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Innovation in Education a Project Based Learning Implemented in Engineering using Global Classroom Methodology

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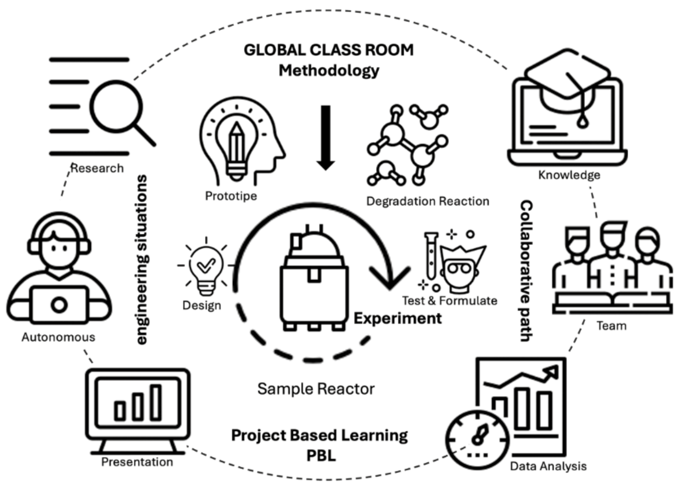
Graphical abstract



Abstract

Nowadays, strategies have been developed to enable online international and multicultural collaboration experiences. The Global Classroom (GC) project represents an advanced educational strategy that promotes international online collaboration. This experience brought together students of Biotechnology Engineering from the Tecnológico de Monterrey in Mexico with students of Chemical Engineering from the Universidad EAN in Colombia. These groups participated jointly in the Analytical Chemistry with Product and Process Design courses during the semesters from August to December 2020 and from February to June 2021, in two cohorts. At the heart of this collaboration was the implementation of online Project-Based Learning (PBL), designed to deepen students' intercultural and technical educational experience. The core project involved an experimental study of the heat of reaction in the decomposition of hydrogen peroxide using an enzyme extracted from avocados at different stages of ripening. To evaluate the effectiveness of the GC program, three evaluation instruments were used: written reports, oral presentations, and anonymous surveys. The results of this assessment indicated a notable enrichment in several key competencies. Among them, teamwork stood out, where students learned to collaborate effectively despite cultural and location differences; problem-solving, encouraged by the challenging nature of the projects; and the exchange of ideas, which was enhanced by the diversity of perspectives and academic contexts. In addition, students showed an increase in the acquisition of new knowledge, successfully applied what they learned in previous scenarios, and optimized the use of computational and digital tools.

***Keywords:** Global classroom; Online project-based learning; Engineering; Educational innovation; Prototype design.*

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Innovación en Educación: un aprendizaje basado en proyectos implementados en ingeniería utilizando la metodología Global Classroom

Resumen

Actualmente se han desarrollado estrategias que permiten vivir una experiencia de colaboración internacional y multicultural en línea. El proyecto Global Classroom (GC) representa una avanzada estrategia educativa que promueve la colaboración internacional en línea. Esta experiencia unió a estudiantes de Ingeniería en Biotecnología del Tecnológico de Monterrey en México con estudiantes de Ingeniería Química de la Universidad EAN en Colombia. Estos grupos participaron conjuntamente en los cursos de Química Analítica con Diseño de Productos y Procesos durante los semestres de agosto a diciembre de 2020 y de febrero a junio de 2021, en dos cohortes. En el corazón de esta colaboración se implementó el Aprendizaje Basado en Proyectos (ABP) en línea, diseñado para profundizar en la experiencia educativa intercultural y técnica de los estudiantes. El proyecto central involucró el estudio experimental del calor de reacción en la descomposición del peróxido de hidrógeno utilizando una enzima extraída de aguacates en distintos estados de maduración. Para evaluar la efectividad del programa GC, se utilizaron tres instrumentos de evaluación: reportes escritos, presentaciones orales y encuestas anónimas. Los resultados de esta evaluación indicaron un enriquecimiento notable en varias competencias clave. Entre ellas, destacaron el trabajo en equipo, donde los estudiantes aprendieron a colaborar de manera efectiva a pesar de las diferencias culturales y de ubicación; la resolución de problemas, fomentada por la naturaleza desafiante de los proyectos; y el intercambio de ideas, que se vio potenciado por la diversidad de perspectivas y contextos académicos. Además, los estudiantes mostraron un incremento en la adquisición de nuevo conocimiento, aplicaron exitosamente lo aprendido en escenarios previos y optimizaron el uso de herramientas computacionales y digitales.

