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Collaborative Online International Learning (COIL) in chemical engineering: Preparing students for multicultural and international work environments

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ABSTRACT

In today's interconnected society, chemical engineering students must be prepared to work in international and multicultural environments. However, in our experience, current chemical engineering curricula often fail to develop these competencies. This study aims to demonstrate the benefits of Collaborative Online International Learning (COIL) in chemical engineering education. For the first time, the COIL approach has been implemented in a simulation course. In addition to preparing students for international and multicultural work environments, this experience enhances their problem-solving and critical-thinking skills. Unlike other COIL applications, this project allows for multiple valid solutions, though not all are necessarily optimal. After two successful COIL projects involving chemical engineering students from the Universidad de Valladolid (Spain), the Universidad Nacional de Colombia, and the Universidad Autónoma de Nuevo León (Mexico), students reported feeling more confident in their knowledge and abilities, better prepared for multicultural and international work environments, and more capable of performing well in their first job. In both project editions, survey responses to related questions averaged above 4 out of 5. Key takeaways from this work are that, to accomplish the objectives of a COIL, it is essential to define the project timeline in advance, ensure a similar level of knowledge among students, confirm software access, establish a unified communication platform, and conduct individual kickoff meetings for each team. Additionally, effective international collaboration is more likely when no more than 50 % of a team's members come from the same institution.

1. Introduction

In today's global, interconnected society, it is essential to integrate the development of soft skills, particularly the ability to work in international and multicultural environments, into the engineering curricula (Martín-Lara et al., 2019; Winberg et al., 2020). Hadjileontiadou et al. (2003) argued that the engineering curriculum must be designed to prepare the student for the transition from education to professional life, and that this transition is smoother when the students participate in engineering projects that imply a multidisciplinary and multicultural approach. In this same line, Lohmann et al. (2006) stated that, as we are currently living in a global society, students must be prepared to collaborate with individuals from other countries. Winberg et al. (2020) analyzed different engineering curricula to identify components focused on promoting students' employability. In that work, the authors recommended a problem-solving-oriented perspective, highlighting the importance of interpersonal and communicative skills, which are easily developed through collaborative learning experiences. In this context, a group of professors from the University of Granada (Spain) underscored the importance of offering students the opportunity to undertake internships abroad to enhance their international working capacity (Martín-Lara et al., 2019). Luengo-Aravena et al. (2024) analyzed the social dimension of the problem, identifying that, in higher technical education, there is a direct correlation between the digital competencies of the students, their capacity to work in international environments, and their socioeconomic background. Finally, Franco et al. (2023) went further developing a competency-based curriculum that trains the students in soft skills.

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Recognizing the importance of preparing students for multicultural and international work environments, various initiatives based on Collaborative Online International Learning (COIL) have emerged over the past twenty years. However, to our knowledge, only a few of them have been applied in the field of chemical engineering (Le Roux et al., 2009, Vasquez and Ramos, 2022, Durand and Balhasan, 2023). The term COIL refers to a collaborative educational approach wherein a specific course, or a part of it, is taken simultaneously by groups of students from different universities. The course can be taught either by a single professor or by a group of professors. The main idea is that, after the explanation, a specific project or challenge is addressed by groups of students from all the participating institutions. This type of practice provides the students with international experience, promoting faster development in their future professional careers (Borger, 2022). In this line, some of the first COIL collaborative initiatives were carried out by Grimheden et al. (2004) and Žavbi and Tavčar. (2005). Grimheden and his coworkers developed a cooperative venture between KTH University (Sweden) and Stanford University (USA) focused on product development. One of their main findings was that the differences in the time zones and locations presented learning opportunities, as these challenges enhanced students' flexibility. On the other hand, Žavbi and Tavčar. (2005) created an inter-university program also focused on product development, where, apart from being exposed to a multicultural environment, the students worked with online tools. In 2011, Oladiran et al. (2011) developed a program called "Global Engineering Teams" based on the collaboration among students and global partners in a virtual environment. The students who participated in the initiative were organized into different groups supervised by both professors and industry members. They had two in-person face-to-face meetings at the beginning and end of the project, using videoconference and email for communication. After the project, the authors concluded that it was possible to deliver the course via an industry-university-based collaboration and that these types of experiences facilitate multidisciplinary teamwork at an international level. Over the last ten years, the number of COIL initiatives has drastically increased. Although these initiatives have focused on different knowledge fields, their conclusions are quite similar. Naicker et al. (2022), Simões and Sangiamchit. (2023), Vahed and Rodriguez. (2020) and Yang et al. (2014), found that COIL projects improved the international awareness of participants. Gutiérrez-González et al. (2023) and Rodriguez-Sanchez et al. (2020) reported enhancements in the professional competencies of the students, especially their communication skills, and even their capacity to critically judge the information received from media, as pointed out by King de Ramirez. (2021). In 2023, Hackett et al. (2023) measured the effectiveness of COIL participation, finding that students already exposed to international environments in their universities did not benefit as much from participating in these initiatives as those students from less international environments. However, for students experiencing international collaboration for the first time, a COIL project not only improved their teamwork and communication capacities in international settings but also motivated them to pursue further work in international environments, as corroborated by Esparragoza et al. (2015). Finally, Ingram et al. (2021) reported that a successful COIL experience depends not only on the motivation of participants but also on the commitment of the participating institutions, especially at a resource level. However, examples of COIL implementation specifically within chemical engineering education remain limited. for multicultural and international work environments. COIL involves students from different universities working together on projects, often supervised by professors or even industrial partners, fostering international experience and teamwork. Previous experiences have shown the learning potential of time zone and location differences and the enhancement of international awareness, communication skills, and critical thinking. While widely applied in various fields, COIL has seen limited implementation in chemical engineering. In this work, we introduced a novel COIL initiative focused on process design and simulation, a field of chemical engineering where problems have no single correct solution. Unlike other COIL applications, our approach required students to address a chemical engineering problem where multiple solutions could be valid, but not necessarily optimal. This structure fostered critical thinking and collaborative problem-solving skills. Moreover, process simulation demands close teamwork, as students must work with a single simulation file, making parallel work more challenging. By integrating COIL into this type of course, we aimed not only to provide students with an international collaboration experience but also to enhance their problem-solving, adaptability, and teamwork skills.

