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Industrial Processes Online Teaching: A Good Practice for Undergraduate Engineering Students in Times of COVID-19

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Abstract: The COVID-19 pandemic required higher education institutions to change the modality of face-to-face to online learning overnight. Adaptations were needed, particularly in industrial process training in Chemical Engineering and related careers. Students could not access companies and industries for internships or industrial visits, intended to allow undergraduate students to observe the process engineers' work in professional spaces. This paper describes a pedagogical strategy to overcome this limitation. Here, we report an approach applied in an Industrial Processes course, with students from the 8th to 10th semesters and alumni, from the undergraduate Petrochemical Engineering program at Yachay Tech University (Ecuador). In this course, the students developed group projects involving an industrial process analysis focused on economic sectors of interest in the country. The projects also included a revision of official figures and statistics on production data, consumption, and perspectives of the different markets. The execution of these projects promoted students' active participation through technical discussions by exchanging ideas. A high level of attendance at synchronic classes reflected a high motivation. Through feedback and interviews, the students' comments confirmed the relevance and value of the strategy applied in the course.

Keywords: industrial processes; industrial training; process engineering; problem-based learning; online modality; COVID-19 pandemic

1. Introduction

The training of undergraduate students in engineering—in different disciplines—involves conceptual, practical, and industrial process components. In the specific case of Chemical Engineering and related areas, conceptual training is provided mainly in courses on Fundamentals of Chemical Engineering, Unit Operations, Transport Phenomena, and Chemical Kinetics. Practical training is obtained both in laboratory activities and through the development of 3D scale models representing the topics studied in theory classes. Training in industrial processes can be conducted through elective courses that address industrial process analysis and process design or through internships and industrial visits carried out by students directly in companies and industrial facilities, as their first experience in a real-work context [1,2]. In general, industrial tutors' perception of the internships as pedagogic tools is good or very good [3]. Currently, the recruitment of new professionals in companies is commonly based on their performance during internships. Moreover, industrial visits are an excellent practical pedagogical tool that allows undergraduate students to expand their vision about the development of engineers in professional spaces [4].

Two experienced professionals in the industrial area, Phillips [5] and Ribes [6], agreed that to achieve success as a professional in the industrial sector, three elements of interest are necessary: (i) a strong understanding of engineering fundamentals, (ii) the application of that knowledge in real-world cases, and (iii) the integrating vision of the work environment. It is paramount that engineering students acquire these skills early. Project-based learning in real scenarios is implemented worldwide to complement the training of engineering students in the industrial component [7–10].

One of the challenges of teaching in Chemical Engineering programs and related careers in times of the COVID-19 pandemic is training in industrial processes [11]. Online learning and distance learning are challenges for STEM (Science, Technology, Engineering, and Mathematics) academic programs, with the additional difficulty of making changes overnight. An advantage of the online modality is that it allows the professor to record classes, and later, students can view them repeatedly [12]. However, an online modality presents some deficiencies; it considerably decreases the interaction and collaboration between students and professors and among the students themselves. It also minimizes group work and discussions. Internet connection problems can occur [13], forcing students to be absent from synchronic classes or prioritize recorded classes [14].

Due to the collective isolation measures taken worldwide to deal with the COVID-19 pandemic, many of us went into prolonged confinement, being forced to carry out academic, professional, and work activities from home. This situation caused companies to suspend internship programs intended to receive students or carry out industrial visits. In some cases, students carrying out internships at companies and factories at the time were untimely suspended. Different strategies have been proposed in universities and polytechnics worldwide to provide high-quality training in the industrial component [15], "either by offering students alternative electives online or by carrying out various forms of project work in their home environment under the online guidance of a tutor" [16]. Additionally, virtual reality usage in training for the chemical industry has been proposed [9]. Nowadays, the terminology "emergency remote teaching" has come up as an "alternative term used by online education researchers and professional practitioners to draw a clear contrast with what many people know as high-quality online education" [17]. With the appearance of new variants of COVID-19 [18], it has been necessary to offer educational strategies that guarantee the training of students at different levels of education, with high-quality standards [19], including the online modalities [20–25] and blended learning [26].