***Palabras clave**: Global classroom; Aprendizaje basado en proyectos en línea; Ingeniería; Innovación educativa; Diseño de prototipos.*

Inovação na Educação: aprendizagem baseada em projetos implementada em engenharia usando a metodologia Global Classroom

Resumo

Atualmente, foram desenvolvidas estratégias que permitem viver uma experiência de colaboração internacional e multicultural online. O projeto Global Classroom (GC) representa uma estratégia educacional avançada que promove a colaboração internacional on-line. Esta experiência uniu estudantes de Engenharia Biotecnológica do Tecnológico de Monterrey, no México, com estudantes de Engenharia Química da Universidad EAN, na Colômbia. Esses grupos participaram conjuntamente dos cursos de Química Analítica com Design de Produto e Processo durante os semestres de agosto a dezembro de 2020 e de fevereiro a junho de 2021, em duas turmas. No centro desta colaboração foi implementada a Aprendizagem Baseada em Projetos (PBL) online, concebida para aprofundar a experiência educacional intercultural e técnica dos alunos. O projeto principal consistiu no estudo experimental do calor de reação na decomposição do peróxido de hidrogênio utilizando uma enzima extraída de abacates em diferentes estágios de maturação. Para avaliar a eficácia do programa de GC, foram utilizados três instrumentos de avaliação: relatórios escritos, apresentações orais e pesquisas anônimas. Os resultados desta avaliação indicaram um enriquecimento notável em diversas competências-chave. Entre eles, destacou-se o trabalho em equipe, onde os alunos aprenderam a colaborar de forma eficaz apesar das diferenças culturais e de localização; resolução de problemas, incentivada pelo caráter desafiador dos projetos; e a troca de ideias, que foi potencializada pela diversidade de perspectivas e contextos acadêmicos. Além disso, os alunos demonstraram aumento na aquisição de novos conhecimentos, aplicaram com sucesso o que aprenderam em cenários anteriores e otimizaram o uso de ferramentas computacionais e digitais.

***Palavras*-chave:** *Global Classroom; Aprendizagem baseada em projetos on-line; Engenharia; Inovação Educativa; Projeto de protótipo.*

Introduction

Interactions and collaborative tasks are increasingly used around the world. On the other hand, it has been observed that these influence students' perceptions of cultural diversity and their ability to work in multidisciplinary and multicultural environments. The importance of strengthening technical and academic skills, from the Global Classroom, fosters a greater understanding and appreciation of cultural differences, preparing students to be competent global professionals in an increasingly interconnected labor market. In the 21st century, university students are increasingly aware of their role as responsible and proactive citizens of their country and the world. As a result, the development of internationalization and multicultural skills has become a critical requirement [1-3]. To meet this need, Tecnológico de Monterrey, through the Office of the Vice-Rector, has implemented the Global Classroom (GC) experience, which connects its students and professors with foreign universities in a digital environment using advanced technological tools [4]. This study explores the implementation of the Global Classroom (GC) experience between Mexico and Colombia, using the online Project-Based Learning (PBL) didactic technique. The collaboration took place during the August-December 2020 (AD20) and February-June 2021 (FJ21) semesters, involving students enrolled in the Analytical Chemistry courses of the Biotechnology Engineering degree at Tecnológico de Monterrey (Mexico), and Design of Products and Processes courses of the Chemical Engineering degree at EAN University (Colombia). Graphical abstract represents the methodology of the "Global Classroom" under the framework of Project Based Learning (PBL). It illustrates various stages and components of a collaborative educational process that includes both individual and team activities.

The main objective of this case study was to assess the efficacy of the multicultural, international, and interdisciplinary learning experience offered by the GC program. Specifically, the study sought to evaluate the impact of online Problem-Based Learning (PBL) on engineering students. By examining this, the research aims to shed light on the GC program's capacity to foster cross-cultural collaboration and enhance the development of students' interdisciplinary skills.

Development

Theoretical framework

In today's interconnected world, the emphasis on inclusivity and diversity is more pronounced than ever before, underlining the necessity for cultural competency, global citizenship, and related skills within the education framework, especially for future engineers. These competencies are not merely supplementary but are central to preparing students to engage productively with diverse cultures and to craft innovative solutions to complex global challenges. Consequently, it has become imperative for universities to move beyond traditional curricular frameworks and actively foster a global perspective among their students.

This shift necessitates the integration of comprehensive global education programs that not only cover theoretical knowledge but also emphasize practical engagements with international communities. Universities should consider partnerships with institutions around the world to facilitate exchange programs, collaborative projects like the Global Classroom, and virtual internships with international organizations. Such initiatives help students appreciate different cultural nuances and understand the broader global context of their technical skills.

Moreover, the curriculum should include dedicated modules on global ethics, sustainability, and cross-cultural communication to equip students with the necessary tools to navigate and address the socio-economic and environmental dimensions of their engineering solutions. Engaging students in discussions and projects that require them to solve real-world problems from a global perspective can spur innovation and creativity, while also embedding a strong sense of global responsibility.