This work presents the outcomes and the benefits of Collaborative Online International Learning in chemical engineering. It is motivated by the own experience of the authors. Professor Luis Vaquerizo spent eight years working at an international Spanish engineering firm, where he observed that the chemical engineering degrees from most Spanish universities did not adequately prepare students for working in international environments with colleagues across different time zones. After returning to Accademia in 2022, he discussed this issue with Professor Rafael Mato, former coordinator of the chemical engineering master's program, who maintains close contact with alumni and agreed with Professor Luis Vaquerizo. Together, they decided to initiate a COIL by reaching out Professor Iván Darío Gil. Over two consecutive academic years, bachelor's students from the Universidad de Valladolid (UVa, Spain), the Universidad Nacional de Colombia (UNAL, Colombia), and the Universidad Autónoma de Nuevo León (UANL, México) have collaborated in two different simulation projects developed in groups of four to six students who belonged to the three participating universities. While the chemical engineering curricula and program focus are similar across the institutions, the main difference lies in program length: the bachelor's programs at the Universidad Nacional de Colombia and the Universidad Autónoma de Nuevo León last five years, whereas at the University of Valladolid, it is a four-year program. Despite this variation, all programs are designed to train professionals in the development of chemical products and processes. Through this COIL experience, students not only gain international exposure, an aspect often limited in most current chemical engineering curricula (Borger, 2022), but also enhance their teamwork, critical thinking, and collaborative problem-solving skills.

2. Case studies

2.1. Case study 1: 2023 simulation project participants: UVa-UNAL

In 2023 we decided to start an international collaborative project in chemical engineering.

The chemical engineering bachelor program at the Universidad de Valladolid includes an elective simulation course. Before the implementation of the Bologna process, 80–90 % of our students typically enrolled in this course, with an average of 25–30 students per year out of a total of 30–35 chemical engineering students per cohort. However, after Bologna's adoption, the enrollment dropped to an average of 20 %, with only 6–8 out of 30–35 students selecting the course. This decline may be attributed to the reduction of the chemical engineering program from five to four years and the additional workload that this course required compared to other elective courses. We considered this course particularly suitable for such an experience, as it already includes a simulation project that, in addition to training the students in process simulation, contributes to the development of their soft skills. The project requires students to work in groups and present their main results through an oral presentation. This type of work helps them enhance their teamwork and presentation abilities.

In December 2022, we reached out Professor Iván Darío Gil at the Universidad Nacional de Colombia to propose a collaborative COIL project. Despite the inexistence of previous relationships among our groups, Professor Gil kindly agreed to participate in the project. Thus, during the academic course 2022–2023, the last-year students of the bachelor's in chemical engineering of the Universidad de Valladolid collaborated with their counterparts from the bachelor's in chemical engineering of the Universidad Nacional de Colombia on a simulation project. We designed a concise, structured simulation project that could be completed within three to five weeks, using the same grading system at both institutions, in line with the recommendations of Vasquez and Ramos (2022). Participation in the COIL experience was mandatory for all the students and replaced the simulation project that already existed in both participating universities. The simulation course is offered at both universities during the eighth semester. Although this is the first experience of the students with a process simulator, both at the Universidad de Valladolid and the Universidad Nacional de Colombia, they have already completed or are currently taking courses in thermodynamics, reactor design, and separation processes. The students' prior knowledge of process simulation was comparable, as both universities cover the fundamentals of process engineering simulation including the selection of an appropriate thermodynamic package, process units modeling (with a special emphasis on reactors and distillation columns design), flowsheeting options, and sensitivity analysis. In the case of the Universidad Nacional de Colombia, as the simulation course is mandatory, a higher number of students are enrolled in the course, so 29 Colombian students participated in the experience. Table 1 summarizes the universities and the number of students who participated in the COIL project. The students were divided into six groups, with each group containing one Spanish student to promote international cooperation and teamwork skills. The groups worked on a project involving the simulation in Aspen Plus® of a methanol production plant via CO_2 hydrogenation. This type of work limits parallel progress, as a single simulation final file must be delivered. As a result, the students either had to work together, strengthening their collaborative problem-solving skills, or communicate their ideas effectively to persuade their teammates and implement changes in the simulation. The students were given the plant's feed streams, required product purities, reactor kinetics, and a preliminary flowsheet. The goal of the project was to simulate the process and conduct sensitivity analyses on key design variables, such as the reactor feed stream ratios, reactor operating conditions, catalyst load, and the main operating parameters of the distillation columns. An exemplary flowsheet is shown in Fig. 1. Within their groups, students collaboratively identified the most critical design variables and determined how to optimize them. This approach fostered critical thinking and enhanced their collaborative problem-solving skills. Additional details and information for the simulation project can be found in the Supplementary Information file.

During this first collaborative experience, several meetings were held among the professors in charge of coordinating the experience as well as with the students. As reported by Ingram et al. (2021), scheduling regular meetings during the COIL implementation phase is critical for the final success of the experience. Three meetings were held before presenting the project to the students. A first introductory meeting to define the project schedule, as each university has its own calendar and exam periods. The second meeting focused on discussing the project proposal. Since this was the first time that the project was done, it was important to clarify what level of detail was going to be requested to the students, as well as the final deliverables. Finally, a third meeting was held to discuss the students' distribution and set the groundwork for the kickoff meeting.

The students were called for a kickoff meeting where the professors presented the project, outlined the deliverables, explained the teams' distribution, and provided the project timeframe. Once the project was launched, students were given the autonomy to define their work distribution. The only imposed conditions were complying with the project deadline and using the same version of the simulator (V11.0), as while versions V11.0 and V12.0 were available at the Universidad de Valladolid, only V11.0 was available at the Universidad Nacional de Colombia.

During the project, each group was assigned a supervisor whom the students had the option of contacting for Q&A sessions. On average, each professor received a couple of meeting requests, although some groups did not request any meetings. Two months after the beginning of the experience, the students submitted their projects to an online platform. As the number of groups was relatively low (six), all three professors could evaluate the deliverables from all the groups, which consisted of a final report, the simulation file, a process flow diagram (PFD), and a presentation that summarized the main conclusions and critical aspects of the process.

Five days after submission, the students attended a general defence meeting. In this meeting, all the teams had to present the main conclusions of their work. We also asked them to discuss specific parts of their simulations with other groups. Submitting technical documents and a memorandum as deliverables, along with defending the project in a final presentation, is an approach that has already been considered by other authors working on COIL (Vasquez and Ramos, 2022). After this meeting, a survey was distributed to gather students' feedback and ask them about several aspects of the project.

Finally, two last meetings were held by the professors. The first meeting was used to consolidate the evaluations for each group and assign a final mark. The second meeting, the last of the project, was held to analyze the students' replies to the survey and decide on the continuation of the experience or not and modifications to address in next year's edition. Holding a final meeting to review what worked well and what did not and plan future COILs, has been also suggested by Ingram et al. (2021). All the COIL activities presented in this section are summarized in Table 2.

