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Artisanal Wine Production as a Linked Class Strategy for Experiential Learning in Microbiology

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Abstract– – This work presents a student-centered, interdisciplinary and international learning strategy implemented in the Microbiology course of the Environmental Engineering program at the Technological University of Bolívar (UTB), within the UTB Linked Class framework (since 2020). The activity involved artisanal wine production to provide hands-on understanding of microbial and biochemical processes in alcoholic fermentation. Students applied prior knowledge of yeast metabolism and sugar transformation into ethanol, strengthening the theory–practice connection, and evaluated the product through sensory analysis. Results from observations and surveys indicate improved learning and motivation, supporting the strategy as an active and collaborative tool for teaching microbiology.

Keywords-- alcoholic artisanal, experiential learning, Microbiology education, student-centred learning, winemaking fermentation

I. Introduction

Teaching microbiology in engineering and applied science programs faces challenges in implementing didactic strategies that aim to link theoretical knowledge with practical application in real and meaningful contexts especially given the interdisciplinary nature of these programs and the limited curricular space often allocated to biological sciences[1],[2]. Traditional lecture-based approaches have proven insufficient to promote a deep understanding and long-term retention, especially when students struggle to understand the relevance of microbiological concepts to engineering practice [3], [4] .

Active learning methods, such as problem-based learning, project-based learning and the use of case studies, have shown great potential to bridge this gap by embedding theoretical content in real-world engineering challenges, including bioengineering, environmental remediation and public health systems [5]. Moreover, the integration of laboratory experience with inquiry-based and experiential learning frameworks can improve conceptual understanding and the development of professional skills, while also increasing the motivation and commitment of students [6]. These approaches are aligned with constructivist and social constructivist teaching theories, which emphasise that knowledge is not passively received but actively constructed by learners through interaction with their environment, peers, and real-world problems. In this sense, learning is understood as a process of meaning-making, where students build conceptual understanding through inquiry, dialogue, and reflection rather than memorisation[7]. Recent research highlights that constructivist environments promote deeper cognitive engagement by encouraging students to formulate questions, test hypotheses, and collaboratively negotiate meanings, particularly in science education contexts.[8]

Consequently, within this educational framework, the Microbiology course in the environmental engineering program at the Technological University of Bolívar (UTB), Cartagena, Colombia, has implemented the *UTB Linked Class strategy* from 2020, based on a partial mirror-class model. This initiative aims to combine student's background knowledge with hands-on activities and collaborative learning dynamics to promote meaningful learning experiences. For 10 consecutive semesters, the strategy has helped to create an enriched academic environment in which students develop scientific competences by designing and implementing projects that are contextually relevant. By placing microbiological concepts in the context of real environmental engineering problems, the UTB Linked Class approach effectively bridges theory and practice, increases the student's commitment and promotes the development of transferable skills relevant for the field of practice.

In this context, the joint participation of students and faculty from two or more foreign universities in synchronized and asynchronous delivery of a full course or selected sessions, facilitated by a common digital platform, is a key mechanism for internationalizing learning processes. According to this framework, the UTB Linked Class is defined institutionally as an internationalization at home strategy that incorporates online faculty collaboration with international peers with the goal of fostering intercultural competencies and global citizenship skills in addition to reinforcing disciplinary concepts and subject-specific content. This strategy also reinforces academic networks by promoting permanent institutional partnerships to consolidate research lines and develop inter-institutional collaborative academic and research projects. (Technological University of Bolívar).

The experience of making artisanal wine, as part of the UTB Linked Class Strategy, is a pedagogically meaningful application of the experience of teaching microbiology. One of these activities involved the production of artisanal wine through alcoholic fermentation, which allowed students to directly observe the role of yeasts—particularly *Saccharomyces cerevisiae*—in the biochemical transformation of sugars into ethanol and carbon dioxide [9],[10]. This hands-on training not only reinforces basic theoretical concepts related to microbial metabolism and fermentation processes, but also stimulates scientific curiosity, enhances the appreciation of empirical knowledge and develops analytical and critical thinking skills. This article therefore aims to document this learning experience, assess its impact on the learning outcomes of students and discuss its potential as an effective didactic tool to reinforce microbiological education for future environmental engineers.