This contemporary educational perspective emphasizes the importance of effective communication, multidisciplinary collaboration, and the keen ability to analyze and identify cultural, economic, and political differences within various social contexts. Recognizing the imperative to equip students with these competencies, Tecnológico de Monterrey has pioneered the Global Classroom initiative, adopting the Collaborative Online International Learning (COIL) methodology as outlined by Rubin in 2017 [5]. This innovative approach transforms traditional teaching and learning paradigms by enabling direct collaboration between teachers and students across international borders, overcoming barriers related to culture, language, and geography through sophisticated technological tools. The Global Classroom initiative extends beyond simple academic exchange; it fosters a virtual environment where students engage in rich, cross-cultural dialogues and work on joint projects that reflect real-world challenges. This setup not only enhances students' global awareness but also develops their problem-solving skills in diverse teams, preparing them for the global workforce. Furthermore, the initiative integrates various academic disciplines, allowing students to approach problems holistically and appreciate different viewpoints, thereby enriching their educational experience.

The GC initiative provides a unique opportunity for students to develop their cross-cultural competencies and global perspective, which are essential skills for future engineers [6-7]. The application of PBL has been shown to be effective in developing both disciplinary and transversal competencies in the field of engineering [7]. However, in the 21st century, it is crucial to develop these competencies in an international, multidisciplinary, and multicultural context to address global challenges such as COVID-19, poverty, social and environmental sustainability [8]. Recent studies have demonstrated that online PBL can foster competencies such as collaboration, problem-solving, effective communication, and the ability to learn and discuss current events from diverse perspectives, even in socially and culturally diverse environments [9-11]. These competencies are considered essential by the international accreditation board ABET (Acreditation Board for Engineering and Technology) for engineering curricula.

Description of the Innovation

This study aimed to explore a unique approach to fostering multicultural and multidisciplinary learning in engineering courses through a combination of the Global Classroom (GC) linking strategy and online project-based learning (ABP) didactic technique. The project task involved determining the heat of reaction of the decomposition of hydrogen peroxide (H2O2) using an enzyme found in different stages of ripeness of Hass avocado, with the objective of evaluating the use of food residues. This task was aligned with the Sustainable Development Goals (SDGs), specifically target 12.3, which aims to reduce crop waste and promote sustainability in the food industry. Table 1 provides an overview of the institutions involved, the courses, the number of groups, the semesters, the programs, and the number of participating students.

It is worth noting that the Problem-Based Learning (PBL) technique was implemented during the collaborative activity stage as stated in the Course Guide (GC). This was achieved through a series of academic activities that allowed students to:

a) Acquire new knowledge by building an electronic device adapted to a temperature sensor.
b) Learn to create flowcharts and models for process simulation using the computational tool Aspen Hysys for process design.
c) Develop the ability to perform an experiment from home and obtain results with an acceptable standard deviation.
d) Analyze experimental data with multiple variables compared to data obtained in the Aspen Hysys simulator, specifically for the reaction between hydrogen peroxide and catalase contained in avocado.
e) Generate spaces for effective communication with different audiences and class schedules between Mexico and Colombia.
f) Work effectively as a team to develop leadership skills, create a collaborative and inclusive environment, establish goals, plan tasks, and achieve objectives.
g) Interact with another culture to understand differences in treatment, ways of addressing people, work pace, and language used.

Methodology

It is worth noting that before implementing the three stages of the CG (Ice Breaker, Collaborative Activity, and Final Reflection) depicted in Figure 1, the TEC and EAN University professors underwent a preparation stage that included. First, reviewing the curricula of the Analytical Chemistry and Product and Process Design courses in which the students were enrolled to identify a common topic. Second, designing the Ice Breaker activity and the project to be developed collaboratively using the PBL technique. Third, conducting preliminary tests of the experimental part of the project to verify its feasibility. Next, obtaining authorization from EAN University for TEC students to access Aspen Hysys® software for process simulation and thermodynamic data collection. Fourth, creating a schedule for the entire CG experience, which lasted for seven weeks each semester. Consequently, determining the hours of interaction between TEC and EAN students. Finally, forming eight collaboration teams (TEC–EAN). Generally, each team consisted of three TEC students and three EAN students. A description of the steps carried out in the experience are presented in Figure 1.

Table 1. Courses that participated in the international experience GC.

Institution	Semester period	Semesters	Career	Course (group number)	Students
Monterrey Institute of Technology and Higher Education	AD20	5	Engineer Biotechnology	Analytic Chemistry (2)	63
Ean University	AD20	7	Chemical Engineering	Product and process design(2)	45
Monterrey Institute of Technology and Higher Education	FJ21	5	Engineer Biotechnology	Analytic Chemistry (2)	16
Ean University	FJ21	7	Chemical Engineering	Product and process design(2)	45
Total					169

*During the February-June 2021 semester, the number of participating students was lower compared to the August-December 2020 semester from Monterrey Institute of Technology. This difference is attributed to the fact that in the FJ21 semester, only the remaining students enrolled in the course, as it was the last time it was offered.