As reported in Section 3, the experience was very positive for the students. They recommended continuing with the project but suggested finding a way to increase heterogeneity in the groups. Due to the limited number of Spanish students, all the groups were formed by five Colombian students and only one Spanish student, which somewhat limited the extent of international interaction.

Table 1
COIL participants.

Country	University	Degree	2022–2023 Participants	2023–2024 Participants
Spain	Universidad de Valladolid	4th year, Elective Course, Bachelor in Chemical Engineering	6	6
Colombia	Universidad Nacional de Colombia	4th year, Mandatory Course Bachelor in Chemical Engineering	29	26
México	Universidad Autónoma de Nuevo León	4th year, Mandatory Course Bachelor in Chemical Engineering	-	33

2.2. Case study 2: 2024 simulation project participants: UVa-UNAL-UANL

Following the success of our first experience, we decided to repeat the collaborative project in the next academic year (2023–2024) incorporating the eight-semester bachelor's students from the Universidad Autónoma de Nuevo León (México), led by Professor Salvador Tututi-Ávila, to address the uneven distribution of students in the first COIL experience, where each group consisted of only one Spanish student and five Colombian students. As in the previous year, participation in the COIL was mandatory for all the students and replaced the existing

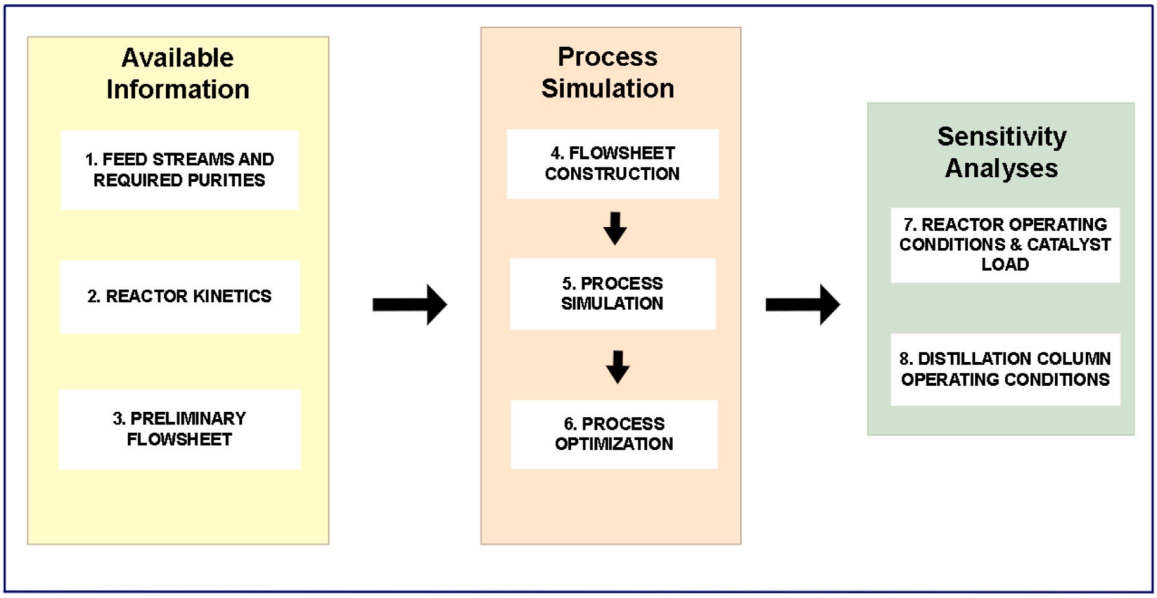

Fig. 1. Simulation project. Exemplary flowsheet.

Table 2
COIL project activities.

ID	Activity	Participants	Description
1	Initial Meetings	Professors	Definition of the project scope, timeline, marking criteria, and distribution of students.
2	Kickoff Meeting	Professors & Students	Presentation of the project to the students. Description of the process, presentation of the working teams, and evaluation criteria.
3	Project Development	Professors & Students	Development of the Project. Clarification meetings with the tutors.
4	Presentations / Q&A	Professors & Students	Evaluation of the groups' performance. Presentation of the main project results. Q&A session.
5	Student's Survey	Students	Gather student's opinions. Strongest and weakest points. What to do and what to avoid in the upcoming COIL editions.
6	Evaluation Meeting	Professors	Internal discussion on the project results and marking. Discussion on the survey results and students' opinions. Lessons learned for following COIL editions.
6	Final Meeting	Professors & Students	Final comments and improvement suggestions. Discussion with our students.

simulation project. The Mexican students had also completed or were currently taking courses in thermodynamics, reactor design, and separation processes. Additionally, they learn the same fundamental concepts of process engineering simulation as their counterparts from Spain and Colombia. As can be seen from Table 1, the participation of a group of 33 Mexican students allowed us to form much more heterogeneous groups, comprising students from México (33 students), Colombia (26 students), and Spain (6 students).

The students were distributed in sixteen groups, six of them including students from the three participating institutions and the remaining ten groups having at least two students from both the Universidad Nacional de Colombia and the Universidad Autónoma de Nuevo León, in line with the recommendations of Vasquez and Ramos (2022). In this way, international cooperation was favored compared with the previous year's experience.

To further promote the creation of an international environment, Professors Luis Vaquerizo and Rafael Mato, from the Universidad de Valladolid (Spain), were assigned as supervisors of eight of the groups that did not count with the participation of Spanish students. Supervising students from other institutions and addressing their questions was highly beneficial for professors, as it offered insights into the course content and the students' knowledge and abilities at different universities. This process helped to identify strengths and weaknesses, enabling the development of targeted improvement strategies for future years.

This second year, the international project was related to the simulation in Aspen Plus® of a dimethyl-ether (DME) production plant via methanol dehydration. In line with the previous year's experience, the students were also given the plant's feed streams, required product purities, reactor kinetics, and a preliminary flowsheet. The goal of the project was again to simulate the DME production plant and conduct sensitivity analyses on key design variables. Additional details for the 2024 simulation project are also provided in the Supplementary Information file.

As in the previous year's experience, three sets of meetings were held. First, before the beginning of the project, three meetings were held among the professors. The first one was dedicated to introducing Professor Salvador Tututi-Ávila to the project, pointing out the strongest and weakest points of last year's project. Moreover, we defined the timeframe of the project, as in the case of last year's experience, the academic and exam periods vary depending on each region and university.

