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Project-based learning as a strategy for multi-level training applied to undergraduate engineering students

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ABSTRACT

This study presents a project-based learning methodology whose particularity is the inclusion of training at different levels of undergraduate engineering programs, which allows for the interaction among students from different semesters who work together on a common project. To show the applicability of the proposed methodology, a project for the industrial production of ethanol from sugar cane was considered. Students enrolled in *Process Design* (9th semester) and *Computer-Assisted Technical Design* (5th semester), courses included in the engineering programs offered by the Department of Chemical Engineering at Yachay Tech University (Ecuador), jointly developed it. The details of the project were presented to the students of the *Introduction to Engineering* course (3rd semester) to boost their interest in the engineering as applied science. The activities carried out in each of the courses are described in detail together with a description of how the learning outcomes were achieved thanks to the implementation of a multi-level training strategy. Teamwork and collaborative-integrated learning are the elements highlighted by the students who participated in the project. Some of the innovative aspects of the proposed methodology include professional training and multi-level learning, the development of logical thinking typical of engineers, the knowledge handover associated with the professional activities of process engineers engaged with real-world projects. Additionally, this methodology prizes the industrial experience that professors at the undergraduate level may have by allowing them to contribute with an engineering vision to the training of young people in engineering projects. This study was inspired by the principle of Constructive Alignment and by goal # 4 (quality education) of the 2030 Agenda for Sustainable Development.

1. Introduction

Project-based learning (PBL) is used in all stages of education, from the perspective of elementary school students (García-Varcálcel and Basilotta, 2017) to the level of complexity characteristic of different programs in higher education (Mitchell and Smith, 2008; Peachey et al., 2007; Farrell and Cavanagh, 2014). Learning to think like engineers is the greatest challenge for engineering students (Dym et al., 2005). Thinking like an engineer is a mental approach to problem analysis which considers technical, economic, and environmental aspects that allow engineers to “conceive, design, implement and operate products, services, technologies, systems and solutions that improve the quality of life” (Al-Atabi, 2014). One possible way to promote this type of thinking in undergraduate students is to rely on highly educated professors with proven industrial experience. Professors who have had direct exposure to actual engineering projects can transmit their knowledge from their professional and practical experience.

Montastruc et al. (2019) highlight the need for an integration of knowledge to secure the success of engineering projects in their different stages: (a) plant design, (b) conceptual design, (c) process design, and (d) equipment design. Hence, the importance of complementing the training of chemical engineering students and related areas with studies in different domains such as economic analysis, project formulation and management, environmental fundamentals and knowledge of the country's industrial capabilities, and their integration and application in real projects that cover different levels of complexity. The industrial employment of chemical engineering and related areas has remained largely traditional worldwide (Voronov et al., 2017). This requires that the interaction between the academia and the industrial sector allows for the training of undergraduate students according to the technical

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competencies required for employability in the industrial sector itself (De Fuentes and Dutrénit, 2012; Feijoo et al., 2019). UNESCO (2013) establishes that a creative collaboration between the public and private sectors must have government support to promote the development of new technologies and the training of professionals according to a sustainable development model.

The 2030 Agenda for Sustainable Development is an initiative of the United Nations (2015), whose aim is to give continuity to the development agenda after the Millennium Development Goals. The agenda includes 17 goals and 169 targets in areas related to climate change, economic inequality, innovation, sustainable consumption, among other priorities. Goal # 4 (education quality) aspires to "by 2030, substantially increase the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship". In the 21st century there are three aspects that should change the educational reality: diversity, self-organization, and cooperation (Morin, 2001). The combination of these three values is of extraordinary importance. These are elements that must be taken into account in the training of future engineers. The Paradigm of Complexity (Morin, 1992) and the Constructive Alignment (Biggs and Tang, 2011) are principles widely used in course design/instruction, and curriculum innovation. Furthermore, the Design Thinking concept (Castillo-Vergara et al., 2014) can be used in problem solving, strategic planning and the development of ideas within the educational environment, including the conceptualization of new universities.

Yachay Tech University (Ecuador) is a public university that opened its doors to students in October 2014. It was created with the purpose of generating research at the international level, and with the purpose of providing its undergraduate students with a high quality scientific education. This university is expected to establish Ecuador as a center of excellence in Latin America, both for innovation and technology. Its mission and vision aim at producing high quality scientific results for the international community, by training excellent professionals and participating in scientific and technological projects aligned with the need to improve the productive matrix of the country (Castillo-Chavez et al., 2017). The teaching staff is made up of professors of different nationalities, all with PhD degrees obtained from prestigious universities in Latin America, North America, Europe and Asia. The university has five schools, which are: (1) the School of Biological Sciences and Engineering, (2) the School of Physical Sciences and Nanotechnology, (3) the School of Earth Sciences, Energy and Environment, (4) the School of Mathematical and Computational Sciences, (5) and the School of Chemical Sciences and Engineering. Each school consists of two departments, one that focuses on the basic sciences and the other on technology and engineering. The undergraduate programs last 5 years (10 semesters) divided in two curricular units: a common core (4 semesters) and a specific vocational training cycle (6 semesters).

In the specific case of the School of Chemical Sciences and Engineering, students can major in three fields. The fields are Chemistry, Petrochemical Engineering and Polymer Engineering. In these last two majors, the students receive intensive training in fundamental areas of chemical engineering as applied science. Additionally, they can choose elective courses to complement their training; for example, *Computer-Assisted Technical Design* (5th semester) and *Process Design* (9th semester) are two of the available courses. Harris and Briscoe-Andrews (2008) propose to use updated topics in elective courses to complete the training of engineers.

