Online-Journals.org

iJEP International Journal of Engineering Pedagogy

iJEP | eISSN: 2192-4880 | Vol. 13 No. 6 (2023) | OPEN ACCESS

https://doi.org/10.3991/ijep.v13i6.39737

PAPER

Problem-Based Learning. Application to a Laboratory Practice in the Degree of Industrial Chemical Engineering

Oliver Díaz, Elisabet Segredo-Morales, Enrique González(✉)

Universidad de La Laguna, Santa Cruz de Tenerife, España

eglez@ull.edu.es

ABSTRACT

The transformation of university teaching towards a competency acquisition approach requires an update of teaching methodologies. In the case of laboratory practices, the application of the Problem-Based Teaching methodology encourages students to apply their knowledge to solve problems based on real situations, as well as efficient communication in a work environment. This paper presents the results obtained by applying this alternative teaching methodology to a laboratory practice in the last year of the Degree in Industrial Chemical Engineering at the University of La Laguna. The results confirm a greater theoretical understanding of the concepts and the ability to apply them in practice, with a notable increase in motivation and interest in their learning process.

KEYWORDS

motivation, cooperative learning, higher education, Chemical Engineering

1 INTRODUCTION

The convergence of university education to the European Higher Education Area (EHEA) has produced a transformation in learning practices based on active methodologies and collaborative processes, rather than on simple "encyclopaedic" and memorial learning, which calls for a real challenge on how engineering education should be approached [1]. Critical thinking, troubleshooting, autonomy, self-reliance, and communication are skills that are highly valued by the business sector, and the curricula of the subjects taught in Chemical Engineering degrees aim to perfect these skills in those subjects that are mainly practical. However, employers detect deficiencies in these skills in Chemical Engineering graduates [2]. Moreover, traditional learning must be transformed in order to adapt graduates to the current challenges of society such as technical globalization. In other words, teaching must not

Díaz, O., Segredo-Morales, E., González, E. (2023). Problem-Based Learning. Application to a Laboratory Practice in the Degree of Industrial Chemical Engineering. *International Journal of Engineering Pedagogy (iJEP)*, 13(6), pp. 139–150. https://doi.org/10.3991/ijep.v13i6.39737

Article submitted 2023-03-20. Revision uploaded 2023-05-03. Final acceptance 2023-05-16.

only offer a reinforcement of the practical contents of the degrees, but also improve the connection between theoretical and practical contents [3]. The development of certain professional skills requires the introduction of new learning innovation methods. Problem-based learning, self-learning and the introduction of collaborative activities among students are new learning methodologies that are beginning to be widely applied in engineering learning [4]. In practical disciplines such as Chemical Engineering, key skills and transversal competencies can be acquired through problem-based learning [5]. Problem-based learning (PBL) is an educational approach that uses real-world problem solving to enhance students' motivation as well as to promote the assimilation of concepts they need to know [3].

Problem-based learning is built on a socio-constructive learning framework [6], which is based on posing an open-ended problem to students without an obvious solution. In this scenario, students in a guided learning period must plan how to find and implement a solution. This type of methodology allows students to conduct research, integrate theory and practice, and apply knowledge and skills to develop a feasible solution to a defined problem [7]. The PBL methodology can be structured in three phases (I) problem analysis and diagnosis, (II) autonomous study of the problem and (III) solution proposal, which allows students to acquire the new competencies that will be required in their professional exercise [8].

The role of the learner in problem-based teaching methodology is completely different from the traditional role where the learner acts as a supervisor and transmitter of knowledge. In problem-based teaching, the teacher must create or design an appropriate environment for students to manage their own learning and explore the relevant subject matter [9]. The aim of this methodology is to enable students to learn how to apply theoretical concepts in realistic and complex situations, while the teacher provides the necessary guidance for students to achieve the desired results [2]. Under this new scenario, student motivation and commitment are key to achieving the objectives set. Motivation is a broad and complex field of work, being a key factor when designing and applying the problem-based learning methodology [10]. However, most authors confirm that giving learners control over their learning significantly increases their motivation [2], [11], [12]. In this learning context, reinforcing student motivation is key for students to fully enjoy the methodology.