The second meeting focused on the technical aspects of the proposal and was used to discuss whether the level of complexity of the proposal was adequate or not for the students of all the participating institutions. Finally, the last meeting was held to define the distribution of our students and the project deliverables. For this second-year experience, the same deliverables were maintained, replacing the final presentation with a video that summarized the main results of the project. Before the defence meetings, the professors reviewed the videos, allowing the discussions to begin immediately in the final defence meetings. The video accounted for 20 % of the final grade.

After these first three introductory meetings, a general meeting was held with all the students to present the group distribution, project details, deliverables, timeframe, and grading system. The students got complete freedom to define how they wanted to address the project with the only condition of using the same version of the simulator (V12.0), as versions V12.0 and V14.0 were available at the Universidad de Valladolid but only V12.0 was available at the Universidad Nacional de Colombia and the Universidad Autónoma de Nuevo León. During the subsequent two months, the supervisors were available for meetings with the groups. On average, each professor received questions from one out of four groups under their supervision, although multiple meetings were held with these groups.

At the end of the two-month period, the students submitted their projects to an online platform. Given the increased number of groups (sixteen compared to six in the previous year), we adopted a different strategy to evaluate the projects. Each professor evaluated only the projects of the groups he supervised. This approach streamlined the assessment process and ensured a more manageable workload for the professors. To ensure greater consistency, a standardized grading criterion was established together. The final grade was allocated as follows: 10 % for the Process Flow Diagrams, which are created based on the process description provided in the assignment; 20 % for the simulation file, where students must demonstrate that they have successfully conducted the simulation; 50 % for the project report, the main document in which students explain their simulation strategy and justify their selection of key process variables through sensitivity analyses and critical decision-making; and 20 % for the video, which assesses students' ability to summarize and present their work effectively.

Moreover, each professor was responsible for scheduling a defence meeting with their respective groups. The defence methodology followed the same approach as the previous year, based on a set of questions and answers focused on the videos, while promoting discussion among the different groups. As in the previous year's experience, just after the defence, a survey was conducted to gather the opinions of the students. The results are presented in the next section of this work.

Finally, a set of three concluding meetings were held. The first and second ones were focused on grading the projects and evaluating the results of the survey. Regarding the grading process, we analyzed the average, maximum, and minimum scores assigned by each professor. In cases of significant deviations, the agreed procedure was to jointly review the performance of the groups with the largest discrepancies and decide on an appropriate revision. However, our grading proved to be consistent and within the same range, so no further discussion was necessary. Additionally, we observed that students from all three participating universities had similar simulation skills, probably due to comparable student profiles and curricula. Therefore, we believe the influence of individual instructors on grading was low. The last meeting, requested by the students, was held also with the students to allow them to express their opinions, suggestions, and perspectives on the project. Their feedback was aligned with their responses to the last question of the survey (comments and suggestions). This iterative process of feedback and improvement ensured that the collaborative project continued to evolve positively, incorporating the valuable insights and experiences of both students and professors.

3. Results and discussion

Thanks to the results of our first and second COIL experiences, we were able to draw the following valuable conclusions about what is needed to successfully set up a COIL project in chemical engineering:

- It is essential to have a balanced number of students from all participating institutions. Otherwise, students may not be compelled to collaborate effectively. In our first COIL experience, where each Spanish student worked with five Colombian students, some students complained that there was no real interaction between them. However, after our second experience with much more heterogeneous groups, we did not receive any comment in this sense. In our view, no more than 50 % of the students in each team should come from the same institution, in line with the recommendations of Vasquez and Ramos (2022).
- The academic calendar at each institution can affect the project timeline, as also reported by Ingram et al. (2021). One of the first steps in planning a COIL project is to identify the optimal period for collaboration, as exams and vacation breaks may limit participation. In the case of these COIL experiences, our simulation courses start by mid-February and last until late May.
- Ensuring that the students' skill levels are comparable is important. Sharing assignments from previous years can help assess whether students from all participating institutions are prepared to tackle the same tasks. This strategy was followed in this COIL program before deciding whether our students have a similar level of skills and therefore they were prepared to work together on a simulation project.
- When software is required for the COIL project, it is crucial to ensure that all students have access to the same version. In our second COIL experience, some students complained that they did not have access to the same versions as their counterparts at the remaining universities, which hindered their collaboration.

3.1. Project performance

The first quantitative indicator to measure the performance of our students in the COIL project was the final marks. This is a quick indicator that allows for an at-a-glance evaluation of the performance of COIL experiences. We believe the final grade is a valid indicator in this case due to the similarities among the three participating universities: comparable curricula focused on chemical process and product design, the simulation course being taken in the eighth semester by our students, and the similar fundamental concepts covered in the course. Fig. 2 illustrates the evolution of the average grade achieved in the simulation project over the past six years. As shown, apart from the Universidad Nacional de Colombia, where the final grade has consistently increased, there is no clear trend at the Universidad Autónoma de Nuevo León or the University of Valladolid. In the first year of COIL (2022–2023), the average project mark was 8.4 (out of 10), with the minimum mark being 7.6 and the highest 9.4. On the other hand, in the second year's experience (2023–2024), the average mark was 8.5, being the minimum mark 7 and the highest one a 9.8, demonstrating successful technical skill application. The standard average deviation between the average mark of each professor was only 0.5 points, indicating a consistent marking criterion. However, evaluating the effectiveness of collaboration required further analysis. At the Universidad de Valladolid, the COIL project is evaluated after the final exam, so it was not possible to determine whether students performed better on the exam after COIL implementation in the simulation course. In contrast, at the Universidad Nacional de Colombia and the Universidad Autónoma de Nuevo León, there was no noticeable variation in final exam scores.

3.2. Student feedback and survey analysis

Although the final marks were highly satisfactory, considering that a student passes the course with a minimum grade of 5 and the maximum grade achievable is 10, we were concerned that they might not fully guarantee successful collaboration among the team members. For this reason, as mentioned in the previous section, after the defence meeting and before publishing the final marks, we surveyed the students to gather their opinions and find the strongest and weakest points of the experience. The surveys were fully anonymous, so we did not know how many students from each university completed them. We acknowledge the limitations of the survey results. The dataset is relatively small, and the 2024 cohort differs from the 2023 cohort due to the addition of a third institution. These differences complicate direct comparisons between cohorts and should be considered when analyzing the survey findings. The questions included in each year's survey are presented in Table 3, and the results in Table 4 and Table 5 and from Fig. 3 to Fig. 8.

