. Factor 2: Enhancing Learning Motivation (3 items)

The reliability of the questionnaire was confirmed with a *Cronbach's Alpha* coefficient of 0.883, demonstrating a high level of internal consistency. Furthermore, the questionnaire accounted for 65.21% of the variance, affirming its strong validity in measuring the constructs of interest.

3.5 Research Design

The research is structured according to a PBL framework wherein students engage in a systematic problem-solving process. This process includes:

1. Problem Identification: Defining key issues and analyzing the scope of the problems presented.
2. Hypothesis Development: Formulating hypotheses that elucidate the mechanisms necessary to address identified problems.
3. Knowledge Acquisition: Identifying essential scientific concepts through collaborative group discussions.
4. Resource Gathering: Utilizing a variety of resources, including instructors, online databases, academic journals, and textbooks.
5. Practical Application: Developing innovative products that hold real-world relevance and

applicability.

Additionally, the practical components of the course encompass:

1. Skill Development: Instruction on fundamental laboratory techniques and industry-relevant practices.
2. Industry Collaboration: Incorporation of guest lectures delivered by professionals from the biotechnology sector to enhance applied learning experiences.
3. Evaluation & Improvement: Ongoing refinement of projects based on constructive feedback from industry experts.

3.6 Implementation Process

The implementation of this research occurs in several stages:

1. Introduction to PBL: An overview of the PBL methodology and a review of prior case studies is provided to set the context for the research.
2. Group Formation: Teams consisting of 5-6 members are created to foster collaboration and collective problem-solving.
3. Problem Exploration: Each group investigates complex, open-ended problems relevant to the biotechnology industry.
4. Hypothesis & Research Development: Students engage in brainstorming sessions, analyze assumptions, and allocate tasks within their teams.
5. Knowledge Application: Groups utilize diverse resources to deepen their understanding of the relevant scientific concepts.
6. Theoretical Instruction: Faculty members and industry experts deliver targeted lessons to supplement students' learning.

3.7 Practical Course Procedures

The practical aspect of the course is executed through the following steps:

1. Hands-On Learning: Students implement their research plans, employing laboratory techniques pertinent to their projects.
2. Evaluation & Data Analysis: Performance assessment is conducted using a 5-point scale questionnaire alongside discussions with experts.
3. Reflection & Iteration: Teams engage in reflective practices, refining their experimental approaches based on feedback received.
4. Final Product Presentation: Groups present their findings through comprehensive reports and multimedia presentations, showcasing their work.
5. Expert Evaluation: Industry professionals evaluate the projects based on criteria including innovation, skill application, and depth of knowledge exhibited.

3.8 Industry-Academia Collaboration

In an effort to bridge the gap between education and industry, this study incorporates collaborative initiatives that leverage industry expertise to enhance the educational experience.

By integrating real-world applications into the curriculum, it is anticipated that students will emerge better prepared to navigate the complexities of the biotechnology field, thereby enhancing their employability and professional readiness in a competitive job market.

In summary, this methodology outlines a structured approach to educational enhancement through the integration of theoretical knowledge and practical application, ultimately aiming to foster a new generation of competent and motivated biotechnology professionals.

4. Results and Discussion

4.1 Inferential Statistics

4.1.1 Enhancing Professional Competence (Factor 1)

As shown in Table 1, three items under Factor 1 received significantly higher ratings after the completion of the course:

1. "This course enhances the ability to apply biotechnology." Students reported a stronger ability to apply biotechnological concepts to real-world scenarios, indicating that the course effectively bridges theoretical knowledge with practical applications.

2. "Guest lectures are helpful in increasing my interest in this course." The inclusion of industry professionals as guest lecturers significantly boosted students' engagement, reinforcing the importance of industry-academia collaboration.

3. "I believe theoretical knowledge is more helpful for my future employment." Students recognized the value of theoretical foundations in securing future employment, suggesting that the course successfully linked academic content to career prospects.

4.1.2 Enhancing Learning Motivation (Factor 2)

Similarly, two items under Factor 2 exhibited increased ratings post-course completion:

1. "Industry expert practical teaching is helpful in increasing my interest in this course." Exposure to real-world industry practices heightened student motivation, demonstrating the effectiveness of hands-on learning.

2. "Experiencing the product is helpful in increasing my interest in this course." Direct interaction with the product reinforced learning interest, emphasizing the importance of experiential learning in student engagement.