At the end of the common core, the students at Yachay Tech University must select their undergraduate program. To help this selection process, students can take the *Introduction to Engineering* course (3rd semester), which aims at presenting students with theoretical and practical aspects related to the engineering profession in its different disciplines. Engineering schools all over the world adopt different strategies for the development of this course. Sadikin et al. (2019) highlight the importance of courses similar to *Introduction to Engineering* as a basis for the training of future engineers, since this allows them to gain experience in solving real-world engineering problems through the best professional practices.

This study presents a project-based learning methodology, whose particularity is the inclusion of training at different levels of undergraduate engineering programs, which allows for the interaction and interrelation of students from different semesters who work together on a common project. It is important that the selected project is based on updated topics relevant to the industrial reality of the country. To show the applicability of the proposed methodology, the professor had 9th and 5th semester students work jointly to develop an industrial production project, within the *Process Design* and *Computer-Assisted Technical Design* courses, respectively. Subsequently, the results of the project were presented to 3rd semester students, in order to boost their interest in the study of programs in the engineering area, specifically in chemical engineering and related areas. Additionally, this methodology prizes the previous industrial experience that professors at the undergraduate level may have by allowing them to contribute with an engineering vision to the training of young people in the area of engineering projects. Rodríguez et al. (2018) stated that the use of non-traditional pedagogical tools promotes learning motivation, hence the need to propose a project-based multi-level learning as an innovative strategy in the training of future chemical engineers.

PBL is widely used in higher education in different fields of knowledge which range from areas related to health sciences to areas associated with engineering. Various studies have proposed improvements/modifications to this methodology. Cifrain et al. (2020), Heinis et al. (2016), and Nikiema et al. (2009) developed project-based learning as an engineering student training strategy, and applied it to the same group of students in consecutive semesters. Furthermore, Zupančič et al. (1997) worked on joint training between undergraduate and graduate students. However, there are no specific studies on the application of the multi-level criterion in the training of undergraduate students. For this reason, this study presents a new learning methodology, based on the development of engineering projects with the joint participation of undergraduate students from courses at different levels of their programs.

2. Course design and implementation

The courses directly involved in this study are *Process Design*, *Computer-Assisted Technical Design* and *Introduction to Engineering*. These courses correspond to different semesters in the curriculum of the undergraduate programs in Petrochemical Engineering and Polymer Engineering at Yachay Tech University.

2.1. Course description

- The course *Process Design* (9th semester) incorporates technical and engineering elements for the analysis and understanding of raw material transformation into finished products. Besides, it aims at the development of engineering skills necessary to carry out the different activities related to the execution of different stages of engineering projects. This course complements the training of students in the industrial chemical processes area. It covers some technical topics for an effective process analysis and plant design, which are mainly based on principles, practices and economic subjects related to undergraduate design projects. In addition, flowsheet development, financial analysis, safety and

Table 1
Course syllabuses: learning outcomes and competencies developed.

Course	Learning outcomes (the students will learn to)	Competencies developed (the students will be able to)
Process Design (9th semester)	• Develop the capacity to analyze industrial processes based on the general description of processes and process flow diagrams. • Develop advanced understanding of the fundamentals of process engineering. • Perform a preliminary economic evaluation of industrial projects. • Carry out a basic engineering project applied to an industrial plant design. • Apply science and engineering principles to understand chemical process. • Develop teamwork strategies to solve engineering problems.	• Apply engineering and design criteria in the analysis of chemical processes. • Describe a chemical process from engineering diagrams (BD, PFD, and PI&D). • Identify processing alternatives for manufacturing specific products. • Apply technical criteria and rules of thumb for process design. • Make effective technical reports in the process engineering area.
Computer-Assisted Technical Design (5th semester)	• Develop skills for distinguishing between different types of engineering drawings. • Develop the abilities to read drawings used in the chemical engineering field. • Develop the competences to use design software (AutoCAD, MS Visio). • Develop capacities to analyze industrial processes, based on the general description of processes and process flow diagrams. • Develop advanced understanding of the fundamentals of process engineering, which allow predicting and interpreting the performance of industrial plants. • Develop teamwork strategies to solve engineering problems.	• Read chemical engineering and related drawings. • Use computer-aided design software, commands and tools, which will allow him/her to create, visualize and edit two-dimensional drawings. • Solve problems related to the tasks of the profession, with the application of scientific bases of a basic nature. • Communicate graphically through flowsheets, diagrams, slides, following national and international standards.
Introduction to Engineering (3rd semester)	• Be introduced to engineering as a profession to inform them broadly on the different scenarios, which the undergraduate students will face in their professional activities. • Will be informed adequately in order to be able to choose an undergraduate program into chemistry as basic science or chemical engineering (Petrochemistry / Polymers) as applied chemistry discipline.	• Give a global vision of the engineering profession and the contribution in the development of humanity. • Understand the relationship science - technology within the context of the profession. • To have a clearer idea of the contents of the chemistry and chemical engineering. This will allow making an informed choice.

environmental impact, and industrial process optimization are introduced too. The course comprises of the development of an engineering project that consists mainly into carrying out a basic engineering design applied to a large-scale industrial plant using chemical engineering principles and economic indicators.