II. Materials And Methods

A. *Context and Design of the Educational Experience*

The educational experience was implemented as part of the institutional pedagogical strategy UTB Linked Class within the Microbiology course of the Environmental Engineering program. This initiative was developed in collaboration with the Instituto Tecnológico Superior del Oriente del Estado de Hidalgo (ITESA) in Mexico, fostering an environment of international and collaborative learning.

In total 32 third year students participated in this activity. This course is part of the core curriculum of applied basic science in the Engineering field. Although the group had different academic interests, all participants had prior basic knowledge of cell biology, general chemistry and basic biotechnological techniques, which facilitated the incorporation of new microbiological concepts.

The activity was designed as a partial mirror class, carried out through intensive theoretical and practical learning session. This format allowed conceptual knowledge to be articulated by meaningful experimental experience developed in a controlled and collaborative academic environment.

B. *Structure of the Intervention*

The learning experience was structured in three main stages

Stage 1: Theoretical Preparation

This stage involved a guided review of the principles of alcoholic fermentation, yeast metabolism (particularly *Saccharomyces cerevisiae*), and the biochemical conversion of sugars into ethanol, supported by readings, audiovisual materials, and a brief lecture to establish a solid conceptual foundation for the experiments.

Stage 2: Experimental Fermentation Process

The students made an artisanal wine using selected fruit (grapes or pineapples, depending on availability), sugar, water and an active dry yeast. The work was carried out in small groups and students documented the conditions of preparation, including the proportions of ingredients, the maceration time, ambient temperature, hygiene procedures and total fermentation time (7 to 10 days).

Each group kept a detailed logbook for monitoring key variables such as initial and final pH, relative density changes (measured by hydrometer), foam formation, gas production and the development of characteristic aromas.This systematic collection of data has enabled students to link observable macroscopic changes to underlying microbiological and biochemical processes.

Stage 3: Microbiological Observation and Analysis

The third stage consisted of the observation and analysis of microbiological changes during fermentation. Students observed fermentation behaviour every day, recorded indicators of microbial activity and compared these with environmental conditions. This stage was needed to establish the direct role of microorganisms in substrate transformation and to improve the dynamic character of microbial metabolism in applications in the real world.

C. *Data Collection and Evaluation of the Experience*

The educational impact was assessed using multiple data collection tools. At the end of the activity, students completed a survey on their understanding of the microbiological process and satisfaction with the teaching approach. Laboratory records were also collected, along with individual written reflections on learning outcomes, challenges, and knowledge applicability.

As a final activity, a wine tasting session was organized by a jury of faculty members and students, who selected the best samples according to criteria such as taste, presentation, labelling and clarity of the oral explanation of the production process. This final activity not only provided proof that students had taken up theoretical and practical content, but also helped to develop communication skills, argumentative thinking and critical evaluation in participants.

III. Results

A. *Observations during the Fermentation Process*

During the fermentation period (7 to 10 days) several visual and physico-chemical indicators of microbial activity were recorded systematically. In most groups of students, significant bubbles and surface foamy formation were observed from days 2 to 5, interpreted as evidence of active production of carbon dioxide (CO_2) associated with metabolic activity of the yeast.

Simultaneously, the gradual decrease in liquid density was monitored using a hydrometer. The average reduction was between 15 and 20 percentage points compared to the original values, indicating efficient conversion of fermentable sugars to ethanol. These changes helped students directly connect quantitative data with the biochemical processes involved in alcoholic fermentation.