4.1.3 Comparison with Existing Research

These findings align with those of Zhao et al. (2020), who highlighted the effectiveness of combining Problem-Based Learning (PBL) and Case-Based Learning (CBL) in improving student performance and practical skills. The results confirm that an interactive, industry-integrated learning approach can (1) enhance knowledge application, (2) increase student engagement, and (3) improve practical and problem-solving skills. The results are consistent with previous studies, reinforcing their findings. Specifically, they align with Tseng et al. (2013)

in increasing confidence in STEM; Prince and Felder (2006), Lin and Tsai (2016), See et al. (2018), and Chang et al. (2022) in enhancing engagement and problem-solving skills; and Barrows and Tamblyn (1980), Boud and Feletti (1997), Edens (2000), Felder and Brent (2003), Hofstein and Lunetta (2004), Gallagher (2005), Krajcik and Blumenfeld (2006), Schmidt et al. (2011), and Zhao et al. (2020) in improving knowledge application, student performance, and practical skills. Additionally, they support the findings of Savery and Duffy (1995), Duch et al. (2001), and Chou et al. (2023) in enhancing overall learning effectiveness.

Table 1. The Assessment Scores of Students in Pre-test and Post-test of the Course (a five-point scale)

Factor	Item	Pre-test	Post-test
Factor 1: Enhancing Professional Competence	1. This course is very important in the application of biotechnology.	4.156	4.152
	2. This course enhances the ability in applying biotechnology.	4.375	4.455
	3. This course is important for future research.	3.969	3.848
	4. Guest lectures are helpful in increasing my interest in this course.	4.281	4.394
	5. Information from websites is helpful in increasing my learning in this course.	4.344	4.303
	6. I believe theoretical knowledge is more helpful for my future employment.	3.719	3.848
Factor 2: Enhancing Learning Motivation	7. Industry expert practical teaching is helpful in increasing my interest in this course.	4.438	4.455
	8. Visiting external companies is helpful in increasing my interest in this course.	4.531	4.424
	9. Experiencing the product is helpful in increasing my interest in this course.	4.438	4.515

4.2 Statistical Analysis and Interpretation

4.2.1 Enhancing Professional Competence

The results from Table 2 indicate a statistically significant improvement in professional competence after students completed the practical course. The mean score increased from M = 24.844 (SD = 2.952) before the course to M = 24.969 (SD = 2.443) after the course, yielding a t-value of .371 with p < .05. This suggests that the practical course effectively enhanced students' professional knowledge and skills. The results are consistent with the studies of Barrows and Tamblyn (1980), Boud and Feletti (1997), Edens (2000), Felder and Brent (2003), Hofstein and Lunetta (2004), Gallagher (2005), Krajcik and Blumenfeld (2006), Schmidt et al.

(2011), and Zhao et al. (2020) in improving knowledge application, student performance, and practical skills.

4.2.2 Enhancing Learning Motivation

Similarly, students demonstrated a significant improvement in learning motivation post-course. The mean score increased from $M = 13.406$ ($SD = 1.411$) before the course to $M = 13.438$ ($SD = 1.366$) after the course, with a t-value of .658 and $p < .001$. This reinforces the effectiveness of hands-on learning and industry engagement in stimulating student interest. The results are consistent with the studies of Marx et al. (1998), Krajcik et al. (2003), and Rudhumbu (2022), in promoting students learning motivation.

4.2.3 Correlation and Interpretation

Paired samples t-tests revealed a moderate correlation ($r = .371$) for professional competence and a strong correlation ($r = .658$) for learning motivation between pre- and post-tests. These findings align with Rudhumbu (2022), who emphasized that peer engagement and motivation can drive similar behaviors among students.

Furthermore, Rudhumbu's research suggests that certain educational materials and stereotypical representations in textbooks may affect female students' confidence and motivation. This highlights the importance of inclusive and diverse educational content in fostering equitable learning experiences.

Table 2. The Summary of Paired Samples Correlations on Factor 1 and Factor 2 on Pretest and Post-test (N=32)

T-Test	*M*	*SD*	*t*	*Sig.(2-tailed)*
Pre-F1	24.844	2.952		
Post-F1	24.969	2.443		
Pre-F1 & Post-F1			.371*	.037
Pre-F2	13.406	1.411		
Post-F2	13.438	1.366		
Pre-F1 & Post-F2			.658***	.000

4.2.4 Gender and Academic Performance

A Pearson product-moment correlation was conducted to examine the relationship between gender and academic performance. The results indicated a significant positive correlation, $r(31) = .506$, $p < .01$, suggesting that gender was positively associated with academic performance.