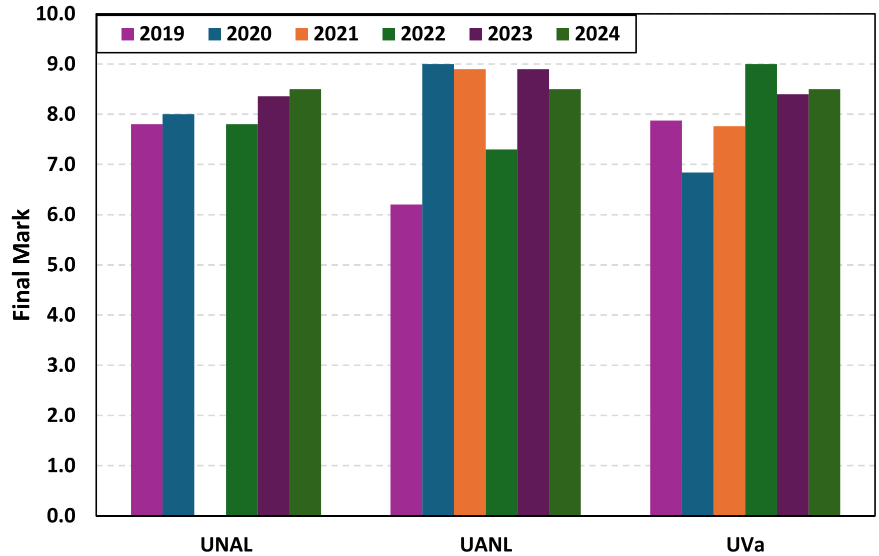

Fig. 2. Evolution of the simulation project final mark in the three participating universities over the past six years. No simulation project was carried out at UNAL in 2021.

Table 3
Questions included in the final survey. Question 13 was only surveyed in the second year.

First set of questions	
Q1:	I believe that having participated in this experience will be positive for me once I join the job market.
Q2:	I believe that having participated in this experience has helped me to acquire new knowledge and reinforce the knowledge I already had.
Q3:	After having worked with students from other universities, I feel more confident in my knowledge and abilities.
Q4:	My overall assessment of the experience is positive.
Q5:	I recommend repeating this experience in future years.
Second set of questions	
Q6:	The workload has been appropriate considering the number of members in each group and the time to complete the project.
Q7:	Despite the time difference, communication has been carried out smoothly.
Q8:	The distribution of tasks among the members of each group has been balanced.
Q9:	The coordination among the different members of each group has been adequate.
Third set of questions	
Q10:	The coordination among the professors has been adequate.
Q11:	The project evaluation system has been explained clearly and is fair.
Q12:	I would prefer to carry out the project with students with whom I could only communicate in English to enhance my ability to work in this language.
Q13:	The resources and technical support provided by the universities were adequate to complete the project.

Except for Question 14, which was an open question, the rest of the questions asked the students to provide their opinions marking from 1 to 5, with 5 meaning total agreement and 1 indicating total disagreement. The participation in both surveys was fairly reasonable, with 29 out of the 35 students that participated in the 2023 experience (82.6 %), and 42 out of the 65 students in the 2024 experience (64.6 %). These high participation rates lead us to believe that the results of the surveys are representative of the opinions of all the students. Both surveys were published in the same way, and regular email reminders were sent each year. Therefore, in our opinion, there is no specific reason to explain the participation decline.

The survey was divided into three sets of questions. The first five questions aimed to gather students' opinions and satisfaction regarding general aspects of the COIL project, while the next four focused on the success of collaboration within each group. Finally, the last set of four questions addressed more technical aspects of the project. To elaborate on the statistical methodology, the Mann-Whitney *U* test was employed as a non-parametric test to determine if statistically significant

Table 4
Detailed statistical measures by question and year.

Question	Mean	Median	Std Dev	Skewness
Q1 (2023)	4.66	5.00	0.60	−1.55
Q1 (2024)	4.45	5.00	0.91	−1.78
Q2 (2023)	3.79	4.00	1.16	−0.53
Q2 (2024)	4.43	5.00	0.76	−1.22
Q3 (2023)	4.21	4.00	0.92	−1.47
Q3 (2024)	4.74	5.00	0.58	−2.10
Q4 (2023)	4.28	4.00	0.78	−0.96
Q4 (2024)	4.69	5.00	0.60	−1.77
Q5 (2023)	4.62	5.00	0.85	−2.93
Q5 (2024)	4.62	5.00	0.72	−1.94
Q6 (2023)	4.07	4.00	1.10	−1.12
Q6 (2024)	4.19	5.00	1.19	−1.33
Q7 (2023)	3.97	4.00	1.24	−1.08
Q7 (2024)	4.24	5.00	0.96	−1.00
Q8 (2023)	3.55	4.00	1.12	−0.60
Q8 (2024)	3.81	4.00	1.19	−0.58
Q9 (2023)	3.31	3.00	1.11	−0.32
Q9 (2024)	4.24	5.00	0.93	−0.85
Q10 (2023)	4.28	4.00	0.80	−0.96
Q10 (2024)	4.31	5.00	1.09	−1.43
Q11 (2023)	4.28	5.00	1.00	−1.24
Q11 (2024)	4.45	5.00	0.83	−2.03
Q12 (2023)	3.38	3.00	1.24	−0.29
Q12 (2024)	3.48	3.00	1.31	−0.21

Table 5
Statistical test results.

Question	Mann-Whitney U p-value	Cohen's d	Significant	Effect Size
Q1	0.477	−0.264	No	Small
Q2	0.020	0.649	Yes	Medium
Q3	0.002	0.689	Yes	Medium
Q4	0.010	0.595	Yes	Medium
Q5	0.836	−0.002	No	Small
Q6	0.401	0.106	No	Small
Q7	0.430	0.246	No	Small
Q8	0.297	0.223	No	Small
Q9	0.001	0.907	Yes	Large
Q10	0.347	0.035	No	Small
Q11	0.556	0.192	No	Small
Q12	0.803	0.076	No	Small

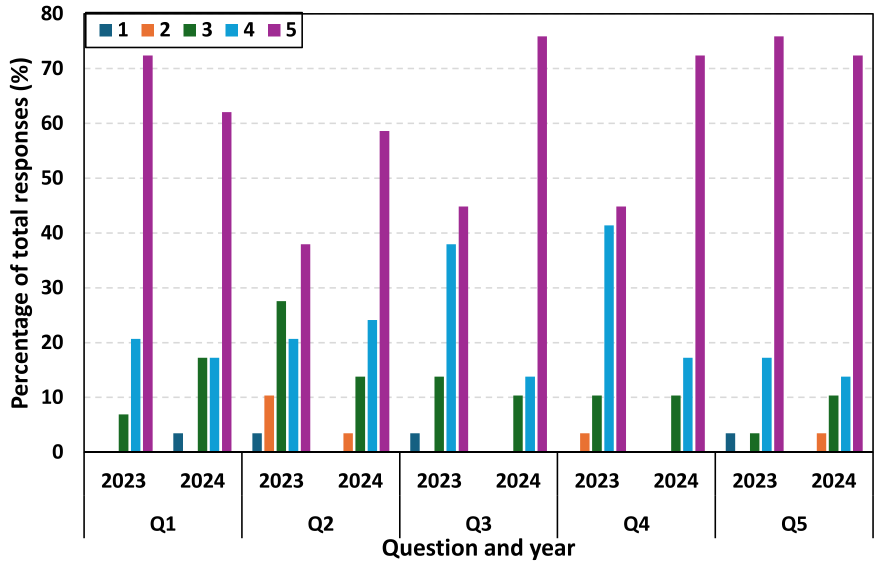

Fig. 3. Distribution of survey responses (Q1-Q5).