Significant pH variations were also observed during the process. The initial pH values, which were usually near 4.2, dropped to a final range of 3.5 to 3.8. This acidification is consistent with the production of organic acids and secondary metabolites resulting from yeast metabolism [11]. In some samples, an increase in liquid turbidity was observed at the end of the fermentation process. Students associated this phenomenon with the presence of suspended microbial cells and colloidal particles, interpreting it as further evidence of sustained metabolic activity and biomass accumulation.

Overall, these observations allowed students to link macroscopic changes to underlying microbiological and biochemical processes, reinforcing conceptual understanding through direct experimental evidence. Table 1 provides a summary of the observations made throughout the fermentation process.

TABLE I
MAIN PHYSICOCHEMICAL AND VISUAL INDICATORS RECORDED DURING THE FERMENTATION PROCESS

Indicator	Initial Value	Final Value	Observed Trend	Educational Interpretation
Fermentation time	—	7–10 days	Stable	Adequate time for yeast metabolic activity
Bubble and foam formation	Absent	High (days 2–5)	Increase → decrease	Evidence of active CO_2 production
Relative density	100% (reference)	80–85%	Decrease (15–20%)	Conversion of sugars into ethanol
pH	~4.2	3.5–3.8	Decrease	Formation of organic acids
Turbidity	Low	Moderate–high	Increase	Suspension of yeast cells and metabolites

B. Survey Results

Following the completion of the activity, a post-experience survey was administered, consisting of both closed- and open-ended questions, to assess the impact of the intervention on student learning. The results indicated significant improvements across all assessed indicators compared to students' self-reported perceptions prior to the activity.

The percentage of students who demonstrated adequate understanding of yeast's role in fermentation went from 41 percent before the intervention to 92 percent after. Similarly, the proportion of students reporting the ability to explain the biochemical process of alcoholic fermentation increased from 35% to 88%. These findings suggest significant increases in conceptual understanding associated with the experiential learning approach.

The proportion of students recognizing experimental work as an effective learning strategy showed a notable increase, from 62% to 95%. Recognition of the relevance of microbiology in industrial processes increased from 48% to 90%, highlighting the effectiveness of the activity in contextualizing microbiological concepts within real-world applications. The proportion of students reporting motivation to complete the course increased from 60% prior to the experience to 93% following it. Table 2 and Figure 1 provide a summary of the comparison between students' self-reported learning outcomes prior to and following the intervention.

TABLE 2
SELF-REPORTED LEARNING OUTCOMES BEFORE AND AFTER THE INTERVENTION

Evaluated Indicator	Before Activity (%)	After Activity (%)	Gain (%)
Understanding the role of yeasts in fermentation	41	92	+51
Ability to explain biochemical fermentation pathways	35	88	+53
Valuation of experimental work as a learning method	62	95	+33
Recognition of microbiology in industrial processes	48	90	+42
Motivation toward the course	60	93	+33

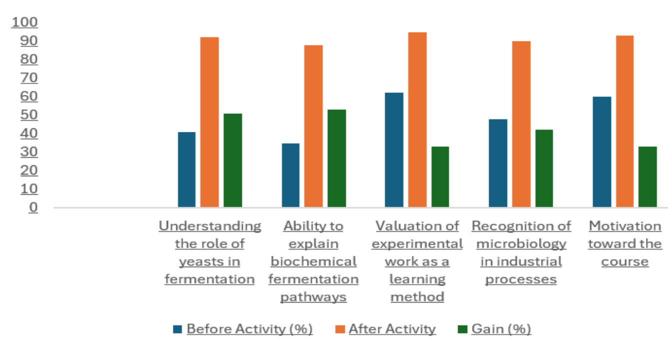

Figure 1. Comparison of Self-Reported Learning Outcomes Before and After the Intervention.

C. Student Reflections and Qualitative Evidence of Learning

Apart from the quantitative data of the survey, qualitative evidence was obtained from individual written comments. A qualitative analysis of open-ended responses and individual reflections showed that students particularly appreciated the opportunity to observe microbiological phenomena in a concrete and practical context. Many highlighted the integration of theory and practice as a key factor in improving their understanding, while others stressed the collaborative nature of the activities and their contribution to the development of analytical, observational and critical thinking skills.