- The course *Computer-Assisted Technical Design* (5th semester) allows the students to implement chemical engineering ideas graphically in a clear and quick manner using a computer-aided design software. Furthermore, the course incorporates technical and engineering elements for the analysis and understanding of raw material transformation usually carried out in industrial facilities. This course introduces the students to the interpretation and creation of engineering drawings using the typical standards and set of symbols for equipment, piping, and operating conditions applied to chemical engineering and related areas in an effective way. In addition, the course offers a basic learning of computer-aided design software (AutoCAD, MS Visio) for drawing technical flowsheets and engineering documents, i.e. block diagrams (BD), process flow diagrams (PFD), and piping and instrumentation diagrams (P&ID).
- The course *Introduction to Engineering* (3rd semester) is essentially a theoretical course that introduces the students to a wider and general understanding of the characteristics of the engineering profession and, at the same time, it helps them assess the aspects that are required for their professional formation. The contribution of the course is focused on introducing the students to engineering as a profession, and on informing them broadly about the different scenarios they will face in their professional activities. The main topics covered in the course are related to the knowledge of the engineering fundamentals, the responsibilities of the engineer, working opportunities, types of engineering degrees, as well as to the alternatives for their professional development. Due to the informative and guiding nature of this course, it is organized in seminars given by several professors who can transmit their professional experience as engineers. The course *Introduction to Engineering* is taken by all the common core students of Yachay Tech University.

The underpinning principle used to design the courses was the "seven complex lessons in education for the future", which was proposed by Morin (2001). Table 1 shows the learning outcomes and competencies developed in each of the courses.

The courses *Process Design* and *Computer-Assisted Technical Design* are taught six hours per week each. Additionally, the students have access to two tutoring hours per week where they can have open consultations with the professor about any of the topics covered in class. The *Introduction to Engineering* course is taught with a frequency of three hours per week. At Yachay Tech University, regular semesters last eighteen weeks, sixteen of which are used for regular classes and the last two weeks are used for final exams and semester closure.

It is desirable that the professors who teach these courses possess solid experience as technical specialists in the industrial sector and/or as engineers in engineering projects. This will allow them to teach from the practical perspective of professionals who have directly participated in the operational dynamics of an industry or in the execution of real engineering projects. The professors involved in this study have directly participated in engineering projects in the oil & gas industry, specifically in projects related to the processing and conditioning of natural gas. Jamieson and Shaw

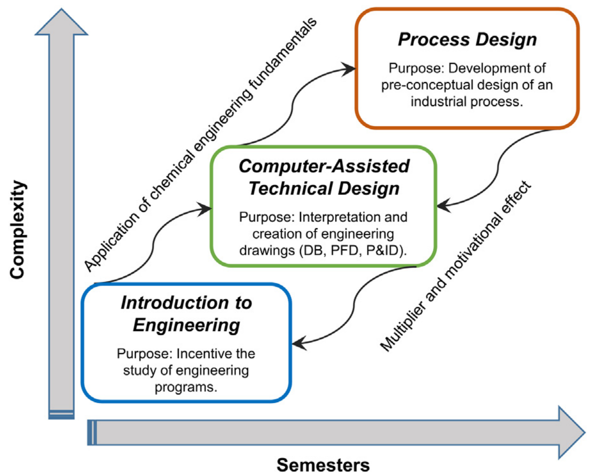

Fig. 1. Multi-level training implementation: master plan.

(2020) highlight the benefits derived from the return of industry based professionals to universities and academia, as they can act as advisors on courses related to *Process Design*.

2.2. Multi-level training implementation

The methodology developed in this study is based on project-based learning techniques, whose particularity is the inclusion of training at different levels of the engineering programs. In this case, project-based learning techniques are based on industrial projects of interest to the country. The interaction and interrelationship of students from different semesters who work on a common project has a multiplying and motivational effect on young people who have recently started their studies in the area of engineering as applied science. Project-based learning as a strategy for multi-level training applied to undergraduate engineering students is inspired by the principle of Constructive Alignment (Biggs and Tang, 2011) and goal # 4 (quality education) of the 2030 Agenda for Sustainable Development (United Nations, 2015). The idea is conceiving teaching/learning activities and assessment tasks that directly address the intended learning outcomes in a way not frequently achieved by traditional lectures, tutorial classes and exams. This is done by requiring the students to engage in learning activities strictly related to the desired outcomes.

Fig. 1 shows the implementation of multi-level training and highlights how the level of complexity in the application of concepts and fundamentals of chemical engineering increases proportionally in the most advanced courses of the undergraduate engineering programs.

The methodology proposed in this study, requires the selection of an industrial project focused on the transformation of raw materials into highly profitable products. To achieve this, the identification of the available resources and of the opportunities of developing projects that contribute to the economic and productive matrix of the country is necessary. The development of the project is carried out in a methodical way within the domain of two or more courses of the undergraduate programs in different semesters, where the students of the engineering programs participate according to their level of experience. The professor's guidance and supervision are important for the correct selection of a project that could be developed on an industrial scale, especially in the case of a project that requires the application of fundamentals and concepts of chemical engineering.

The students learn how to develop conceptual and basic engineering elements of an industrial project during the *Process Design* course, which is taught at the final stage of the undergraduate programs. The project should include a brief market research, a plant location analysis, the design bases establishment, the technology selection, a detailed process description, the specifications of main equipment, and an economic study (class V).