Yachay Tech University (YTU) is a public higher education institution located in Ecuador, created in December 2013, where scientific and technological undergraduate programs are taught in STEM areas. The programs have a duration of five years (10 semesters). To graduate, students must complete an undergraduate thesis focusing on applied research or developing case studies on an industrial scale. Currently, this university has five cohorts of graduates who stand out for their excellent training, which has allowed them to successfully apply for graduate programs in countries in Europe, the Americas, and Asia. More details about YTU can be found in Ricaurte and Viloria [27]. Before the COVID-19 pandemic, the YTU organized technical visits to different companies with the intention that the students could directly observe industrial activity, learn about the value chain, the role of process engineers or plant engineers, and the applicability of the theoretical foundations learned during the undergraduate program. The industrial sectors included in the visits involved cement, textile production, sugar cane processing to obtain sugar or bioethanol, metalworking, and oil and gas.

To the best of our knowledge, educational strategies related to teaching in industrial processes for undergraduate engineering students in response to emergency remote education and the emerging need for practical courses are not reported. Therefore, this study presents a pedagogical proposal for undergraduate students' training in industrial processes in times of COVID-19. The motivation was to learn about different industrial processes from a comprehensive vision focused on the industrial activity in the country, which allowed them to complement their training in Chemical Engineering and related areas in times of pandemic, where access to companies and industries is limited for internships or industrial visits. Videos were presented on different processes to immerse themselves in their technical and technological aspects. A fundamental element of this proposal is that students were asked to review official figures and statistics (global and local) on production data, consumption, and perspectives of the different markets. The Industrial Processes course taught in the Petrochemical Engineering program at YTU was chosen to demonstrate the proposal's applicability. The students were organized into two-member teams and were assigned to analyze the country's industrial processes of economic interest. The industrial processes analysis was carried out throughout the semester, with oral presentations that allowed showing the preliminary results and promoting discussion in class, with the active participation of all students. A technical report was submitted at the end of the semester, analyzing each industrial process's technical, technological, statistical, and economic elements.

2. Course Design and Implementation

2.1. Course Description

The Industrial Processes course is an elective subject in the Petrochemical Engineering program, which students take from the 8th to 10th semesters. It complements the training in industrial and large-scale chemical processes. The Industrial Processes course incorporates technical and engineering elements to analyze and understand the transformation of raw materials into finished products, where Unit Operations and Transport Phenomena are applied. Technical aspects are introduced to carry out helpful analysis, based mainly on the description of typical industrial processes, using Block Diagrams (BD), Process Flow Diagrams (PFD), and Piping and Instrumentation Diagrams (P&ID). In addition, these processes help identify critical variables, so students can study the influence of variables on normal operating conditions to obtain the desired product. The hydrocarbon processing, petrochemical, chemical, food, and beverage sectors are reviewed. Students also developed skills to deliver oral presentations and write technical reports in process engineering. Table 1 shows the course syllabus, including the learning outcomes, the competencies developed, and the class units.

The course was taught six hours per week. At YTU, the semesters are 18 weeks long, that is, 16 weeks for regular classes and the final 2 weeks for final examinations. The Industrial Processes course had a duration of 108 h. This course was developed in the Fall semester of 2020, from October 2020 to February 2021. Because of the COVID-19 pandemic, the course was designed entirely online, using Zoom and Moodle platforms. The online classes (synchronous classes) were recorded and made available for students to view later.

2.2. Methods and Students' Evaluation

The course was based on theoretical-practical classes where different concepts are dealt with in an organized way, according to the class units proposed in Table 1. The technical and technological elements of the industrial processes studied were detailed, analyzing the value chain in-depth. In addition, it considered the following aspects: raw materials, operating conditions, the technology used and its maturity, finished products, by-products, and costs. A comparison was made of the main producing and consuming countries of the finished products to establish balances between the exporting and importing countries. Additionally, in each class unit, time was devoted to studying the particularity of said industrial processes in the country and their impact on the domestic economy.

Table 1. Industrial Processes course: syllabus.