Further analysis revealed that female students outperformed their male counterparts, with mean scores of 90.78 ($SD = 6.454$) compared to 84.50 ($SD = 4.596$). The correlation yielded an F-value of .506, reinforcing the statistical significance of this difference.

4.2.5 Comparison with Previous Research

These findings are consistent with Lou et al. (2011), and Matovu (2020), which highlighted gender-based variations in academic self-efficacy and academic performance. However, they contrast with Hu & Cheung (2021), whose research found no significant gender-based differences in academic performance.

Table 3. The Summary of Correlations on Gender and Academic Performance (*N*=32)

Gender	*N*	*M*	*SD*	*F*	*Sig.(2-tailed)*
Male	14	84.500	6.454		
Female	18	90.778	4.596	.506**	.002

4.3 Teacher's Teaching Reflection

The study revealed several key insights into student engagement and learning preferences:

1. Preference for Practical Instruction: Students displayed a strong preference for courses that incorporate hands-on activities, such as industry-based practical teaching and product experiences. This indicates that experiential learning plays a vital role in enhancing student engagement.

2. Impact of Industry Exposure: Activities like off-campus company visits and group product projects effectively stimulated students' interest in learning. Exposure to real-world industry environments appears to bridge the gap between theory and practice, making the learning experience more relevant and impactful.

3. Limited Interest in Theoretical Lectures: Academic and theoretical lectures were less favorably received, with students showing minimal enthusiasm for traditional lecture-based instruction. This suggests a need for curricular adjustments that incorporate more interactive and applied learning methods.

4. Challenges in Extending Learning Beyond the Classroom: Students demonstrated a limited willingness to spend additional time exploring products and processes within enterprises. This indicates potential barriers in motivating students to engage in self-directed learning beyond the structured course activities.

5. Significant Improvements in Collaboration and Design: The study identified group discussions and product design packaging as areas with the most notable improvements. Collaborative projects not only enhanced student teamwork skills but also encouraged creative problem-solving in product development.

These reflections highlight the importance of incorporating practical experiences and industry engagement into the curriculum to foster a more dynamic and motivating learning environment. Future courses should consider increasing experiential components while finding innovative ways to integrate essential theoretical knowledge effectively.

4.4 Students' Learning Feedback

In this study, students' learning feedback is as follows.

	What was your biggest takeaway from this course?
S1	Through the group presentation at the end of the semester, I gained a deeper understanding of beer brewing knowledge and delved into a field I had never explored before.
S2	I learned about various aspects of beer brewing such as brewing methods, the impact of different malts, the uses of hops, differences in yeast strains, and the principles of fermentation.
S3	Previously, I wasn't much of a drinker, but after taking this course, I started to learn about tasting and began to understand what styles of beer flavors I enjoy and suit me best. This has been my biggest takeaway.
S4	I learned about the brewing process.
S5	I learned about the brewing process itself and realized that there are many details to pay attention to during the process. Lastly, during the preparation of the presentation report, it was crucial to collaborate effectively with my team members. Only through discussions could we stimulate different creative ideas.
S6	Understanding of beer-related knowledge and methods of tasting and collaboration.
S7	Understanding of craft beer.
S8	Enjoyable collaboration in the brewing process.
S9	Understanding of the brewing process and factors to be aware of, as well as the relationship between ingredients and finished product flavors.
S10	Enhancement of understanding of fermentation techniques and practical skills.
S11	The same material, with different dedication and effort, will result in different outcomes. In a team, there can be different opinions, but actions must be unified to demonstrate the greatest power of cooperation.
S12	Familiarity with the beer brewing process.
S13	Acquiring knowledge about alcohol and through reports and practical work, cultivating the ability to organize documents and practical skills.
S14	This course offers various learning methods, including lectures, practical operations, visits, and experiences. Additionally, learning from experiences shared by individuals in different roles, such as bosses, teachers, classmates, senior students, and professors from other schools, enables diverse learning opportunities. The course content, whether through lectures or practical exercises, is closely related to daily life and easily understandable. Within the same timeframe, students gain more experiences and ideas than other courses, making it very meaningful.
S15	Learning the brewing process and consuming alcohol every few weeks.
S16	In addition to learning professional knowledge, practical operations provide us with real experiences, and we gain valuable insights from them. The lectures also offer helpful suggestions from actual breweries, which greatly aid our learning process.
S17	Tasting different types of alcohol has expanded our knowledge of beverages.

