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Innovative Educational Strategies: Integrating Problem-Based Learning and Cross-Cultural Collaboration in Biotechnology Engineering

Danay Carrillo-Nieves, PhD.[1]
[1] Tecnologico de Monterrey, Escuela de Ingeniería y Ciencias, Av. General Ramón Corona 2514, Nuevo México, Zapopan, Jalisco, Mexico, danay.carrillo@tec.mx

Abstract*–This article explores the implementation of the Tec21 educational model within the Biotechnology Engineering curriculum at Tecnologico de Monterrey, Mexico. The model emphasizes challenge-based learning, personalized instruction, and the integration of global perspectives to equip students with competencies for addressing contemporary challenges in bioprocess engineering. Collaborative initiatives like the Global Shared Learning Classroom (GSLC) program enable cross-cultural collaboration and practical simulations to enhance learning experiences. Innovative teaching methods include hands-on simulations with tools like Super Pro Designer and the creation of scientific outreach podcasts. Personalized interviews and surveys provide valuable feedback for continuous improvement. This article underscores the significance of innovative educational approaches in preparing students to excel in the field of biotechnology engineering and beyond.

Keywords-- TEC21, Higher education, educational innovation, Global Shared Learning Classroom.

I. Introduction

In today's rapidly evolving educational landscape, institutions worldwide are grappling with the challenge of equipping students with the skills and competencies necessary to navigate an increasingly complex world. Tecnologico de Monterrey stands as a beacon of educational excellence in Mexico, embodying the values of innovation, diversity, and academic rigor. As a leading private, non-profit university, Tecnologico de Monterrey boasts a widespread presence across the Mexican territory, with campuses spanning the majority of states in the Republic. Its educational offerings encompass a diverse array of academic programs, ranging from high school to graduate studies.

At the undergraduate level, Tecnologico de Monterrey offers a comprehensive selection of academic disciplines, including Engineering, Information Technologies, Business, Humanities and Social Sciences, Architecture, Art and Design, and Health Sciences. Notably, it ranks among the top 50 private universities globally and holds the prestigious position as Mexico's premier private institution according to the QS World University Ranking. The university's commitment to innovation is further underscored by its impressive record of patent registrations over the past five years.

In the face of contemporary challenges, such as globalization, rapid technological advancements, societal scrutiny of higher education's value proposition, and evolving demands in the job market, institutions of higher education are undergoing transformative shifts. This paradigm shift necessitates the development of new educational models tailored to meet the needs of today's students, equipping them with the competencies essential for navigating the complexities of the modern world.

As educational institutions adapt to meet the demands of the 21st century, Tecnologico de Monterrey stands at the forefront of educational innovation, poised to shape the future of higher education and empower students to thrive in an ever-changing landscape. Through its commitment to excellence, research, and student-centered learning, Tecnologico de Monterrey remains dedicated to preparing the next generation of leaders, innovators, and global citizens.

At the forefront of this educational revolution stands Tecnologico de Monterrey, renowned for its innovative TEC 21 model—a pioneering framework designed to cultivate robust and comprehensive competencies essential for tackling both present-day challenges and those on the horizon [1].

The TEC 21 model represents a paradigm shift in education, characterized by its emphasis on challenge-based learning and the development of creative and strategic problem-solving abilities. What sets it apart is its foundation on four fundamental pillars: Challenge-Based Learning, Personalization and Flexibility, Inspirational Faculty, and Memorable Experiences. At its core, the model seeks to empower students to confront real-world issues head-on, fostering a mindset of resilience and adaptability [2].

The Tec21 Educational Model reimagines undergraduate learning as a dynamic process anchored in the student-teacher relationship and enriched by immersive engagement with the surrounding environment. Within this model, students cultivate both discipline-specific and cross-cutting competencies through the resolution of real-world challenges, serving as the cornerstone of their academic journey.

Central to the Tec21 paradigm are the challenges, experiential learning opportunities meticulously designed to immerse students in complex real-world scenarios aimed at achieving specific learning objectives. Challenges serve as catalysts for the development of disciplinary and transversal competencies, encouraging students to apply their knowledge, skills, attitudes, and values both individually and collaboratively.

The Tec21 Educational Model propels students towards mastery by embracing challenges as the cornerstone of learning, nurturing a culture of critical thinking, problem-solving, and innovation. Through this transformative approach, students emerge not only as adept practitioners within their respective disciplines, but also as agile thinkers equipped to navigate the multifaceted challenges of the modern world.