<table>
<tr><th>Learning Outcomes</th><th>Competencies Developed</th></tr>
<tr><td>The students will learn to:
○ Identify the different stages that make up an engineering project.
○ Know the documents and deliverables associated with an engineering project.
○ Describe an industrial process based on engineering drawings (e.g., BD, PFD, and P&ID) and identify the value chain of raw materials.
○ Make a critical comparative analysis of existing processes.
○ Analyze typical chemical industry processes in the South American region, emphasizing Ecuador.</td><td>The students will be able to:
○ Develop the capacity to analyze industrial processes based on their general description and engineering drawings.
○ Skills to identify the steps of a typical large-scale value chain.
○ Advanced understanding of process engineering fundamentals to predict and interpret the performance of industrial plants.
○ Know the industrial processes of interest to Ecuador.
○ Application of science and engineering principles to understand chemical processes.
○ Develop teamwork strategies to solve engineering problems.</td></tr>
<tr><th colspan="2">Class Units</th></tr>
<tr><td colspan="2">1. Introduction to Industrial Processes:
• Engineering design process: project steps, project documentation. Drawings: BFD, PFD, and P&ID.
• Industrial and chemical process analysis: raw materials, chain values, product specifications, supply chains, technical and economic aspects.
• The Rules of thumb for Chemical Engineering and related areas.
2. Hydrocarbon Processing Industry:
• Natural gas chain value: conditioning, natural gas liquids recovery, and fractionation. Natural gas valorization.
• Crude oil chain value: E&P and refining: production, treatment, distillation. Gasoline and diesel as the major petroleum products.
• Oil and gas industry in Ecuador: production vs. reserves review, production and refining areas location, domestic market analysis, future projections.
3. Petrochemical Industry:
• Petrochemical industry review: main products (olefins, aromatics, synthesis gas, methanol).
• Olefin production: ethene, propene, butenes, and butadiene.
• Main downstream products from the petrochemical industry: ammonia, urea, and fertilizers.
• Urea and fertilizers in Ecuador: domestic market analysis, imports, future projections.
4. Chemical Industry:
• Chemical industry review: main products, global top chemical firms.
• Surfactants: sodium dodecyl sulfate (SDS) as the surfactant with the highest production worldwide.
• Production and usage of sulfuric acid, chlorine, and caustic soda.
• Lubricating oils: types, world demand, recovery of used lubricating oils.
5. Food and Drinks Industry:
• Food industry outlook: feeding the entire world population as the technological challenge.
• Food and drinks industry in Ecuador: main products, domestic market, sugar production from sugar cane, dairy farming, beer production, cocoa sector.</td></tr>
</table>

Audiovisual elements were used to support the understanding and analysis of the industrial processes studied. Videos were taken from online video platforms (e.g., YouTube), faculty resource centers (e.g., Jove), and corporate videos of large companies. The use of educational videos in Chemical Engineering programs and related areas is likely to encourage interest and motivation in undergraduate students [28,29]. Likewise, collaborative learning [10,30] was promoted in the course, with the active participation of students through the exchange of ideas and constant interaction with the course's professor.

The industrial processes studied in classes aimed to show how the knowledge acquired in Unit Operations and Transport Phenomena is integrated. Also, students were introduced to aspects related to supply chain management and logistics and the role of chemical engineers and related areas in the company operations.

The students' evaluation comprised formative evaluation (30%) and industrial analysis projects (70%). Each of these components is briefly described below:

- Formative evaluation included the development of weekly short assignments and oral seminars. The score considered academic quality and punctuality for the short assignments. Examples of short assignments were (i) the search for statistical data on fertilizer consumption in Ecuador in the last 10 years, and (ii) the identification of the stages that make up the urea production process using a PFD. The oral seminar involved an individual presentation on free issues associated with process engineering and industrial processes. Additionally, some academic projects in process engineering topics from previous cohorts at YTU, presented at different international events and in peer-reviewed journals, were also included in the oral seminars as a strategy to motivate students [31–33].
- The industrial analysis projects consisted of developing a project based on the exhaustive analysis of an industrial process of strategic and commercial interest for the country. The course was divided into teams, and each team was assigned the responsibility of identifying industrial processes in three areas of economic interest. The industrial analysis project consisted of two parts, identified as A and B. Part A (process selection) included the justification of the process and industrial interest, a brief market study (supply and demand), block diagrams, raw materials, main inputs, and products. Part B (process description) required a detailed description of the process, process flow diagrams, identification of main streams, critical operational variables, major equipment, operational philosophy and control, and product quality specifications. The students made oral presentations (30 min) in each part, with an executive summary of the process studied. In addition, the delivery of technical reports was requested under the characteristic format of engineering documents. Partial deliveries of the project were made in weeks #8 and #16 of the semester for parts A and B, respectively. To develop the industrial analysis projects, the students had to review technical information related to the value chain in each process and its graphic representation through BD and PFD. Also, it was necessary to check figures and statistics of production and consumption by consulting official sources, both national and international. In addition, relationships were established between the country's industrial activities and their impact on the economy and society. Project-based learning is one of the most common techniques for training engineering students in different disciplines [34,35].