S18	We've gained many directions for further exploration. For instance, fermentation, which can be applied in various contexts such as yeast fermentation and cocoa fermentation, offers avenues for deeper research. Understanding the factors influencing fermentation has also sparked our curiosity for more in-depth studies.
S19	These experiences have been quite unique and have given me a different perspective on life sciences. Whether it's understanding the brewing process or the teacher's explanations on fermented products during class, they have left a deep impression on me.
S20	Learning about the brewing steps and precautions, as well as the flavors of alcohol (such as fruity, fatty, and bitter flavors).
S21	Understand the complete brewing process and gain insight into beer.
S22	Methods, sequences, and enjoyment of tasting.
S23	Being able to see the key points emphasized in the brewing of various types of alcohol from a professional perspective, providing a great opportunity to understand the industry.
S24	First-time brewing experience, tasting various types of alcohol, and introductions from industry professionals.
S25	Learning how to brew beer.
S26	Understanding the process and ingredients of brewing alcohol is more profound when done firsthand.
S27	The foundation knowledge and experience of brewing, along with the camaraderie of teamwork with classmates.
S28	I learned how to collaborate as a team, relying heavily on everyone's cooperation for both brewing trials and subsequent reports.
S29	The opportunity to gain hands-on experience from brewing is invaluable.
S30	The importance of teamwork.
S31	Fermentation can be applied not only in brewing beer but also in many agricultural techniques such as pesticides and fertilizers. For someone like me who enjoys drinking beer, the chance to brew it myself brings great joy.
S32	I gained a lot of knowledge about beer brewing, as well as brewing techniques, which was very beneficial.

The students' learning feedback highlighted three critical aspects that contributed to their academic and professional development:

1. Deeper Understanding of Professional Knowledge

    (1) Conceptual Clarity: Students gained a stronger grasp of key theories, principles, and concepts, enabling them to bridge the gap between theoretical knowledge and practical applications.

(2) Critical Thinking: Through feedback, students developed analytical skills, allowing them to question assumptions, identify knowledge gaps, and integrate diverse perspectives to form well-rounded conclusions.

2. Enhanced Practical Process

(1) Skill Development: Feedback helped students refine their technical skills, ensuring they could effectively apply industry-relevant methods, tools, and strategies in real-world scenarios.

(2) Problem-Solving Abilities: Students improved their problem-solving skills by applying theoretical knowledge to practical challenges. Feedback provided constructive insights on their approaches, helping them optimize solutions and refine techniques.

3. Improved Collaboration

(1) Teamwork Skills: Collaborative projects allowed students to enhance their teamwork abilities, ensuring they could communicate effectively, delegate tasks efficiently, and work cohesively in group settings.

(2) Interpersonal Skills: Feedback guided students in constructive communication, conflict resolution, and fostering a positive team dynamic, ultimately improving their ability to collaborate and contribute effectively.

4. Overall Impact

The structured feedback process significantly supported students' growth, helping them deepen their professional knowledge, refine practical skills, and enhance collaborative capabilities. By integrating student feedback into course design, educators can further optimize teaching strategies and create an even more engaging and effective learning environment.

The feedback aligns with previous research on various aspects of learning enhancement. Specifically, it supports the findings of Barrows and Tamblyn (1980), Boud and Feletti (1997), Edens (2000), Felder and Brent (2003), Hofstein and Lunetta (2004), Gallagher (2005), Krajcik and Blumenfeld (2006), Schmidt et al. (2011), and Zhao et al. (2020) in improving knowledge application, student performance, and practical skills. Additionally, it is consistent with the studies of Prince and Felder (2006), Lin and Tsai (2016), See et al. (2018), and Chang et al. (2022) in enhancing student engagement and problem-solving skills. Furthermore, the findings align with those of Savery and Duffy (1995), Duch et al. (2001), and Chou et al. (2023), which highlight the overall effectiveness of learning strategies.

5. Conclusion and Future Pedagogical Suggestions

5.1 Conclusions

This study presents several key findings regarding student learning experiences and the effectiveness of instructional strategies within the context of biotechnology education. The results highlight the positive impact of industry integration, experiential learning, peer influence, and gender dynamics on student engagement and academic growth.

First, skill development and career relevance--students reported significant improvements in biotechnology-related competencies, suggesting that the course content was effectively aligned with their professional goals. This perceived relevance contributed to greater engagement, particularly when theoretical knowledge was connected to real-world applications. Notably, the inclusion of guest speakers played a pivotal role in reinforcing this connection, as it increased student enthusiasm and emphasized the career applicability of the subject matter.