Then, in the *Computer-Assisted Technical Design* course (dedicated to learning interpretation techniques and creating engineering drawings, symbology, and applied regulations), students are able to develop the diagrams necessary for the project, namely BD, PFD and PI&D. All the documentation generated in the above mentioned courses is used to encourage the study of engineering programs, through practical examples of what the professional career of engineers dedicated to the conceptualization and design of large-scale industrial projects might entail.

For an effective implementation of the methodology described above, the integration and participation of different professors from the Department of Chemical Engineering is recommended. In addition, a regular contact between the students and chemical and process engineers from different industrial sectors, which could happen because of pre-professional internships or organized industrial visits, should be privileged.

The project selected as an example of application of the methodology proposed in this study was *"Design of a plant for ethanol production from sugar cane: application to the northern zone of Ecuador"*. The selection of the project was motivated by the need to valorize an agricultural item (sugar cane) to contribute to the industrial production of ethanol as an additive used in the formulation of biofuels. It is important to highlight that in the year 2018, the consumption of biofuels in Ecuador represented 56.3 % of the national demand for gasoline for the automotive sector, with a tendency to continue increasing in the coming years (Chiriboga et al., 2020).

The project was developed jointly by students enrolled in different courses, with the following specific objectives:

- The development of conceptual and basic engineering strategies for the project was carried out in the *Process Design* course, which were structured and organized in the way engineering projects are commonly executed. Fig. 2 shows the activity plan with the specific project tasks organized on a weekly basis, with the definition of three technical reports that could be delivered throughout the semester (# 1 process selection (4th week), # 2 process description (10th week), and # 3 process design (16th week)). At the end of the course, the students carried out a project dissertation to show the results of their work before a panel of experts made up of professors from Yachay Tech University, with practical experience in engineering projects at different scales.
- The students of the *Computer-Assisted Technical Design* course were in charge of the elaboration of the engineering drawings (DB, PFD, PI&D) so that, through the technique of learning-by-doing, they became familiar with the use and management of computer tools to carry out process flowsheets. Additionally, as a final evaluation of the course, they produced a 3D model as a graphic representation of the industrial process of ethanol production.

There were regular class and tutoring sessions with the joint participation of students from the *Process Design* and *Computer-Assisted Technical Design* courses, where technical aspects related to the project were discussed, and working groups were established to carry out the different project activities. This initiative contributed to multi-level training among students from different semesters of the same undergraduate engineering programs.

The project results were presented to students of the *Introduction to Engineering* course, through a series of seminars aimed at showing the applicability of engineering in industrial projects. In addition, the seminars illustrated the role of the process engi-

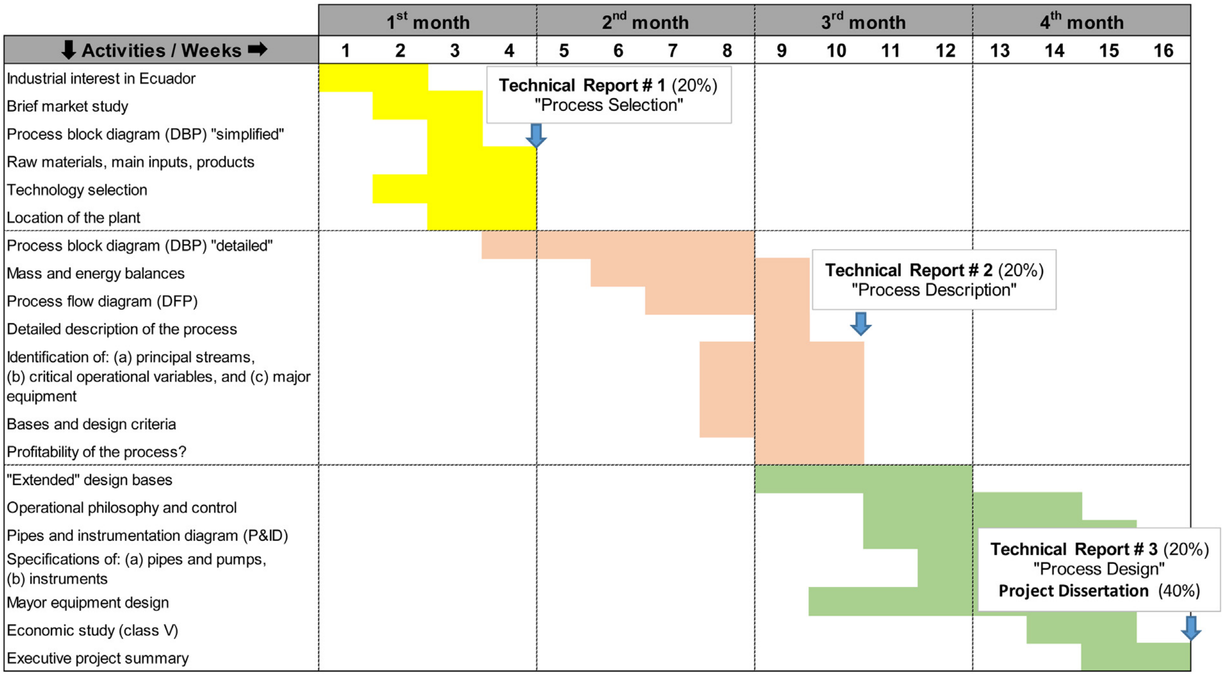

Fig. 2. *Process Design* course: activity plan.

neer as one of the possible career opportunities for engineers. Furthermore, the outcome of the project was on display for the entire university community for a month, which included the main results of the project together with the elaborated 3D model. Students from each of the courses held presentations followed by question-and-answer sessions with people interested in the project.