In previous semesters, some topics developed by the students of the Industrial Processes course were related to sugar production from sugar cane, dairy sector, beer production, and cocoa industry.

An important aspect to highlight was that during the development of this course, three YTU alumni actively participated, they supported the development of process analysis projects and gave seminars based on their undergraduate theses [36–38]. The aforementioned could motivate students and promote the formation of knowledge networks in industrial processes among undergraduate students and alumni of the Petrochemical Engineering program at YTU. Chandra and Supangkat [39] considered that forming knowledge networks increases students' technical skills and allows networking with professionals from different areas of engineering.

3. Research Methodology

A qualitative research methodology was used in this study [40]. Notes were taken along the course about technical and educational aspects to respond to "how" was the development of the projects. A feedback session was held to determine the students' perception of the Industrial Processes course at the semester's end. In addition, the students were invited to participate in semi-structured interviews. The purpose was to gain insight into how students adapted to industrial processes online learning during the COVID-19 pandemic and their appreciation of the strategy applied to teach the course. Filimonyuk et al. [41] commented on the importance of knowing the opinion of students in the implementation of educational programs during the pandemic time. We used the purposive sampling technique, typically used in qualitative studies, in which the researchers decided on the selection of individuals or groups that have rich knowledge and experiences with a phenomenon of interest [42]. The students agreed to participate in this study and recorded the interviews. The interviews had a duration of between 20 and 45 min, with an average interview time of 30 min. All participants answered voluntarily and freely.

The interview included a total of 8 questions and one additional question exclusive for alumni who participated in this study. The interview questions contained two sections: (i) those relating to students' perception of the project during the learning process (Q1 to Q5), (ii) the strategy applied in the development of this course in times of COVID-19, and the distance learning (Q6 to Q8). An additional question (Q9) was intended to know the alumni's motivation to take this course. Appendix A shows the interview questions.

4. Findings and Discussion

4.1. Course Development

Ecuador is a developing country with an excellent vocation for exporting both raw materials and finished products; among the main export items are crude oil, minerals (gold and silver), agricultural products (mainly sugar cane, banana, oil palm, and cocoa), and aquaculture (shrimp and fresh fish). Non-traditional products have been exported recently, such as cut flowers, canned fish, textiles and apparel, processed food, and metallurgy. Based on the contribution to the Gross Domestic Product (GDP) of Ecuador [43], the projects considered for the analysis of industrial processes were grouped into three categories: the oil and gas industry, agroindustry, and the circular economy. Table 2 lists the subjects of the projects developed by the students. Students selected the subject connected to their undergraduate thesis topics in some cases. Therefore, it was expected that the information analysis carried out for the Industrial Processes course was also helpful to complete their Petrochemical Engineering program.

Table 2. Industrial processes course: industrial analysis projects.

Teams	Subjects	Economic Sectors
A	Main processes in oil chain value at the Esmeraldas refinery.	The Oil and Gas industry
B	Natural gas production and processing in the Amistad offshore field.	
C	Palm oil production and the market study in Ecuador.	Agroindustry
D	NPK fertilizer production and the domestic market needs.	
E	Biofertilizer production from natural and mineral sources.	
F	Magnetic separation of black sands with applications in strategic sectors.	The Circular Economy
G	Corrosion inhibitor production from natural sources.	

Next, the technical and methodological elements of interest in developing projects in each economic sector are presented.