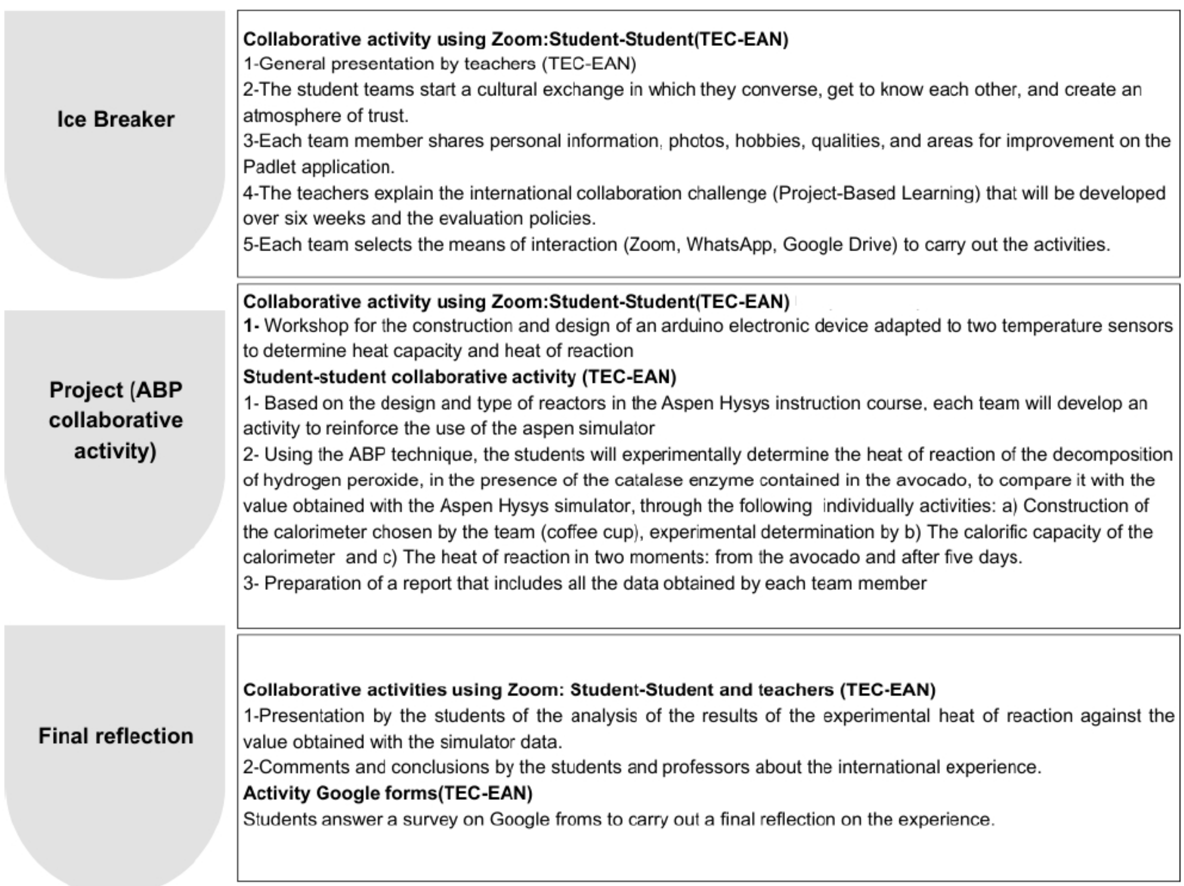

Figure 1. GC methodology implemented in the TEC–EAN international experience.

Evaluation Instruments

To evaluate the learning experience of PBL in TEC-EAN courses during the AD 20 and FJ21 semesters, three evaluation instruments were utilized:

a) Report: The students of TEC-EAN prepared a report which considered their understanding of the topic and the comparison of experimental data with the Hysys® simulator. The report was evaluated using a rubric based on the proposal from the Revista Fitotecnia Mexicana. This assessment tool allows for evaluating their comprehension of the subject matter, analytical skills, and proficiency in utilizing technological tools and resources. Additionally, it provides a detailed written account of the students' obtained results.

b) Presentation: The students' ability to effectively communicate their findings was observed through a 15-minute presentation using an observation guide. This oral evaluation assesses their communication skills, clarity in presenting the results, as well as their ability to argue and persuade. Furthermore, it enables the students to demonstrate their mastery of the topic and their capability to effectively present the findings obtained through PBL.

c) Survey: An anonymous survey consisting of seven questions was administered. The first six questions delve into the students' perception of how collaborative activities and interactions contribute to strengthening the necessary skills for their academic development. This assessment instrument enables the collection of information on the value that students assign to collaborative activities (use of computer tools, construction of the electronic device to mesure tempeture, prepare a report and experiments from home) and their opinion on how these activities contribute to their growth. The last open-ended question allows for understanding the challenges overcome during team collaboration, providing insights for the continuous improvement of PBL.