Several students emphasized that this type of hands-on experience should be more frequently integrated into the curriculum, highlighting its value in promoting knowledge appropriation through practical, participatory, and contextualized learning. Such reflections indicate that the activity fostered not only cognitive gains but also positive affective and motivational responses toward microbiology as a discipline. See table 3.

These statements illustrate a transition from abstract conceptualisation toward an experience-based form of understanding

TABLE III
REPRESENTATIVE CATEGORIES EMERGING FROM QUALITATIVE ANALYSIS OF STUDENTS REFLECTIONS

Category	**Representative Student Statements**	**Educational Interpretation**
Experiential understanding	“Seeing microbiology in action”	Learning through direct observation
Relevance to daily life	“Microorganisms are part of everyday processes”	Contextualization of scientific knowledge
Theory–practice integration	“What we studied became real”	Meaningful learning
Curriculum relevance	“These activities should be more frequent”	Positive perception of active methodologies

D. Interpretative Synthesis of Results

Taken together, the quantitative and qualitative data reveal a significant shift in students’ understanding and valuation of microbiology as an applied science. Beyond reinforcing technical knowledge related to alcoholic fermentation, the experience promoted a deeper integration of microbiological concepts with authentic engineering contexts, enabling students to transition from abstract theoretical representations to a more situated, functional, and experience-based understanding. These outcomes align with the principles of active learning, as the intervention—centered on artisanal wine production—required students to directly engage with microbiological processes, thereby facilitating knowledge construction through observation, experimentation, and reflection[12].

Importantly, these findings support the effectiveness of active, hands-on pedagogical strategies in science education, particularly for non-microbiology majors, for whom disciplinary relevance and contextualization are often critical for meaningful learning[13]. The intervention not only strengthened conceptual comprehension related to fermentation and microbial activity but also fostered increased motivation, academic engagement, and participatory involvement. Students reported a heightened perception of the relevance of microbiology within engineering and industrial contexts, recognizing its applications in biotechnological, food, and production systems. Collectively, these results suggest that experiential and context-based approaches, such as the linked-class strategy implemented in this study, enhance cognitive learning outcomes while simultaneously promoting positive affective and motivational responses—factors that are essential for sustained engagement and the development of transferable scientific understanding in microbiology education[14].

IV. DISCUSSION

The experience of artisanal wine production, carried out under the UTB Linked Class Strategy, revealed several pedagogical advantages of using active and hands-on methods in microbiological education. One of the most important findings was a significant improvement in the students' understanding of fermentation and microbial metabolism, as demonstrated by both the results of the quantitative survey and the qualitative reflection narratives. These data show that direct exposure to fermentation processes allowed students to consolidate basic microbiological concepts while linking metabolic pathways to observable results in a validated application context.

This type of practice effectively addresses the well-documented limitations of traditional, lecture-based instruction by allowing students to directly observe and experience biological processes as they unfold in real time[15]. Visualizing phenomena such as gas formation, changes in pH and density, and the development of fermentation aromas transforms the classroom into a living laboratory, fostering deeper and more enduring learning. These outcomes align with constructivist and experiential learning theories, which emphasize the central role of direct experience and reflective processes in meaningful learning[16], [17].

The creation of a final product that could be assessed both sensorially and scientifically significantly increased the motivation and emotional involvement of students in the learning process. The opportunity to observe, analyze, and ultimately assess the tangible results of their work fostered a sense of ownership and personal investment in the activity, reinforcing students' commitment to the learning tasks. These affective dimensions—motivation, engagement, and emotional involvement—are widely recognized as key factors that positively influence learning outcomes in science education, as they support sustained attention, deeper cognitive processing, and meaningful knowledge construction [18]. Consequently, the integration of assessment and experience components in the activity not only enhanced conceptual understanding but also contributed to a more holistic and motivating learning experience.