At the end of each course, professors and students held a joint reflection session where they discussed how the activities carried out during the semester contributed to the achievement of the learning outcomes. This happened because students' feedback is important to identify opportunities for course improvement in the following semesters. As Biggs and Tang (2011) pointed out "a characteristic of award-winning university teachers is their willingness to collect student feedback on their teaching, in order to see where their teaching might be improved. Expert teachers continually reflect on how they might teach even better".

Finally, to measure the students' appreciation of the methodology proposed in this study, different types of surveys were conducted at the end of each course. For the *Process Design* and *Computer-Assisted Technical Design* courses, institutional surveys were used to assess the professors' performance. On the other hand, for the *Introduction to Engineering* course, a specific questionnaire survey was developed in order to quantify the impact of the project presentation on the motivation and interest of young people when selecting undergraduate programs from the Department of Chemical Engineering.

The project was executed between the second semester of 2018 and the first semester of 2019, with the joint participation of the four and ten students enrolled in the *Process Design* and *Computer-Assisted Technical Design* courses, respectively. A project presentation talk was given during the *Introduction to Engineering* course for three successive semesters (to approx. 150 students). Yachay Tech University started its undergraduate academic programs in October 2014. The group of *Process Design* students who participated in the project belonged to the first group who graduated from the University in September 2019.

3. Impact on students' learning

3.1. Process design

To establish the initial technical parameters for the project of designing an ethanol production plant from sugar cane, the students spent two weeks searching for and analyzing information associated with statistics on the production, consumption, and current usage of ethanol in Ecuador. The established processing capacity was 315,000 tons / year, which allows for the obtainment of 25.87 million liters of anhydrous ethanol per year. The defined end-use of the alcohol produced in the plant is as an additive in the formulation of biofuels for the automotive sector. The purpose of this first stage of the *Process Design* course was for the students to explore and study the topic (usage of ethanol in Ecuador). Furthermore, they could understand the importance of industrial projects and their direct involvement in the satisfaction of the country's needs.

The selection of the technology to be used was made after a bibliographic review of different sugar cane fermentation and distillation processes, which allowed for the identification of conventional processes with proven technological maturity. The proposed value chain (Fig. 3) was based on the extraction, treatment and concentration of sugar cane juice, a simple fermentation process using bacteria, and a two-stage azeotropic distillation with hexane.

During the development of the project, the students completed each of the activities defined in the initial planning (Fig. 2); they also delivered additional weekly progress reports together with the technical reports. Weekly meetings were held with the professor in charge of the course in order to support the decision-making process regarding the establishment of technical and engineering criteria. For example, the meetings dealt with design factors, flexibility in process operation, process control considerations, etc. (Towler and Sinnott, 2013). All the equipment in the plant were suitably sized, but each student was responsible for creating the detailed design of one unit process.

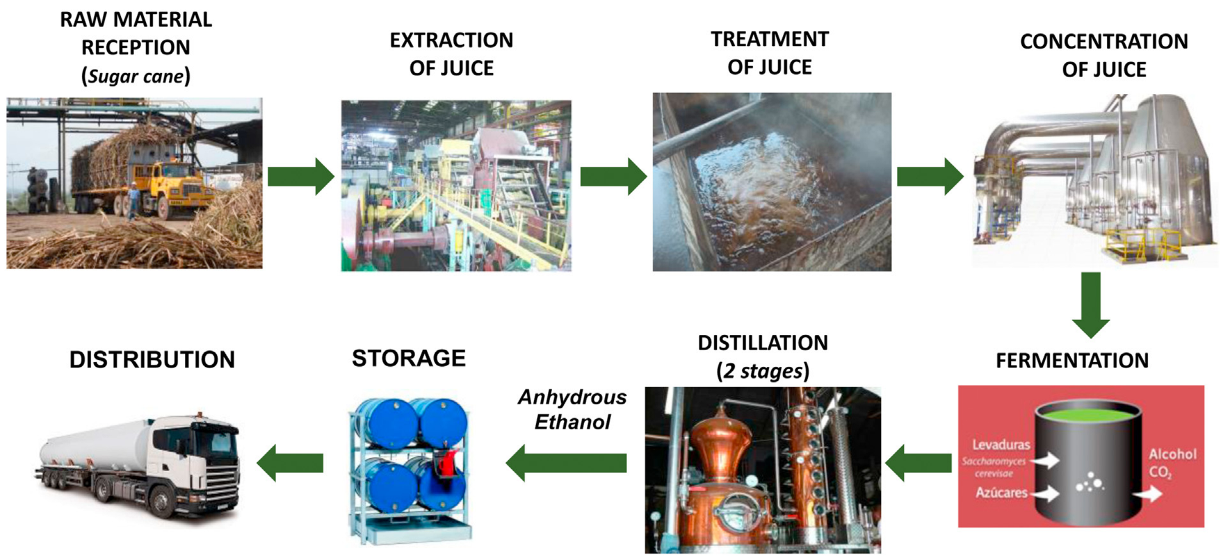

Fig. 3. Ethanol project: Block diagram (BD).