By utilizing these three assessment tools, a comprehensive evaluation of the GC learning experience linked to PBL is obtained. The report evaluates both theoretical and practical aspects, the presentation assesses communication and argumentation skills, and the survey provides valuable information on student perception and experience. This combination of assessment instruments allows for obtaining a complete and enriching perspective on the effectiveness of PBL in courses TEC-EAN during semesters AD20 and FJ21.

Results and discussion

During the evaluation of the GC learning experience, the students' experimental values of the heat of reaction were found to have a wide range due to the degree of ripeness of the avocados used. To address this challenge, the TEC-EAN teams analyzed and discussed the experimental results alongside those obtained from the simulator, culminating in a report as the first evaluation instrument. The report not only assessed their mastery of the subject but also their ability to analyze and communicate the results effectively.

To further evaluate the GC experience, an anonymous survey was administered as the third evaluation instrument. The survey's first question used a Likert scale of 1–5 to evaluate the impact of the GC activities on the students' professional lives. The results were positive in both the AD20 (86.6 %) and FJ21 (99.3 %) semesters, as indicated in Figure 2. In the AD20 semester, students recognized that teamwork had the greatest impact on their professional lives. On the other hand, in the FJ21 semester, the exchange of ideas and knowledge was deemed to have the greatest impact. These perceptions align with the findings of the research conducted by García-García *et al*. [14], who explored the effectiveness of project-based learning in a multidisciplinary and international context. Their findings support the idea that collaborative work significantly influences students' recognition of its importance for their future professional achievements. Additionally, Munoz-Escalona's *et al*. [15] study reveals that the implementation of a specific methodology promotes collaboration among students from different countries, allowing them to work together on projects and effectively solve problems. Furthermore, Oklaey *et al*. [16] highlights the benefits of collaboration, peer interaction, and intercultural learning through a project in which students from different schools participate in digital text exchanges.

Additionally, a new option "new way of approaching knowledge in engineering" was included in question 1 (FJ21), which was favorable in the students' perception. In the AD20 semester, only 10 % of students, on average, had a perception that was indifferent, disagreeing, or strongly disagreeing across questions 1-6.

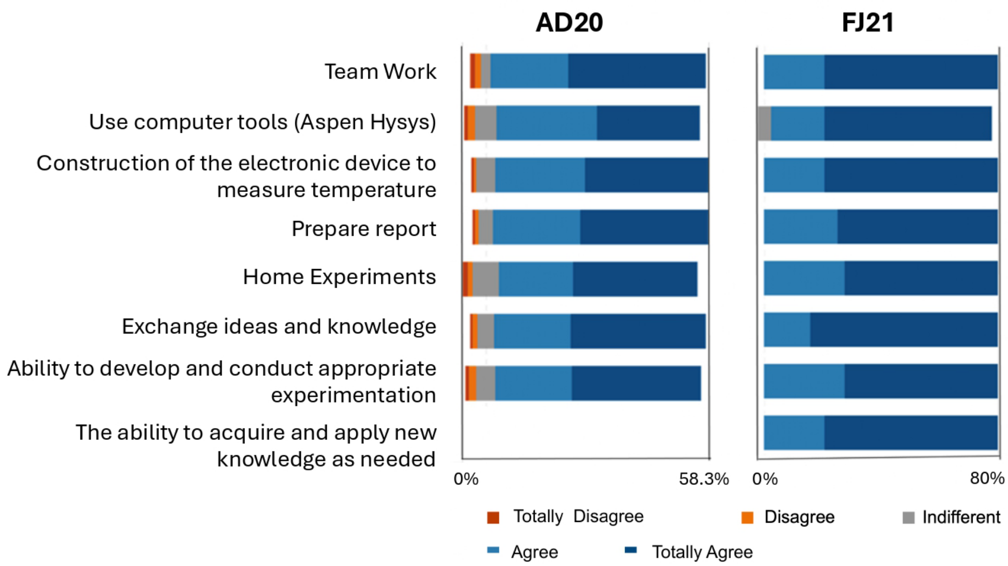

Figure 2. Results AD20 and FJ21 of the activities that will impact the professional life of the students.

In addition to the first question, the survey included two other questions, question 2 and question 3 (Figure 3 and Figure 4, respectively), to evaluate different aspects of the GC experience. Question 2 evaluated the aspects that contribute to improving the students' resumes, while question 3 evaluated the skills that influence their academic training in the context of PBL within the GC experience. Both questions yielded positive results, with an average of 88.7 and 97.5 % of students in the AD20 and FJ21 semesters, respectively, indicating that they totally agreed or agreed with the options provided. In the FJ21 semester, two new options were included, namely a) the use of computer tools and b) new learning alternatives, which were also well received by the students.