4.1.1. The Oil and Gas Industry

Oil exportation is the most important economic activity in Ecuador [44]. The average oil production in 2020 was 479 MBD [45]. Until 2020, it belonged to the Organization of the Petroleum Exporting Countries (OPEC). The hydrocarbon value chain includes onshore oil production and refining activities and offshore natural gas production and processing. The projects considered in this economic sector were "Main processes in oil chain value at the Esmeraldas refinery" (Team A), and "Natural gas production and processing in the Amistad offshore field" (Team B). The refinery in Esmeraldas province, Ecuador, is a high-conversion refinery with the country's largest hydrocarbon processing capacity [46]. The Amistad field is Ecuador's only offshore natural gas field currently in production [47].

Initially, the students reviewed hydrocarbon production data from official national entities [48]. They analyzed the geographical distribution and the available infrastructure of the hydrocarbon business in the country [49]. The students then conducted a detailed analysis of oil refining and hydrocarbon processing unit operations. They prepared specific BD and PFD for the refinery in Esmeraldas and the Amistad offshore field natural gas processing facilities. Students provided a detailed description of each process. Finally, they analyzed the finished products, quality specifications, and consumption in the domestic market. Team A had the opportunity to interact with an engineer who works in the refinery, which was an enriching experience; it allowed them to learn first-hand about the engineering activities carried out in that industrial facility.

During the oral presentations, relationships between the principal process units in the oil and gas industry and the fundamentals of Unit Operations and Transport Phenomena were established. Fregolente et al. [50] highlighted the importance of integrating the primary subjects of Chemical Engineering and related areas and demonstrating their applicability in the industrial sector.

4.1.2. Agroindustry

According to agricultural statistics from Ecuador, 2.25 million hectares were planted in 2020, corresponding to approximately 7.93% of the territory [51]. The crops with the highest production (million metric tons) are sugar cane (11.016), banana (6.023), oil palm (2.446), rice (1.509), and dry maize (1.431). At the economic level, the GDP of the agricultural sector amounted to 8,684 MMUSD, which represented about 8.74% of the national GDP [52]. Given the importance of agricultural activities in the national economy, studying industrial processes in this economic sector and fertilizers in agricultural processes is of interest. The projects considered in the agroindustry were "Palm oil production and the market study in Ecuador" (Team C), "NPK fertilizer production and the domestic market needs" (Team D), and "Biofertilizer production from natural and mineral sources" (Team E).

Initially, the students assessed agriculture statistics related to Ecuador (agricultural land use, agriculture contribution to GDP, fertilizer consumption by agricultural items, fertilizer supplies in the domestic market) from official national sources [51–53]. Additionally, they reviewed technical documentation on industrial fertilizer production [54], the fertilizer market worldwide [55,56], and eco-friendly fertilization [57,58]. The students then carried out a detailed analysis of the value chain of each of the processes, using BD and PFD, highlighting raw materials, main inputs, finished products, and by-products. They also analyzed the supply-demand of the products in the domestic and international markets.

Before the COVID-19 pandemic, a member of Team C completed a six-week internship in a large-scale, palm oil production company. This experience deepened the students' analysis of the industrial processes and identified critical operating variables according to the variability of the raw materials. Team D recognized that NPK (Nitrogen, Phosphorus, and Potassium) fertilizers are positioned as the most widely used chemical fertilizer in the agricultural sector. Students found that 99.50% of the fertilizer used was imported [59].

There is no local industry focused on meeting domestic demand. Most of the imported fertilizers come from companies in the USA, China, and Russia. There is an excessive dependence on fertilizer imports; it is a tremendous potential risk for a strategic sector, such as agriculture. Team E worked with bokashi (a type of compost) as an alternative for the eco-friendly fertilization of banana crops. The process of banana cultivation and its treatment for the export market was detailed. Ecuador is the largest banana exporter globally, and its presence in world trade is increasing [60].

4.1.3. The Circular Economy

The circular economy has been shown to minimize waste generation. Companies can convert non-traditional natural resources into higher-value products [61]. In Ecuador, there are ferruginous and titaniferous sands on the coastline, known as black sands, with potential applications in different economic sectors [62]. Additionally, waste generated in agro-industrial activities could be recovered on a large scale. The projects considered in the circular economy were "Magnetic separation of black sands with applications in strategic sectors" (Team F) and "Corrosion inhibitor production from natural sources" (Team G).