For the final grading, the students prepared an executive summary of the project and made an oral presentation before a panel of professors with experience in the industrial sector. The use of real and updated data within the project and a description of its feasibility in Ecuador, according to the technical and economic indicators obtained, were highlighted. The results of the conceptual engineering process developed by the students of the *Process Design* course were presented at the international event Humboldt Kolleg Ecuador 2019, followed by a publication in a peer-reviewed journal (Ricaurte et al., 2019). San-Valero et al. (2019) underline how important it is for students of chemical engineering and related areas to develop writing and presentation of project results and communication skills, by using oral presentation and/or production of posters in a professional-like environment.

Vega and Navarrete (2019), who used a pilot plant to capture CO_2, developed a teaching methodology similar to that proposed in this study. The advantage of our methodology is that it is applicable to an industrial-scale project, which includes the stages of technology selection and economic analysis, and does not take into consideration an already built facility. This offers students the opportunity to learn about technology selection strategies based on technical, economic and environmental criteria, and about economic studies involving the estimate of capital costs, operating costs, the determination of net present value (NPV) and internal rate of return (IRR), which are characteristic economic indicators of a project.

The positive impact on the learning process of the students of the *Process Design* course was that they were able to carry out analysis of industrial processes and perform the activities characteristic of the basic engineering of an industrial-scale project. In addition, communication, the exchange of information and joint work with the students of the *Computer-Assisted Technical Design* course allowed them to get practice in preparing the flowsheets required in the project. In general, the students learned about the organization of engineering projects, planning activities and meeting deadlines according to the proposed planning, thanks to the support of professors with experience in project development at different scales. Ramazani and Jergeas (2015) underline the importance of undergraduate students getting involved with the execution of engineering projects, since this practice prepares future engineers for the dynamics of the projects, which include the development of critical thinking skills to deal with complexity, and the development of leadership and interpersonal skills. Eventually, this type of practice helps train project managers to be engaged within the context of real life projects.

3.2. Computer-assisted technical design

The first section of the course was dedicated to the training of students in regulations and symbols used for the elaboration of technical drawings in engineering, and to the development of skills for the description and analysis of industrial processes. Then, the students were trained in the management and use of 2D and 3D computational tools for the elaboration of engineering drawings (BD, PFD, PI&D). The level of complexity of the drawing up of the process flowsheets gradually increased, starting with sections of plants from a single flowsheet, continuing with a series of flowsheets representing complete plants, until reaching the PI&D with details associated with the control strategies of equipment and technical specifications of pipes.

The academic evolution of the students was remarkable because at the beginning the flowsheets did not include complete information, and as the students acquired expertise in the use and management of the computer-aided design software the quality of their work increased. Finally, they developed technical skills in the domain of graphical symbols for flow and piping diagrams, which allowed them to produce process flowsheets with the professional quality required in an engineering project. Glassey et al. (2013) highlight the importance of the use of computer tools in different areas of chemical engineering as a complement to learners' training.

During the development of the process flowsheets for the ethanol production plant project, there was constant communication between the students of the *Process Design* and *Computer-Assisted Technical Design* courses, which aimed at the exchange of information regarding the process units that constituted the plant, the identification of pipes and equipment, and the detailed mass balance of the plant.

The final evaluation of the course consisted of presenting an executive summary with all the engineering documents developed for the ethanol production plant project. Additionally, the students had to build a 3D model of the project, showing each of the process units and plant layout. For the construction of the 3D model, the students worked together and came up with all the decisions related to the type of materials to be used, 3D representation of the process units, distribution of spaces and the best size of the 3D

Fig. 4. Ethanol project: industrial plant 3D model.

model that should have allowed viewing the entire plant for the production of ethanol from sugar cane as per the proportions of its parts. Fig. 4 shows the 3D model with the sections (treatment, fermentation, distillation, and storage of products) and the spaces for monitoring and controlling the plant.

The students of this course were responsible for organizing an exhibition of the project in the Central Library of the university to show its results together with the elaborated 3D model. This activity aroused the interest of the entire university community due to the strategic and economic importance that this type of projects holds for Ecuador, because sugar cane is one of its important agricultural products and ethanol is the additive for the formulation of biofuels.

The impact on the learning process of the students of the *Computer-Assisted Technical Design* course was that they learned about the methodology and symbology used for drawing flowsheets in the area of chemical engineering and related careers, through the use and management of computer-assisted design software. They also gained knowledge in designing and building 3D models that represent industrial plants. The quality of the students' teamwork during the conceptualization of the 3D model of the ethanol production project from sugar cane was remarkable.

3.3. Introduction to engineering

At Yachay Tech University, the *Introduction to Engineering* course is based on technical seminars taught by different professors, where topics related to engineering as applied science are addressed with the intention of awakening the interest of the students towards undergraduate engineering programs. These seminars are held throughout the semester and focus on presenting updated projects with high relevance in the industrial sector of Ecuador.

The presentation of the ethanol project was carried out in a 1.5 -h session, where the importance of ethanol as an additive in the formulation of biofuels within the industrial context of the country was highlighted through the results of the study. The presentation had the support of the students of the *Process Design* course; in an interactive way, they showed their contributions to the development of the project, which consisted of defining the plant capacity, the technology selection, the equipment sizing, etc. The students of the *Computer-Assisted Technical Design* course, who prepared the 3D model to help improve the understanding of the process, carried out the detailed description of the process. For the evaluation of the seminar, the students wrote an essay about the fuel market in Ecuador and its expected development in 30 years from now, with a particular focus on biofuels within the country's energy matrix.