Several studies support the results obtained in questions 2 and 3 of the survey. For example, the study by Crescenzi-Lanna *et al.* [17] demonstrated that the use of the COIL methodology in various disciplines allowed students to improve cross-cutting skills such as idea and knowledge exchange, enhance written and oral communication, solve problems, and utilize computational tools. Additionally, the study by Priego-Quesada *et al.* [18] applied the COIL methodology in physiology education and found that students developed innovation and business skills when working in international teams. They overcame challenges such as language barriers and developed soft skills. Another relevant study is the one by Mlodzianowska *et al*. [19], who highlighted virtual collaboration between students from Peru and India using COIL and global virtual teams. Through this collaboration, students developed communication and collaboration skills, as well as gaining intercultural understanding.

In both semesters, AD20 and FJ21, the skills that students considered the greatest contribution to their curriculum were a) exchanging ideas and b) problem-solving (Figure 3). While the skills that students recognized as having the greatest impact on their academic training were a) applying previous knowledge, b) learning new knowledge and c) leaving their comfort zone (Figure 4). These skills were reflected in the reports prepared during the activity. Despite it being their first time consulting an author guide, the students demonstrated a remarkable ability to integrate previous knowledge with new concepts. They took advantage of this opportunity to acquire new research and analysis skills. On average, they obtained satisfactory grades, achieving a score of 87/100. Additionally, this experience provided them the opportunity to interact with students from another culture, which contributed to improving their oral communication skills by understanding different styles, norms, and communication perspectives. These skills were manifested during the presentation of the results, where the students demonstrated effective communication by expressing ideas coherently, using relevant and clear examples, capturing the audience's attention, and answering questions satisfactorily. During the evaluation, aspects such as clarity in content organization, fluency in information delivery, and coherence in the structure of the presentation were considered. Furthermore, the students' ability to express themselves clearly was evaluated, using an appropriate tone of voice and understandable language, avoiding excessive use of technical jargon. Their ability to convey confidence and enthusiasm was also valued. At the conclusion of the 15-minute presentation, questions were asked to the presenting team, and their ability to respond clearly and precisely, as well as to provide satisfactory answers, was evaluated

The survey also included questions 4, 5, and 6, which evaluated the students experiences in scheduled activities such as simulated use, construction of the electronic system, and experimentation at home, respectively (Figures 5,6 and 7). In terms of simulated use (Figure 5), students in both AD20 and FJ21 semesters found that studying properties of substances such as enthalpy heat and critical conditions of pressure and temperature, and modeling processes and unitary operations such as reactors, were valuable activities. Regarding the construction of the electronic system (Figure 6), in the AD20 semester, students found that assembling basic electronic elements was the most relevant activity (89.8 %). However, in the FJ21 semester, students considered the integration of software and measurement instruments, such as the temperature sensor, to be an important activity (97.1 %). Regarding the experimental activities carried out at home (Figure 7), in both AD20 and FJ21 semesters, students found that all the components involved in the experimentation contributed significantly to their academic learning.