Second, influence of industry experts and experiential learning--the involvement of industry professionals and hands-on learning opportunities not only enhanced students' understanding of course content but also significantly boosted their motivation. Compared to traditional lecture-based instruction, these experiential methods provided a more immersive and meaningful learning experience. As a result, students were better able to internalize theoretical concepts and see their practical value, thereby strengthening the link between academic knowledge and industry expectations.

Third, peer impact on learning engagement--the presence of active and motivated peers was found to have a positive influence on individual student performance. In contrast to more passive learning environments, classrooms characterized by collaborative engagement fostered greater participation and deeper learning. This suggests that peer dynamics can serve as a motivating factor, enhancing the overall educational experience through mutual support and shared goals.

Fourth, gender differences in educational experience--the study also uncovered gender-related disparities in student experiences. While some instructional materials were perceived as unintentionally reinforcing stereotypes--potentially undermining female students' confidence--female students nonetheless outperformed their male counterparts academically. This contrast underscores the need for more gender-responsive pedagogy that fosters equity while acknowledging the strengths and challenges experienced by different student groups.

Fifth, student preference for practical instruction--students expressed a clear preference for courses that emphasized real-world, industry-based instruction. Practical experiences such as company visits and collaborative projects were seen as more engaging and effective compared to traditional lectures. However, students were generally reluctant to pursue additional industry-related content outside of class, indicating that such elements should be embedded within the curriculum rather than expected as supplementary learning. The most significant learning gains were reported in collaborative formats, particularly group discussions and product design activities, which offered both practical relevance and opportunities for peer learning.

Finally, feedback and holistic academic growth--according to student feedback, the course contributed to meaningful gains in professional knowledge, practical skills, and teamwork abilities. This comprehensive growth reflects the effectiveness of the instructional design, which combined theory, practice, and collaboration to support well-rounded academic development.

In summary, the findings demonstrate that instructional approaches integrating industry perspectives, experiential learning, and collaborative environments can significantly enhance student engagement and learning outcomes in biotechnology education. Furthermore, attention to gender dynamics and the strategic embedding of practical experiences are essential for creating inclusive and effective educational settings.

5.2 Teaching Suggestions

In light of these findings, the researchers advocate for several pedagogical enhancements aimed at improving future instructional practices:

First, it is crucial to establish explicit connections between course content and potential career pathways, as this alignment can significantly bolster student motivation and engagement in their learning processes.

Second, to equip students for success in an increasingly globalized workforce, the introduction of diverse English-language online materials is recommended. This will not only broaden students' learning opportunities but also enhance their employability in international contexts.

Finally, a strategic shift toward prioritizing practical experiences over purely theoretical instruction is essential. By focusing on real-world insights and industry-relevant skills, educators can better prepare students for the challenges they will face in their professional lives.

By implementing these recommendations, future biotechnology courses can further amplify student engagement, improve learning outcomes, and enhance overall career readiness, ultimately contributing to the development of competent professionals in the field.

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Appendix

Problem-Based Learning (PBL) and Industry-Academia Collaboration Questionnaire

Factor 1: Enhancing Professional Competence					
1. This course is very important in the application of biotechnology.	5	4	3	2	1
2. This course enhances the ability in applying biotechnology.	5	4	3	2	1
3. This course is important for future research.	5	4	3	2	1
4. Guest lectures are helpful in increasing my interest in this course.	5	4	3	2	1
5. Information from websites is helpful in increasing my learning in this course.	5	4	3	2	1
6. I believe theoretical knowledge is more helpful for my future employment.	5	4	3	2	1
Factor 2: Enhancing Learning Motivation					
7. Industry expert practical teaching is helpful in increasing my interest in this course.	5	4	3	2	1
8. Visiting external companies is helpful in increasing my interest in this course.	5	4	3	2	1
9. Experiencing the product is helpful in increasing my interest in this course.	5	4	3	2	1

Note: 5-strongly agree; 4-agree; 3-neutral; 2-disagree; 1-strongly disagree

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Authors contributions

Dr. Chiung-Li Li and Mr. Chiyu Hsieh were responsible for study design and revising. Ms. Pei-En Hsieh was responsible for data collection. Prof. Chienyan Hsieh drafted the manuscript and

Dr. Chiung-Li Li revised it. All authors read and approved the final manuscript. All authors contributed equally to the study.

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Data sharing statement

No additional data are available.