The results of the ethanol production plant project were shown for three consecutive semesters to the *Introduction to Engineering* students, as a motivational strategy to encourage them to study the undergraduate engineering programs associated with the Department of Chemical Engineering by presenting a sample of professional activities typically executed by engineers dedicated to industrial projects. Tao et al. (2015) implemented a similar strategy for electrical engineering students.

The *Introduction to Engineering* course impacted the students' learning by allowing them to have a global vision about engineering as a profession as well as learning how to be prepared for activities that engineers will do in the future, especially those associated with engineering projects. In addition, it allowed them to visualize their contribution to the development of technology and industry in the country, taking into account the production of the ethanol production project from sugar cane. Finally, this course helped the students from the common core of Yachay Tech University choose the undergraduate program they would want to study.

3.4. Students' feedback

Teamwork and collaborative-integrated learning are some of the elements highlighted by the students of the courses where the project-based learning methodology was adopted, with the aim of training the learners at different levels of undergraduate engineering programs in the development of a common project. This statement is supported by the feedback received by the students in the reflection session at the end of the courses. Reflective teaching is a strategy that helps improve the teaching-learning process because it allows identifying opportunities for improvement from the perspective of the students (Soodmand and Farahani, 2015).

The *Process Design* students highlighted that the course's planning and development strategy, which was similar to the organization of a real-world engineering project, allowed them to complement their university training and prepare them for future professional activities. Additionally, the experience of interacting with younger students from earlier semesters gave them the opportunity to show their classmates the applicability of the concepts and fundamentals developed in the *Unit Operations* and *Transport Phenomena* courses, which they previously took, by using a technical and engineering language common among the students. In relation to the *Computer-Assisted Technical Design* course, the students enjoyed the possibility of establishing communication between students of the final and the initial stage of the engineering programs.

Fig. 5 shows the results of the evaluation of the professors' teaching performance from the perspective of the students of the courses *Process Design* and *Computer-Assisted Technical Design*. The professor performance evaluation consists of a set of questions focused on evaluating four areas. They are (a) the cognitive area, which refers to

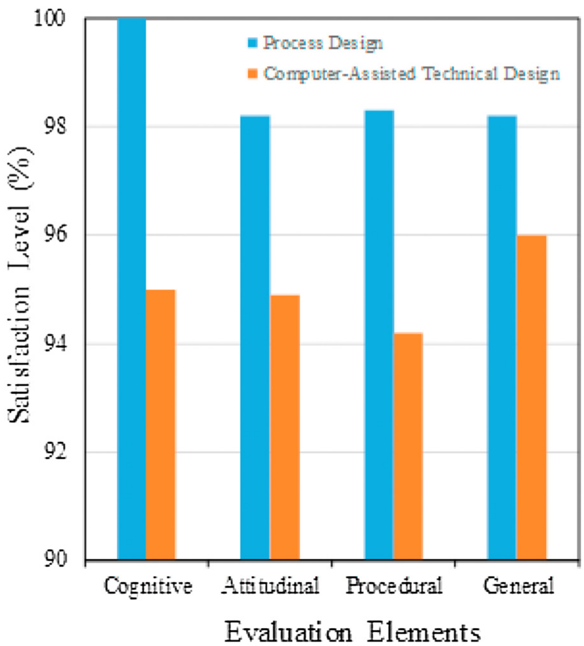

Fig. 5. Course evaluation surveys: *Process Design* and *Computer-Assisted Technical Design.*

the knowledge that the professor shows in the classroom and the ability to clear doubts effectively. (b) The attitudinal area, which deals with the motivational aspect that the professor transmits to the students to help them achieve significant learning and professional ethics standards. (c) The procedural area, which refers to the application of the best pedagogical practices and the use of tools to improve the learning process. And finally, (d) the general area, which refers to the professors' performance from an overall perspective. In general, the feedback received was very suitable, with scores higher than 94.0 % in each of the elements included in course evaluation surveys. Within the quality teaching policies of Yachay Tech University, evaluations higher than 90.0 % are considered very good or excellent.

The comments from the *Introduction to Engineering* students focused on highlighting how up-to-date and relevant to the liquid fuel market in Ecuador the project of the ethanol production plant from sugar cane was. In addition, they also underlined the versatility of the professional performance that a process engineer can demonstrate if he or she is dedicated to the project area. In particular, one of the students said:

"The description of the industrial process aroused my curiosity because I could become aware of how the design of plants could be applied to other areas besides the ethanol project; the fact of combining experimental chemistry and the industrial sector seems quite interesting to me".

To quantify the level of motivation and the interest towards the selection of the undergraduate programs of the Department of Chemical Engineering of the students of *Introduction to Engineering*, a questionnaire survey centered on three fundamental questions was prepared:

- Project interest: Do you consider that the technical and economic aspects associated with the ethanol production plant project presented in class are relevant to your training as a future professional graduate of Yachay Tech University? (Question # 1).
- Motivation towards engineering programs: Would the presentation of industrial projects such as the ethanol production plant from sugar cane motivate you to choose undergraduate programs related to the area of chemical engineering? (Question # 2).
- Choice of engineering program: The elaboration of process flowsheets, the description of industrial processes and the realization of economic studies are daily activities for chemical engineers. Do you think that the presentation of the ethanol project helps 3rd semester students choose an undergraduate program from the School of Chemical Sciences and Engineering? (Question # 3).