Team F reviewed the composition of black sands and their conventional uses in different countries. The students found that the joint presence of iron and titanium oxides naturally could be valued in adsorbents' formulation for removing contaminants with applications in the textile industry [63] and the oil and gas industry [37]. They reviewed statistical data from resource bases of black areas on some beaches of Ecuador. The students proposed BD and PFD of a magnetic separation process with low environmental impact to obtain iron and titanium oxides. Finally, they estimated the economic profit of the process. In particular, Team G identified potential natural sources (from non-edible sources or agro-industrial waste) to formulate a green corrosion inhibitor. They reviewed agro-industrial statistics of the country to obtain data on the production and consumption of agricultural products. The students also examined the traditional value chain of natural sources to quantify the by-products and waste generated. Then, they elaborated BD to illustrate the main stages of the production process of green corrosion inhibitors, whose main stage is the extraction of active ingredients present in natural sources. Inhibitory power data from Cevallos-Morillo et al. [64] was used to compare the inhibition efficiency of the different proposals from natural sources.

A remarkable aspect within the circular economy category is that the students had to review design criteria, engineering criteria, and reference data at a laboratory scale to define the efficiencies and performance of the stages that comprise the analyzed industrial processes. Yang et al. [65] suggested that these activities improve the practical engineering abilities of undergraduate students.

4.2. Students' Learning

With the development of the projects, the students learned to carry out a comprehensive analysis of the industrial processes, which began with a review of engineering drawings (BD, PFD, and PI&D) that allowed them to know inputs, outputs, main streams and equipment, mass and energy balances, and operating conditions. An accurate industrial process description goes beyond describing the PFD; it must inquire about the processes' reference and current operating conditions, supply chain management, and logistics. Also, it must establish comparisons between the available technological options and the technology applied in the industrial processes. Anamova [66] highlighted the competitive advantage of developing competencies in engineering graphics and technical drawing for chemical engineers and related areas. The preparation of oral presentations and technical reports in the format of engineering projects allowed students to acquire skills for reporting results in studies of optimization, scaling, and analysis of industrial processes [67].

In addition to the specialized training related to the analysis of industrial processes, the students reviewed complementary aspects to their academic instruction associated with the following points:

- Economic indicators, based on national and international databanks, that is, the United Nations system [68], and the World Bank [69]. Domestic indicators from official sources, including the Central Bank of Ecuador [53], and the National Institute of Statistics [52].
- Official information on economic sectors at the international level, such as the Organization of the Petroleum Exporting Countries [70], the Food and Agriculture Organization of the United Nations [71], and the United Nations Industrial Development Organization [72].
- Specific official information on economic sectors at the national level, such as the national oil company [48], Ministry of Energy [49], Ministry of Agriculture [51], and Ministry of Production [73].
- Product quality specifications and compliance with standards based on national and international regulations, that is, the International Organization for Standardization [74], and the Ecuadorian normalization service [75].

The preceding points contributed to the holistic training of students because it allowed them to broaden their vision of the economic and technical environment of each of the industrial processes studied [76]. Furthermore, it offered them the opportunity to train in areas related to the planning of the different productive sectors of the country by handling, knowing how to interpret, and extrapolating the statistical data of each economic sector based on official information. Some authors [77–79] agreed that holistic training complements the professional skills and increases the vocational level of undergraduate students, which substantially increases the chances of being absorbed by the industrial sector or being enrolled in specialized postgraduate programs. Moreover, Alam and Forhad [80] claimed, “engineering education produces technically skilled human resources, which is the fundamental key to economic progress”.

4.3. Class Attendance

Figure 1 shows class attendance. The attendance level averaged 91.07% during the 16 weeks of regular classes, with high participation from the enrolled students (#1 to #9) and the alumni (A1 to A3).