differences existed in the distributions of survey responses between 2023 and 2024 for each question. Given the ordinal nature of our Likert-scale survey data, this test was appropriate for comparing the overall response patterns between the two years. Statistical significance was determined at a p-value threshold of 0.05. Furthermore, to quantify the practical importance of any statistically significant differences, Cohen's d was calculated as a measure of effect size. Cohen's d provided a standardized metric to assess the magnitude of the observed differences, categorized as small, medium, or large, allowing for an evaluation of both the statistical significance and the practical relevance of year-over-year changes in survey responses. This combined approach provides a robust analysis of the data, moving beyond simply identifying statistically significant differences to also understanding their substantive impact.

1. Overall students' perception and satisfaction with the COIL project (Fig. 3 and Fig. 4)

- Relevance to professional development (Q1):
  Students have recognized the value of the COIL experience for their future careers, with median scores of 5 in both 2023 and 2024, and average scores of 4.7 and 4.5 respectively. The p-value (0.477) and Cohen's d (-0.264) indicate no statistically significant difference.
- Knowledge acquisition and confidence (Q2 & Q3):
  Students' perceptions of knowledge gains (Q2) and confidence (Q3) improved from 2023 to 2024. For Q2, the average score rose from 3.8 to 4.4 (median from 4 to 5), with a statistically significant p-value of 0.020 and a medium effect size (Cohen's d = 0.649). Similarly, for Q3, the scores increased from 4.2 to 4.7 (median from 4 to 5), also statistically significant ($p = 0.002$; Cohen's d = 0.689). These findings suggest that the 2024 cohort felt more empowered by the experience, possibly influenced by a more diverse and balanced group composition.
- Overall satisfaction (Q4):
  Students reported high overall satisfaction in both 2023 and 2024, with average scores increasing from 4.3 to 4.7 (median from 4 to 5).

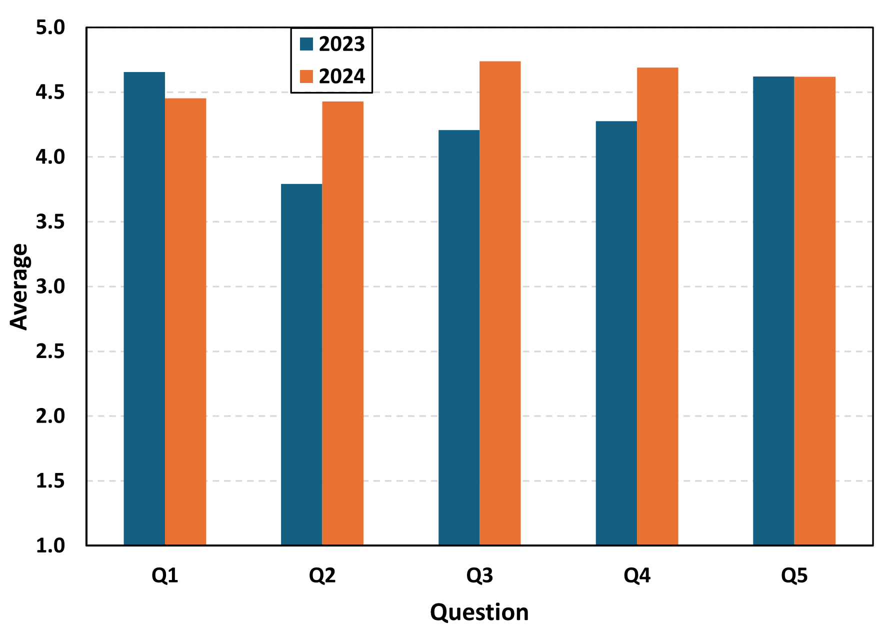

Fig. 4. Average results for the first questions Q1-Q5.

The difference was statistically significant (p = 0.01) with a medium effect size (Cohen's d = 0.595). This is likely linked again to the enhanced group diversity and interaction in the 2024 cohort.

- Willingness to recommend the experience (Q5):

Students strongly supported repeating the experience, with identical average scores (4.6) and median values (5) in both years. The p-value (0.836) and Cohen's d (-0.002) indicate no meaningful difference between cohorts.

2. Collaboration and team dynamics (Fig. 5 and Fig. 6)

- Workload and communication (Q6 & Q7):
  Students found the workload manageable (Q6), with average scores slightly increasing from 4.1 to 4.2 (median rising from 4 to 5). The statistical difference was not significant between both editions (p = 0.401; Cohen's d = 0.106). Similar results were obtained for communication across time zones (Q7), with students reporting an increase from 4.0 to 4.2 in the average score and from 4 to 5 in the median, with no statistically significant difference (p = 0.430; Cohen's d = 0.246).
- Task distribution and coordination (Q8 & Q9):

Compared with other metrics, students' perceptions of fair task distribution (Q8) remained relatively low, with only a slight increase in the average score (from 3.6 to 3.8) and a stable median of 4, suggesting that achieving workload balance among team members remains a challenge. This difference was not statistically significant (p = 0.297; Cohen's d = 0.223). In contrast, students reported a marked improvement in group coordination (Q9), with the average score rising from 3.3 to 4.2, and the median from 4 to 5. This difference was statistically significant (p-value equals 0.001) showing a large effect size (Cohen's d = 0.907), likely related to the more balanced group distributions implemented in 2024.