The 15-week course "Prospection of Bioprocesses," is divided into three distinct periods of five weeks each, where students are immersed within an immersive learning environment, by a central problem situation that serves as the focal point of their exploration. Students delve into the design, performance, and scale-up of a unit operations train for the production and purification of a bacterial-derived biopolymer—a sustainable and biodegradable alternative to traditional plastics. Students, organized into teams of 3-4, climb on a collaborative journey to address this multifaceted challenge, drawing upon their collective expertise and ingenuity to propose innovative solutions.

Throughout the course, students are guided by a comprehensive set of competencies aimed at cultivating a holistic understanding of bioprocess prospecting while honing essential skills for the challenges of tomorrow.

A. Central to this endeavor is the acquisition of competencies such as:

1) Evaluating the Design and Performance of Bioreactors: Students engage in rigorous analysis, utilizing mathematical models and information technologies to optimize bioreactor design and performance.

2) Diagnosing Engineering Design Considerations: With a keen focus on technical, innovative, bioethical, and sustainability aspects, students diagnose the engineering design of bioreactors, fostering critical thinking and ethical decision-making.

3) Developing Dimensioning and Scaling of Unit Operations: Through practical application, students master the intricacies of dimensioning and scaling unit operations in bioseparation, equipping them with invaluable engineering acumen.

Additionally, as a pivotal cross-cutting competency, students are encouraged to:

4) Fostering effective collaboration and negotiation within multicultural contexts. Emphasizing respect and appreciation for the diversity of perspectives, knowledge, and cultures, this skillset prepares students to thrive in an interconnected global landscape.

Navigating the complexities of bioprocess prospecting, these competencies serve as guiding beacons, empowering students to confront challenges with confidence and resilience.

Furthermore, this study aims to address the pressing need for innovative educational approaches within the Biotechnology Engineering curriculum by presenting the implementation of the Tec21 educational model, which effectively tackles real-world challenges through a combination of challenge-based learning, intercultural collaboration, and practical simulations; equipping them with the skills necessary to thrive in a globally interconnected world.

II. Materials and Methods

A. Framework of the TEC21 educational model and characteristics of the course

Innovation stands as a core institutional value at Tecnológico de Monterrey, embodying a commitment to idea generation, paradigm-shifting initiatives, and the transformation of concepts into tangible realities. At the heart of this ethos lies a willingness to embrace risks, learn from failures, and seize opportunities to effect positive change. Within the framework of the Tec21 Educational Model, educational innovation permeates both curricular programs and pedagogical practices, catalyzing transformative learning experiences. Tec21, an educational model introduced by Tecnologico de Monterrey in 2019, emphasizes customization of students' professional profiles to encompass a broader range of competencies, as outlined in their portfolio of solutions to challenges upon graduation [3]. The Challenge-Based Learning approach, structured into Exploration, Focus, and Specialization stages, engages students from their initial semester. Throughout their academic journey, students tackle challenges and cultivate competencies spanning knowledge, skills, attitudes, and values [4].

The Prospection of Bioprocesses course, situated within the Focus Stage of the Tec21 model and scheduled for the sixth semester of the Biotechnology Engineering program, offers students a comprehensive exploration of biotechnological processes. During the initial period of the course, students are actively engaged in research activities and practical exercises under the guidance of their instructor. These activities entail an in-depth review of the problem situation concerning environmental pollution caused by fossil-derived plastics. Drawing from their research insights, students are tasked with selecting a specific bioprocess aimed at developing a microbial-derived bioplastic.

Concurrently, students receive structured instruction on bioreactors while gaining a broad overview of various biotechnological processes. The learning assessment strategy encompasses a range of practical activities, collaborative team assignments, and a midterm examination, all of which contribute to the comprehensive evaluation of student progress throughout the first five weeks of the course. Through this multifaceted approach, students are not only equipped with theoretical knowledge but also afforded ample opportunities to apply their learning in practical contexts, fostering a deeper understanding of bioprocess prospecting principles and their real-world applications.

During the second 5-week period, an international collaborative activity is introduced, wherein students participate in a Global Shared Learning Classroom (GSLC) initiative. GSLC facilitates partial course linkages between Tecnologico de Monterrey and partner institutions abroad, fostering cross-cultural exchanges and distance learning opportunities [5]. This program aims to enhance the depth of learning by providing students with exposure to diverse perspectives and methodologies from different educational contexts. Through GSLC, students engage in collaborative projects, discussions, and joint assignments, enriching their educational experience and promoting global awareness and connectivity. Integration activities are conducted among students from different universities, coupled with a learning activity related to the problem situation.