This intervention confirms previous studies involving fermentation-based education projects (e.g. bread making, yogurt production, microbial fuel cells) that working with microorganisms in an authentic context is easier to adopt, especially in programmes not specifically focused on biological science [19], [20], [21]. In addition, the integration of microbiology into every day and industrial applications - such as the production of food and beverages - reinforces its societal and professional relevance.

Finally, the results suggest that experience-based microbiological activities should not only be maintained but also extended to the core science courses with cross-disciplinary focus in order to strengthen the comprehensive training of future engineers and applied scientists.

V. CONCLUSSIONS AND RECOMMENDATIONS

The implementation of artisanal wine production as a pedagogical strategy within the Microbiology course of the Environmental Engineering program at the Technological University of Bolívar proved to be a highly meaningful and effective educational experience. The activity successfully fulfilled its central objective by linking theoretical concepts related to alcoholic fermentation and microbial metabolism with a practical, tangible, and contextually relevant application. Through direct engagement with real fermentation processes, students were able to move beyond abstract representations and develop a more functional and experience-based understanding of microbiology as an applied science.

A substantial improvement was observed in students' comprehension of key microbiological processes, as well as in their ability to explain complex biochemical and metabolic phenomena using scientifically grounded reasoning. These cognitive gains were complemented by significant increases in student motivation, emotional engagement, and academic involvement, contributing to the creation of an active, collaborative, and learner-centered educational environment. The integration of hands-on experimentation, sensory evaluation, and reflective activities promoted deeper learning while also fostering transversal competencies such as teamwork, systematic observation, data recording, and scientific communication.

Furthermore, the UTB Linked Class strategy, grounded in a partial mirror-class model, demonstrated its effectiveness as a framework for structuring intensive experiential learning experiences that encourage participation, critical reflection, and scientific inquiry. The sustained implementation of this activity over ten consecutive semesters provides evidence of its pedagogical relevance, feasibility, and adaptability within higher education contexts. Taken together, these findings support the value of experiential and context-based instructional approaches for enhancing both cognitive and affective learning outcomes in microbiology education, particularly for non-biology majors, and highlight the potential of linked-class strategies as scalable models for innovation in science teaching.

Recommendations

1. **Scalability:** Replicate this type of experiential activity in related courses (e.g., Biotechnology, Environmental Chemistry, Process Engineering), adapting content to specific disciplinary goals.

2. **Enhanced experimental monitoring:** Incorporate more precise measurement tools (e.g., refractometers, digital thermometers, CO_2 sensors) to strengthen quantitative analysis.

3. **Interdisciplinary integration:** tie the work to areas such as environmental management, circular economy or sensory analysis, to extend its pedagogical relevance.

4. **Academic dissemination:** Promote the presentation of results in science fairs, academic conferences, poster sessions, and student-led publications. This practice strengthens students' scientific communication skills.

5. **Continuous assessment:** Implement diagnostic, formative, and summative assessment instruments to enable a more rigorous and systematic evaluation of learning outcomes and competency development.

6. **International and collaborative strengthening:** Expanding the linked classes model by involving additional partner institutions and fostering continuous student interaction through joint projects and co-authored publications to enhance intercultural and collaborative skills in scientific practice.

This experience confirms that practice-oriented microbiology instruction, grounded in engagement with real-world problems and authentic natural processes, facilitates the comprehension of complex scientific content while promoting deeper conceptual understanding and the construction of meaningful scientific knowledge[22],[23]. Moreover, this approach supports the development of professionals with strengthened critical thinking skills, scientific curiosity, and disciplinary engagement, as students are systematically encouraged to question, analyse, and interpret biological phenomena within relevant applied contexts. Practice-based microbiology instruction promotes active participation, reflective thinking, and sustained motivation, thereby contributing to the formation of professionals capable of integrating scientific knowledge with problem-solving competencies and evidence-informed decision-making in engineering contexts[24].

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