The survey was sent by e-mail to the students of the *Introduction to Engineering* course during three consecutive semesters, with a participation of 90.38 %. Fig. 6 shows the results of the survey.

More than 80 % of the respondents considered the ethanol production plant project to be of interest to their training as a future professional, since it would have them to learn about technical and economic aspects of engineering projects at industrial scale from the early stages of their engineering programs. Regarding the motivation that the project aroused, and its help in the selection process of the undergraduate programs offered by Yachay Tech University, in particular those associated with the area of chemical engineering, 60 % of the respondents considered that said project effectively inspires and encourages the study of engineering as applied science. In addition, more than 90 % highlighted the favorable nature of this type of project for the definitive selection of chemical engineering and related areas. Those students who answered negatively to Questions # 2 and # 3 of the survey did it because their vocational motivation was already oriented towards the study of other undergraduate programs offered by Yachay Tech University (e.g. Biology, Physics, Nanotechnology, Geology, Mathematics, Information tech-

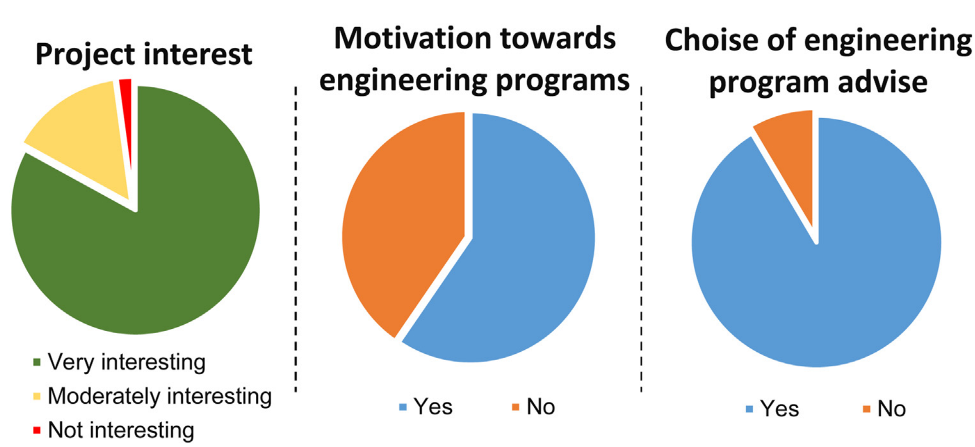

Fig. 6. Introduction to Engineering: survey.

nology, Chemistry, etc.). The correct selection of the degree is a key factor for the professional success and future work of a student.

Asteris et al. (2014) report that "all contemporary reports on engineering education emphasize that engineering graduates need to be able to apply theoretical understanding, creativity and innovation, team-working, technical breadth, and business skills; these reports also emphasize that in order to do this, engineering education must keep pace with the changing requirements of the industry". Hence the need to develop and implement educational methodologies that inform the students of engineering programs about the type of work activities engineers can perform, especially because designing projects is one of the areas of greatest professional development worldwide.

4. Summary and conclusions

This study presented a project-based learning methodology based on an innovative approach which includes training at different levels of undergraduate engineering programs by using industrial projects, which allows for the interaction and interrelation of students from different semesters who work on a common project. In the later semesters, the aim of this methodology is to address the need to teach greater complexity in the application of chemical engineering fundamentals and concepts; while in the earlier semesters, the aim of this methodology is to achieve a multiplying and motivational effect for the students who start their undergraduate program. The study was inspired by the principle of Constructive Alignment and goal # 4 (quality education) of the 2030 Agenda for Sustainable Development. In order to demonstrate the applicability of the proposed methodology, an industrial ethanol production project was devised. Ethanol is used as an additive in the formulation of biofuels. The project was developed jointly by the students of the *Process Design* (9th semester) and *Computer-Assisted Technical Design* (5th semester) courses of the Petrochemical Engineering and Polymer Engineering programs at Yachay Tech University (Ecuador). The planning of the activities was carried out according to the characteristic structure of a real engineering project. In addition, a 3D model was built to represent the industrial process. The details and results of the project were presented to the students of the *Introduction to Engineering* course (3rd semester) to boost their interest in the study of programs in the area of engineering as applied science, especially chemical engineering and related areas. An exhibition was organized in the Central Library of the University in order to show the results of the project to the university community.

At the end of each course, professors and students participated jointly in a reflection section to review how the activities carried out during the semester contributed to the achievement of the learning objectives. In addition, to measure the level of interest of the students towards the implementation of the methodology proposed in this study, different types of surveys were conducted at the end of each course. Teamwork, collaborative and integrated learning are some of the elements highlighted by the students of the courses where the project-based learning methodology was implemented as a strategy for multi-level training of undergraduate students. Some of the notable elements of the proposed methodology are professional development and multi-level learning, development of the logical thinking process characteristic of engineers, knowledge of the professional performance of engineers in real-world projects. Additionally, with this methodology, the industrial experience of professors is valued because it contributes with an engineering vision to the training of young people in the area of engineering projects on an industrial scale. This could translate into a competitive advantage for students because of the technical-economic approach required in projects that would be included in their high-quality training as human capital to benefit the country's industrial development. The methodology proposed in this study can be extrapolated to other areas of training in the field of chemical engineering.

Declaration of competing interest

The authors report no declarations of interest.

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