During the final period, engineering tools are incorporated to support the comprehensive education of engineering students. Professional simulator like SuperPro Designer® Version 12 (Intelligen, Inc., Scotch Plains, NJ, USA) is introduced to simulate an entire biotechnological process [6], encompassing unit operations for the production and purification of a bacterial-derived biopolymer. This process includes synthesizing the biopolymer in a bioreactor, concentrating, and purifying the bioproduct, and concluding with a technical-economic and environmental analysis of the bioprocess. By integrating these engineering tools, students gain practical experience in applying theoretical knowledge to real-world scenarios, preparing them for the challenges of their future careers in biotechnology.

The instructor of this course, as one of the fundamental pillars of Tec 21 model, should possess a blend of academic expertise and practical experience in biotechnological engineering and environmental management to effectively guide students through the research activities and practical exercises outlined in the course. Furthermore, the instructor must be capable of fostering a collaborative and supportive learning environment where students feel motivated to actively participate and develop their problem-solving, critical thinking, and teamwork skills.

In each implementation of the TEC 21 model, which commenced in 2019, educators have been consistently enhancing the course through educational innovations based on student surveys from previous courses. In this course, two new activities, the GSLC methodology and the podcast activity, were introduced, reflecting ongoing refinement and adaptation to meet evolving educational needs.

III. RESULTS

In the bioprocess prospecting course, students were challenged to find innovative solutions to replace fossil-derived plastics with more sustainable bioplastics. To address this issue, the instructor designed a practical project that integrated the development of technical skills, teamwork, and in-class interaction.

The project began with an initial session where the instructor introduced the problem to the students and provided information about different types of bioplastics and the biotechnological processes associated with their production. Then, students were divided into teams and tasked with researching and selecting a specific biotechnological process for bioplastic production.

Over the following weeks, the teams worked together to conduct in-depth research on the selected process, using engineering tools as SuperPro Designer, to analyze its technical and economic feasibility. During this time, the instructor acted as a guide and facilitator, offering guidance and support as students explored creative solutions and developed their problem-solving and critical thinking skills.

As the project progressed, teams delivered regular presentations in class to share their findings, discuss their ideas, and receive feedback from both their peers and the instructor. This in-class interaction fostered collaboration among students and strengthened the relationship between them and the instructor as they worked together to address the challenges posed by the project.

At the end of the course, teams presented their bioplastic production process proposals to a panel of experts, including professors from other universities who were collaborating on the GSLC initiative. This experience provided students with the opportunity to demonstrate their developed skills and receive constructive feedback from experts in the field.

The evaluation plan encompasses a numerical weighting between learning activities and evidence that substantiates the level of competency acquisition by the student. The evidences of all courses are integrated into a portfolio validating the competencies attained in their training as biotechnology engineers.

The numerical weighting is divided as follows: 45% of the assessment pertains to learning activities such as in-class assignments, teamwork activities addressing the problem situation, partial exams, and GSLC involvement. The remaining 55% corresponds to individual evidence submissions required from the student to validate their competencies. This structured evaluation framework ensures a comprehensive assessment of student learning outcomes while emphasizing both collaborative engagement and individual proficiency development.

The level of student satisfaction with the course was assessed using the MUSIC® Model of Academic Motivation Inventory (MUSIC® Inventory) [7], a questionnaire designed to evaluate students' perceptions of the five components comprising the motivational climate within a course. This instrument provided valuable insights into students' attitudes, motivations, and overall engagement with the educational experience. By examining factors such as enjoyment, value, effort, control, and relevance, the MUSIC® Inventory facilitated a comprehensive understanding of the learning environment and its impact on student motivation and academic performance.

The results obtained from the survey to measure course satisfaction using the MUSIC® Model of Motivation were quite compelling. The survey tool comprised 19 questions, see table 1, which involved 25 students, aimed to evaluate two key variables: "academic performance" and "motivation." Respondents were required to rate each item on a scale from 1 to 6, with 1 indicating "strongly disagree" and 6 indicating "strongly agree".