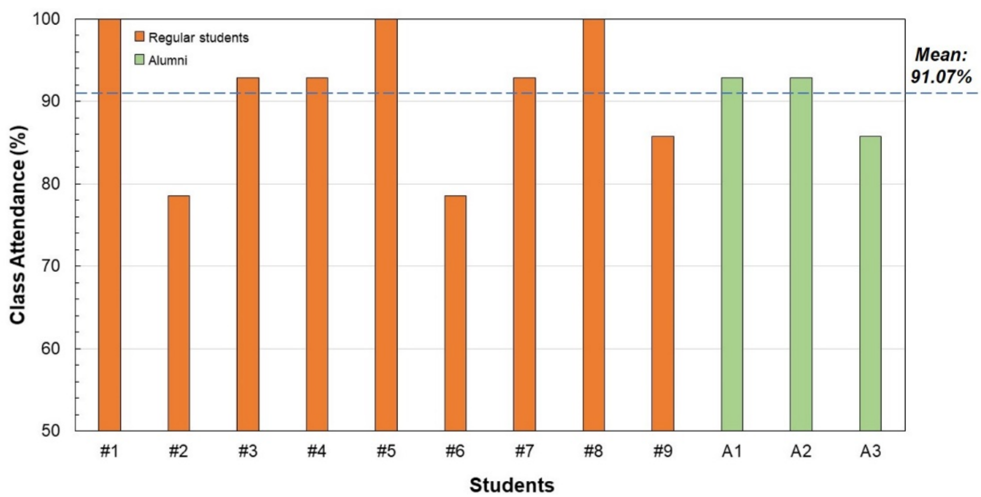

Figure 1. Industrial Processes course: class attendance.

Maintaining student motivation in online courses implies implementing educational strategies that arouse interest [81,82]. The voluntary and constant attendance of the students to the classes during the development of the Industrial Processes course was remarkable.

At YTU, online class attendance can vary widely. Videos were presented in synchronic classes reflecting the main stages of each of the processes. In addition, active participation in student classes was promoted through discussion and the exchange of ideas by proposing scenarios related to the process engineer's role in the context of the industrial processes studied.

Internet connectivity is one of the most frequent drawbacks in online classes worldwide [14,83]. Ecuador is one of the South American countries with the best internet connectivity in urban areas, with the reality being very different in the marginal areas [84]. However, during the development of this study, internet access in various locations in Ecuador did not impede students of the Industrial Processes course from attending classes regularly. Some students (#2, #6) missed classes because of personal problems during the semester that caused them to be absent from some synchronic classes.

4.4. Feedback and Interview Results

The students highlighted the technical discussions in classes, the integration of knowledge, and the analysis of industrial processes focused on the country's interests during the reflection session at the end of the semester. Despite being a course taught online, the classes were not monotonous in the opinion of the students. The constant participation and exchange of ideas during the classes aroused interest in the course, reflected in the high attendance. Likewise, visualizing how the knowledge acquired during the undergraduate program was integrated into industrial processes broadened the students' perception of process engineering. Focusing on the industrial analysis projects on economic sectors of interest to Ecuador allowed students to learn about the country's capacities regarding the availability and value of raw materials. One of the students stated: *"With the Industrial Processes course, it was possible to learn about the adaptability of Chemical Engineering and related areas to understand industrial processes. It involves the raw material transformation into finished products in different economic sectors beyond the oil and gas industry, which provides breadth on the industry sectors in which I could work once I finish my academic program at the University"*.

The interviews were designed to explore students' opinions about the online teaching and learning outcomes of the Industrial Processes course. The most relevant aspects exposed by the students are summarized below:

The first part of the interview included questions related to students' perception of the project during the learning process (Q1 to Q5). The interviews indicated that the development of the projects allowed them to understand and apply concepts learned during the class and from previous courses in the Petrochemical Engineering undergraduate program. The students stressed the importance of teamwork. They indicated that working as a team accelerated the projects' development. In some cases, the teams were composed of students of different semesters; they noted that this was helpful because higher-semester students gave an additional perspective to the project. In general, the teams divided the tasks, established deadlines, and elaborated a schedule to meet (weekly or biweekly) to analyze and discuss the progress of the project. Pang et al. [85] established that universities should allow students to develop soft skills to succeed in their professional life as fresh graduates. Working in teams helped strengthen these skills, including assertive communication, creativity, and resolution of problems.