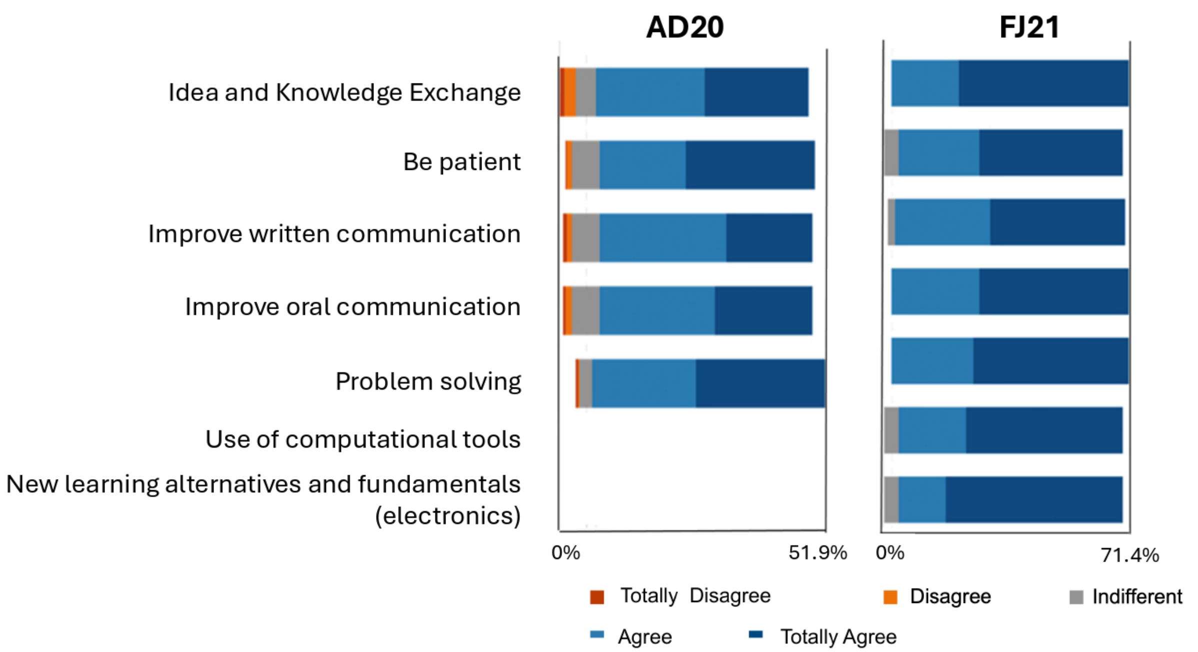

Figure 3. AD20 and FJ21 results of the interactions that improve the curriculum in the students.

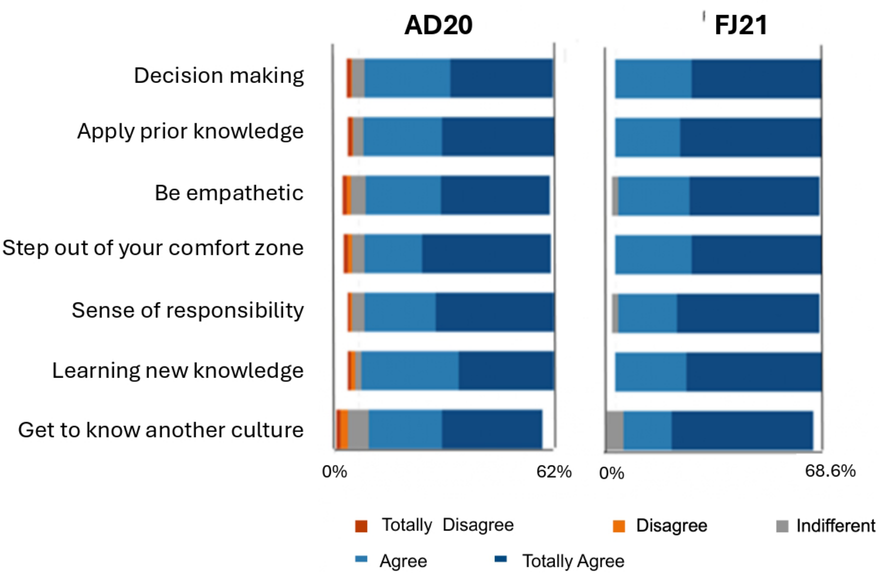

Figure 4. AD20 and FJ21 results of academic skills developed with GC experience.

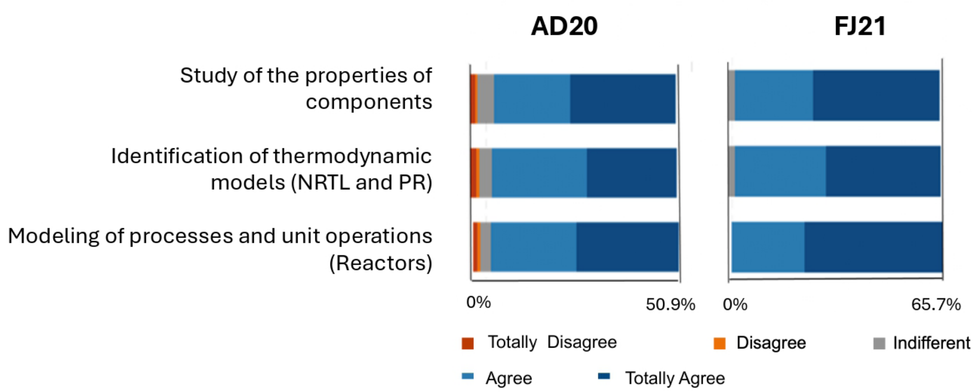

Figure 5. Results AD20 and FJ21 of aspects of learning through the use of the simulator.