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TABLE I

#	Questionary
1	I had the freedom to complete the activity my own way.
2	I had options in how to achieve the goals of the activity.
3	I had control over how I learned the activity content.
4	I had flexibility in what I was allowed to do in this activity.
5	In general, the activity was useful to me.
6	The activity was beneficial to me.
7	I found the activity to be relevant to my future.
8	The knowledge I gained in this activity is important for my future.
9	I was confident that I could succeed in the activity.
10	I felt that I could be successful in meeting the academic challenges in this activity.
11	I was capable of getting a high grade in this activity.
12	Throughout the activity, I felt that I could be successful on the coursework.
13	The instructional methods used in this activity held my attention.
14	I enjoyed the instructional methods used in this activity.
15	The instructional methods engaged me in the course.
16	The instructor was willing to assist me if I needed help in the activity.
17	The instructor cared about how well I did in this activity.
18	The instructor was respectful of me.
19	The instructor was friendly.

The outcomes of the survey revealed high levels of satisfaction across all questions (refer to Fig. 1), indicating that students demonstrated a strong sense of motivation throughout the course. This robust motivation likely contributed significantly to the overall success of the collaborative efforts.

Personalized interviews were conducted with students of the course to assess their level of satisfaction with the activities undertaken. Additionally, students were asked to rank the activities based on their preference order. This qualitative approach provided valuable insights into the individual perspectives and preferences of the students regarding the course activities. To gain deeper insights into the students' perspectives and experiences with the course, personalized interviews were conducted.

The interviews aimed to explore various aspects of the course, including satisfaction with the activities, perceived strengths and weaknesses, and suggestions for improvement. Each interview was structured around the following key areas:

Overall Satisfaction: Students were asked to reflect on their overall satisfaction with the course, highlighting aspects they found particularly engaging or challenging.

Activity Evaluation: Participants were invited to provide feedback on specific course activities, discussing their level of enjoyment, relevance, and perceived effectiveness.

Ranking of Activities: Students were tasked with ranking the course activities based on their preference order, shedding light on the activities that resonated most with them and those they found less engaging.

Suggestions for Improvement: Lastly, students were encouraged to offer suggestions for enhancing the course content, delivery methods, and overall learning experience.

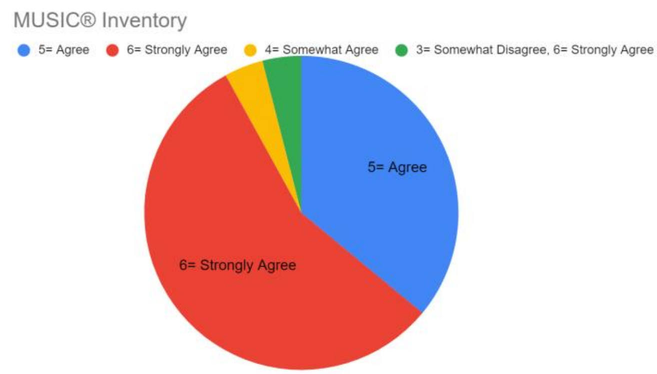

Fig. 1 Survey of Students' Perceptions on Prospection of Bioprocesses course

Among the 25 surveyed students, 80% expressed high satisfaction with the collaborative GSLC activity, citing the opportunity to interact with students from other cultures and tackle solutions from global perspectives.

The implementation of the GSLC methodology yielded significant outcomes, reflecting the effectiveness of our educational innovation project. Through a comprehensive evaluation framework, we assessed various aspects of student engagement, learning outcomes, and collaborative experiences.

The GSLC methodology facilitated the cultivation of essential cross-cutting skills among participating students. Students demonstrated proficiency in navigating diverse cultural contexts, engaging in critical analysis, and effectively collaborating with peers from different backgrounds.

The centerpiece of the GSLC approach was the execution of multicultural collaborative projects. Students actively participated in real-world challenges, such as bioplastic production and bioreactor design, leveraging their interdisciplinary knowledge and problem-solving skills. The collaborative nature of these projects fostered a sense of shared responsibility and collective achievement among students.

Reflective exercises played a pivotal role in deepening student learning and insights. Through structured reflection, students critically evaluated their experiences, identified areas for growth, and articulated the broader implications of their collaborative efforts. These reflective practices enriched the learning process, enabling students to integrate theoretical concepts with practical applications effectively.

Similarly, 70% of participants found the simulation activity challenging but ultimately rewarding, as it allowed them to integrate their knowledge and feel like practicing engineers.