3. Technical and pedagogical aspects (Fig. 7 and Fig. 8):

- Instructor coordination and assessment clarity (Q10 & Q11):
  Students rated professor coordination (Q10) highly, with an average score of 4.3 in both years and a median increase from 4 to 5. The p-value (0.347) and very low Cohen's d (0.035) show no significant difference between cohorts. Similarly, the clarity in the project evaluation system (Q11) was positively valued in both 2023 and 2024, with a slight average increase from 4.3 to 4.4 and a stable median (5). Again, no significant difference was detected (p = 0.556; Cohen's d = 0.192).
- Use of English in collaboration (Q12):
  Students expressed a modest preference for using English in the collaboration (Q12), with average scores of 3.4 in 2023 and 3.5 in 2024, and a consistent median of 3. The p-value (0.803) and small effect size (Cohen's d = 0.076) suggest minimal variation between cohorts. While students recognize the importance of working in English, their preference for Spanish likely reflects a comfort level rather than a lack of interest in international collaboration.
- Access to resources (Q13, 2024 only):

An additional question was included in 2024 (Q13) to survey the adequacy of resources and technical support. The average score was 4.3 with a median of 5, showing that the students felt well-supported in completing the project with minimal technical issues.

Finally, in addition to the previous 13 questions, there was an open-ended question where the students could leave their comments and suggestions. The feedback provided by the students helped us to identify the weakest points of the experience and define the following categories with potential improvement actions:

3.3. Project weighting and group composition

Students suggested increasing the weight of the project in the final course grade to better reflect the effort required. The COIL project contributed 15 % to the final grade at the Universidad de Valladolid, 25 % at the Universidad Nacional de Colombia, and 40 % at the Universidad Autónoma de Nuevo León. In response to this suggestion, we increased the COIL project weight from 15 % to 20 % at the Universidad de Valladolid. We believe this change helped motivate students at the Universidad de Valladolid, leading to better performance in the COIL project. Additionally, concerns were raised about the size and composition of the groups, with students requesting smaller groups with a more balanced distribution of members from different universities. To address this, we incorporated the Universidad Autónoma de Nuevo León in the 2024 edition, reducing group sizes to four students, with a maximum of two students from the same institution.

3.4. Project scope and instructor support

Some students requested clearer guidelines on the project's objectives. To improve this, we revised the project documentation for 2024,

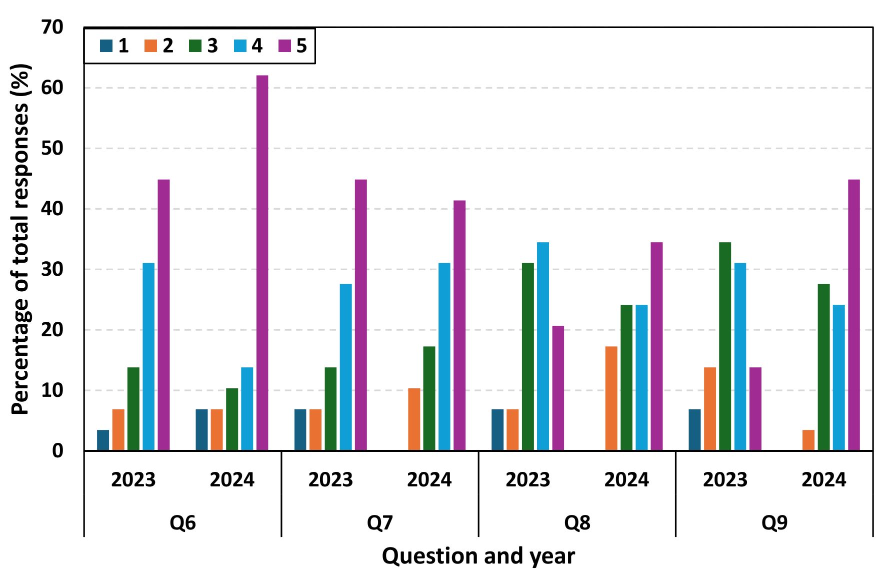

Fig. 5. Distribution of survey responses (Q6-Q9).

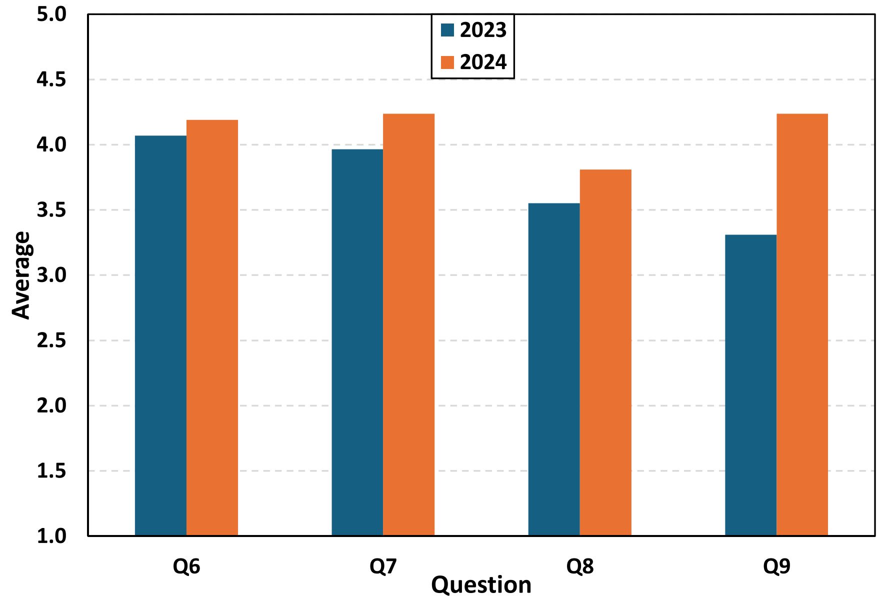

Fig. 6. Average results for questions Q6-Q9.

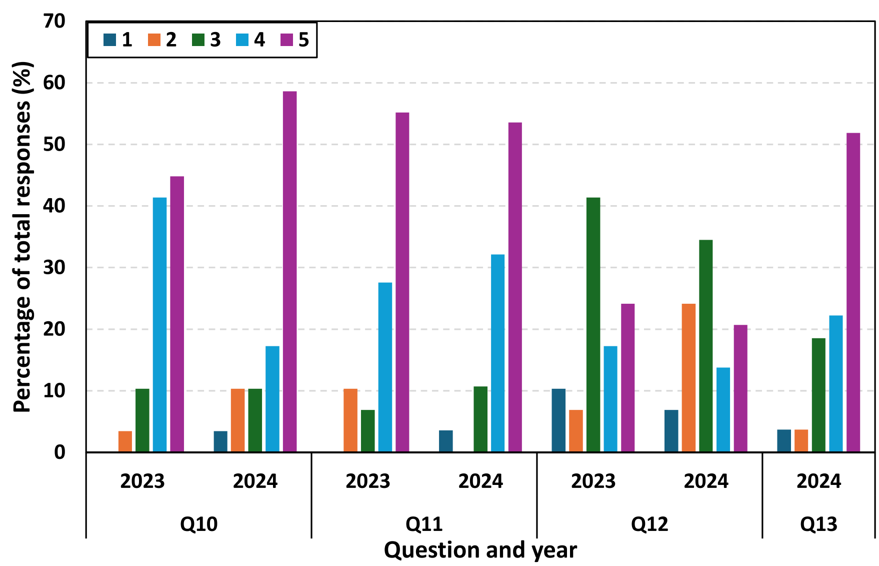

Fig. 7. Distribution of survey responses (Q10-Q13).

providing more detailed explanations and reinforcing these points during the kickoff meeting. Regarding tutor support, some students demanded more structured follow-up meetings. While we remained available for guidance, we deliberately chose not to impose a fixed meeting schedule, as we believe it is important for students to develop autonomy in organizing their work, reflecting real-world professional scenarios.