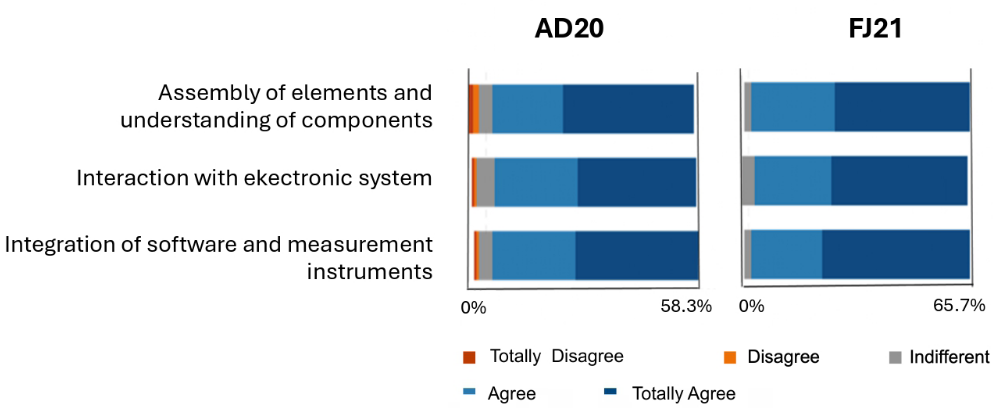

Figure 6. AD20 and FJ21 results of learning aspects through the construction of the electronic system.

The students conducted an experiment to determine the heat reaction of avocados using a homemade calorimeter due to COVID-19 restrictions. They attached temperature sensors to the calorimeter and measured freshly cut avocados that had been stored in the refrigerator and covered with aluminum foil for five days. The results showed no significant difference in the heat of reaction between the two cases. This finding demonstrates the potential to utilize avocados that are no longer recommended for consumption, as they can still release energy by reacting with hydrogen peroxide. The students propose monitoring catalase enzyme activity until just before the avocados decompose completely to maximize their use as energy sources. The students also acknowledge the need to verify the experimental heat of the reaction. They noted that it differs from the value obtained using the Aspen Hysys® computational tool. To achieve greater accuracy, they suggest using a calorimeter with lower heat loss for the measurements. This would allow for a more accurate comparison between the experimental and calculated values, thus strengthening the validity of the results.

Regarding the open question, in both semesters (AD20 and FJ21), the students agree that the main challenges that they had to overcome during the GC experience for the development of the PBL project, the preparation of the report, and the presentation of results were those shown in Table 2.

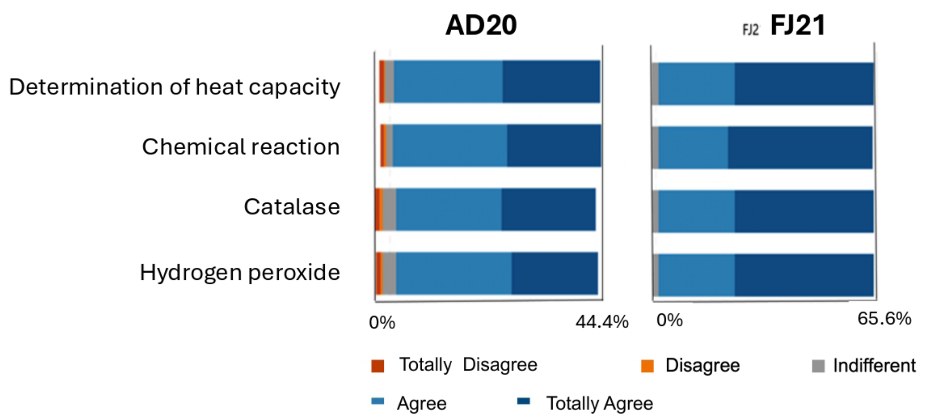

Figure 7. AD20 and FJ21 results of learning aspects through the experimental part at home.

Table 2. Challenges overcome in the Global Classroom TEC–EAN experience.

Challenge	Solution
Time availability of team members to meet and discuss activities	Being empathetic, with the availability of hours (EAN students work in the morning and study in the afternoon).
Communication	1)Respect meeting times to promote constant and effective communication. 2) Be receptive, share the traditions and customs of each country to create an atmosphere of confidence. 3) Value the diversity of meanings.
Work in a multidisciplinary team	1)Generate synergy during the development of collaborative activities. 2) Respect and adhere to the way of working of each member. The students realized that the way of working in both countries was different (for example, the use of commas and points in Excel).
Learn and use the Aspen Hysys ® simulator	Support the skills of teammates to manage the simulator. (The Ean students had a better command of the Aspen ® simulator). In this activity, he fostered teamwork and improved communication.
Analysis of experimental data	Learn to be respectful and tolerant of arguments other than their own.

Conclusions

In conclusion, the Global Classroom (GC) learning experience carried out during the August-December 2020 and February-June 2021 semesters with engineering students fostered positive close interaction between Tecnológico de Monterrey TEC (Mexico) and Universidad EAN (Colombia) students, despite their geographic locations. Additionally, students acknowledge that the implementation of online Project-Based Learning (PBL) in the GC strategy significantly impacted the development of transversal competencies such as teamwork, problem-solving, exchange of ideas and knowledge, learning new knowledge, application of previous knowledge, and the use of computer tools. This project contributed to the students' development in an increasingly competitive and globalized world, recognizing cultural differences in an empathic way.

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