Engaging in simulations that closely mimic professional scenarios not only enhances students' problem-solving abilities but also prepares them for the complexities they will encounter in their future careers.

Moreover, the perception of challenge indicates that students had prompted them to explore new concepts, experiment with different approaches, and confront potential setbacks. This aspect of challenge is intrinsic to the learning process, as it encourages intellectual curiosity, resilience, and perseverance in the face of adversity. The rewarding nature of the simulation activity suggests that students derived substantial benefits from their engagement. The sense of accomplishment and fulfillment experienced by participants signifies more than just academic achievement; it reflects the intrinsic satisfaction derived from overcoming obstacles, applying theoretical knowledge in practical contexts, and witnessing tangible outcomes of their efforts.

Students were able to refine their problem-solving skills, hone their decision-making abilities, and gain insights into the complexities of professional practice.

Moreover, 60% of students reported that the podcast activity provided a unique opportunity to build self-confidence and overcome public speaking fears. In this activity, students worked in teams to produce a scientific outreach podcast discussing a case of applying a separation process. The goal was to explain, in an engaging and original manner, how a separation process is conducted in a scientific context. The podcast was aimed at professionals with a general interest in science, not necessarily in biotechnology.

Public speaking anxiety is a common challenge faced by students across disciplines, and providing structured opportunities for students to engage in public communication can be instrumental in fostering self-assurance and communication skills.

The collaborative nature of the podcast activity further accentuates its value in cultivating interpersonal skills and teamwork. By working in teams to produce a scientific outreach podcast, students were not only tasked with researching and presenting technical information but also with coordinating ideas, sharing responsibilities, and leveraging each other's strengths. This collaborative dynamic not only enriched the learning experience but also mirrored real-world professional settings where teamwork and effective communication are paramount.

While the use of Super Pro Designer for simulating entire bioprocesses was challenging for some, 40% of participants expressed a desire for further integration of such practical simulations. Despite initial difficulties, students recognized the value of hands-on experiences with simulation software like Super Pro Designer to enhance their understanding of bioprocess engineering principles and real-world applications. They suggested additional support and guidance to facilitate smoother engagement with these simulation tools in future coursework.

One of the significant advantages of Super Pro Designer highlighted by students is its comprehensive approach, which goes beyond technical analysis to encompass economic and environmental parameters. This holistic simulation capability offers students more understanding of bioprocess engineering by contextualizing technical decisions within broader economic and environmental considerations. By simulating the economic and environmental impacts of bioprocesses, students are better equipped to evaluate the sustainability and feasibility of bioprocess designs in real-world scenarios.

Providing structured training sessions, tutorial materials, and ongoing mentorship can help alleviate initial barriers and empower students to leverage simulation software effectively in their coursework. Moreover, integrating simulation exercises into the curriculum in a progressive manner, starting with basic concepts and gradually advancing to more complex simulations, can enhance student confidence and proficiency in using simulation tools.

IV. CONCLUSIONS

The implementation of the Tec21 educational model within the Biotechnology Engineering curriculum has yielded significant insights into enhancing student learning experiences and outcomes. Through a combination of challenge-based learning, cross-cultural collaboration, and practical simulations, students have been able to develop a comprehensive set of competencies essential for addressing contemporary challenges in bioprocess engineering and beyond.

The utilization of innovative teaching methods, such as collaborative GSLC initiatives, hands-on simulations with tools like Super Pro Designer, and the creation of scientific outreach podcasts, has provided students with valuable opportunities to apply theoretical knowledge to real-world scenarios. While some activities posed initial challenges, such as the simulation of entire bioprocesses, and the development of podcasts, students recognized the immense value of these experiences in fostering deeper understanding and skill development.

Personalized interviews and surveys have provided valuable feedback for continuous improvement, highlighting areas of strength and areas for enhancement in the course curriculum. Students' suggestions for incorporating more practical simulations, computational problem-solving tasks, and opportunities for creative expression through podcasting underscore the importance of providing diverse learning experiences tailored to the needs and preferences of learners.

The innovative educational approaches explored in this study have demonstrated their effectiveness in equipping students with the skills, knowledge, and confidence necessary to excel in the dynamic field of biotechnology engineering. Moving forward, continued efforts to integrate experiential learning, cross-cultural collaboration, and technology-enhanced instruction, including podcast creation, will further enrich the educational experience and prepare students to meet the evolving demands of the biotechnology industry and beyond.

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