3.5. Technical and logistical considerations

A common challenge identified was inconsistency issues in the simulator versions used by different universities. To address this, we coordinated with our IT teams to ensure that all students had access to the same versions, minimizing compatibility issues.

3.6. Collaboration and communication

Time zone differences were mentioned as a challenge for project coordination by some students, but this aspect remains a core objective of the COIL initiative, as working across time zones is an essential skill in today's globalized world. To further support collaboration, students suggested the creation of a shared communication platform for discussions and group meetings. In response, we plan to implement a Microsoft Teams® workspace with a general discussion forum and dedicated channels for each team. This will not only facilitate communication within groups but also allow for a centralized space where instructors can address common questions more efficiently.

3.7. Teamwork and conflict resolution

A few students reported difficulties with teammate contributions. While we do not intend to intervene in internal group dynamics, as handling such challenges is part of the learning experience, we will introduce a brief session on teamwork fundamentals in future editions to help students navigate these situations more effectively.

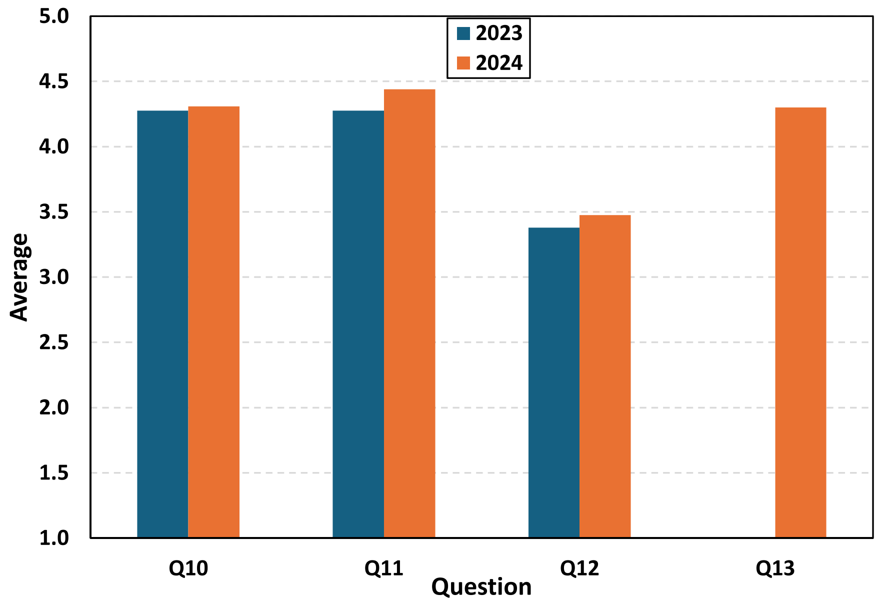

Fig. 8. Average results for questions Q10-Q13.

3.8. Harmonization of course content

Some students suggested aligning the simulation courses across institutions and sharing class materials. While we acknowledge the value of a common curriculum, we believe that working with colleagues who have different academic backgrounds is a more realistic scenario. Our assessment of student projects confirmed that knowledge levels across the universities were comparable, with performance differences being more related to individual effort rather than variations in training.

We are very satisfied with the survey results, which show an increase in the average score from 4.0 to 4.3. Aside from a minor decrease of 0.2 points in the first question, all other questions showed improvement from 2023 to 2024, indicating that the corrective measures taken before the second experience were effective. These results demonstrate the success of COIL experiences in chemical engineering education. After evaluating the students' performance and their satisfaction with the experience, we are committed to continuing our Collaborative Online International Learning projects. We strongly recommend this approach to the chemical engineering education community, as it enhances students' soft skills, particularly their ability to work in international and multicultural environments.

4. Conclusions

This work presents the outcomes and benefits of collaborative online international learning in chemical engineering education. The main outcomes are:

- **Before the beginning of the COIL project:** in line with the recommendations of Vasquez and Ramos (2022) and Ingram et al. (2021), it is helpful to schedule meetings to define the project calendar, as the academic calendar at each institution can affect the project timeline, ensure that students have a similar level of knowledge, confirm that all students have access to the same software version, and distribute the students in a way that no more than 50 % of a team's members come from the same institution.
- **Career Benefits**: The students believe that they will benefit from this experience once they join their first job, reporting an average score of 4.7 (out of 5) in 2023 and 4.5 in 2024 in a dedicated question in this sense asked in the yearly surveys. They feel more confident in their knowledge and abilities (4.2 in 2023 and 4.7 in 2024) and rated very positively the COIL experience (4.3 in 2023, 4.7 in 2024) recommending repeating it in the upcoming years (4.6 in both 2023 and 2024). We believe that the COIL experience has prepared our students to work in multicultural and international environments, enhancing their problem-solving, adaptability, and teamwork skills.
- **Communication Across Time Zones**: The students report effective communication despite the different time zones (4 in 2023, 4.2 in 2024), although they did not clearly feel confident enough to repeat this experience in English rather than in their mother tongue (3.4 in 2023, 3.5 in 2024). As reported by Naicker et al. (2022), different levels of English proficiency can create communication barriers in a COIL experience.
- **Suggested Improvements:** defining a general platform for the communication of all the groups and having an individual kickoff meeting with each team, as also suggested by Ingram et al. (2021). Ensuring that all the students have access to the same version of the software used in the project.

Chemical engineering students who participate in collaborative online international learning are better prepared to face the challenges of a globalized world. In addition to enhancing their technical skills, they build confidence and become better prepared for future professional challenges in diverse and multicultural environments.

CRediT authorship contribution statement

Rafael B Mato: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Iván Darío Gil:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Salvador Tututi-Avila:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Luis Vaquerizo:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ece.2025.07.001.

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