The second part of the interview was related to developing the Industrial Processes course during COVID-19 and distance learning (Q6 to Q8). According to the interviewees, the methodology used in this course was fruitful and enriching. It allowed them to understand the industrial processes and related topics. Activities included discussions in class about the industrial process selected for each team, which helped the students keep connected with the class and give technical contributions. Students also highlighted the quality of provided course material (e-learning content), such as PowerPoint presentations, study guides, charts and engineering drawings, and case studies, as an essential tool for the learning process. The e-learning content had a positive effect on student satisfaction and learning quality. Professors should pay special attention to the material prepared for the class [22]. The students qualified the teaching–learning strategy in industrial processes as excellent. They indicated that distance learning was an advantage because online lectures were recorded and available to the students for later reference. This agreed with previous studies that mentioned this as an advantage of the online modality [12,13]. The most significant disadvantage, touched on by the students, was that they could not go on field trips or industrial visits. Regardless, one of them pointed out: *"Even though we were taught online, we still learned a lot about industrial processes"*.

An additional question (Q9) was used to discover the alumni's motivation to take this course. Alumni took this class for some reasons, including learning more about industrial processes and taking advantage of the instructor's experience in the industry sector before joining academia.

5. Summary and Conclusions

In this study, we proposed a pedagogical methodology for teaching industrial processes courses applied to undergraduate students, which included the development of industrial process analysis projects focused on economic sectors of interest in the country. This methodology was implemented in the elective course Industrial Processes of Petrochemical Engineering at YTU. Students better understood how the industrial process worked thanks to these industrial analysis projects. Some students had the opportunity to visit some industrial plants before the COVID-19 pandemic, allowing them to identify some aspects to be improved on during the processes and the importance of the knowledge of process engineers. The projects also allowed the students to research and analyze the financial information related to the industrial processes and familiarize themselves with the sources of this information, such as national and international official statistics.

In addition, the projects helped students learn about the Ecuadorian industry and the potential that this country could have with its different natural resources and the industrial waste that could be used. Understanding production processes allows chemical engineers to quickly adapt to various industrial sectors, including refineries, floriculture, and food. Integrating Chemical Engineering with other scientific disciplines and a multiscale approach is desired for an optimal design of safe products to satisfy industrial needs and market demands. We believe that this type of practice (i.e., the development of projects) in class can help link university education and the industry requirements for professionals in Chemical Engineering and related areas.

The students' positive comments at the end of the semester, both in the feedback session and in the interviews, showed that it is possible to maintain their attention during online classes. One of the tools that helped keep students engaged with the course was the used material, including videos that reflect the main stages of the studied industrial processes. The active participation of students was promoted through technical discussions and the exchange of ideas in each of the industrial processes studied. Online classes strengthen learning independently and allow recurring access to recorded classes. Alumni participated in the Industrial Process course, helped to develop process analysis projects, and gave seminars on their undergraduate theses. The research and analysis of the information that students carried out for this course were also helpful for the undergraduate theses they were developing to complete their undergraduate program.

Finally, we can affirm that even though the COVID-19 pandemic limits students' access to industrial plants through internships and industrial visits, the implementation of the methodology proposed in this study provided an approximation to the environment in the industry and the role performed by process engineers on an industrial scale. However, the availability of information about a given industrial process and its economic indicators must be considered. This pedagogical methodology could be extrapolated to other engineering disciplines.

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Appendix A Interview Questions

Q1. Did the project help you better understand the concepts of industrial processes and process design?
Q2. Was this project helpful in demonstrating the role of process engineers or plant engineers?
Q3. Was this project helpful in understanding complementary information related to a chemical engineering process, such as economic indicators?
Q4. Was this project valuable in understanding different industrial processes of interest to Ecuador and understanding its potential?
Q5. Since you worked in a team, did the team's interaction help you improve your learning?
Q6. How were the learning and formation you received in the Industrial Processes course during the COVID-19 pandemic?
Q7. What else do you want to say about distance learning in industrial processes?
Q8. How was the strategy applied to develop this class and its characteristics compared to the other courses you took the semester?
Q9. Only for alumni: Since you are already a former student from Yachay Tech University, what was your motivation to take this class?

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