In recent years, the use of problem-based learning has become very common in engineering education curricula. For example, at the University of Minho (Portugal) a multidisciplinary system was implemented in the first year of the Master of Engineering and Industrial Management curriculum [13], [14]. At the University of Brasilia (Brazil), the PBL methodology is used in the final year of the master's degree in chemical engineering [15] and at the University of Seville it has been used for the design and development of a pilot plant project [1]. And it has been applied in various fields such as cloud computing [16], physics [17], and even elementary education [18]. All authors have reported improved learning, increased student participation and that PBL seems to be the way forward to improve the skills of students.

The laboratory practice subjects are key in the training of a Chemical Engineer, as they provide a practical component necessary in their professional practice. In traditional systems, students follow a preconceived experimental procedure designed by the instructor where the results are expected, and the methodology is based on learning through data collection and analysis. However, it does not reinforce the connections between theory and the real world, preventing the development of new skills for the students. Clearly, during the first years of the degree, it is necessary to maintain a standard methodology for students to acquire and internalise basic concepts as already included in most chemical engineering curricula [19]. However, it is important to change the philosophy of the practical subjects during the final years so that students reflect on the knowledge acquired and allow them to develop the new skills required by the industrial sector. Recently, at the University of British Columbia, PBL methodology has been implemented in practical subjects, which consisted of confronting students with a real problem in order for them to decide and design an analysis plan that would allow them to draw their own conclusions [2]. The results found show that the approach used allows for the promotion of all the new skills described above.

The aim of this study is to analyse problem-based learning in the development of a laboratory practical in final year students of the Degree in Chemical Engineering, focusing on the students' impressions when faced with a real problem and on the improvement in the assimilation of the concepts developed in the practical.

2 MATERIALS AND METHOD

2.1 Experimentation in Industrial Chemical Engineering II

The problem-based learning methodology was analysed in a laboratory practice that is part of the subject Experimentation in Chemical Engineering II, which is taught in the last year of the Chemical Engineering Degree at the University of La Laguna. It has a total of 6 ECTS credits. The competencies to be developed in the subject according to order CIN 351/2009, which establishes the requirements for the verification of university degrees that enable Industrial Technical Engineers to practise professionally, are described in Table 1.

Table 1. Competencies of the subject Experimentation in Chemical Engineering II

Type	Skills
Specific	Ability to design and manage applied experimental procedures, especially for the determination of thermodynamic and transport properties and modelling of phenomena and systems in the field of chemical engineering, fluid flow systems, heat transfer, matter transfer operations, kinetics of chemical reactions and reactors.
Generals	Knowledge of basic and technological subjects, enabling them to learn new methods and theories, and giving them the versatility to adapt to new situations.
	Ability to solve problems with initiative, decision-making, creativity, critical thinking and to communicate and transmit knowledge, skills and abilities in the field of Industrial Chemical Engineering.
	Knowledge for carrying out measurements, calculations, valuations, appraisals, valuations, surveys, studies, reports, work plans and other similar work.
	Ability to work in a multilingual and multidisciplinary environment.
Transversals	Ability to analyse and synthesise.
	Ability to organise and plan time.
	Ability to oral expression.
	Ability to write expression.
	Ability to apply knowledge to practice.
	Ability to work effectively in a team.

(Continued)

Table 1. Competencies of the subject Experimentation in Chemical Engineering II *(Continued)*

Type	Skills
Basic	Students have demonstrated knowledge and understanding in an area of study that builds on the foundation of general secondary education, and is usually at a level that, while relying on advanced textbooks, also includes some aspects that involve knowledge from the cutting edge of their field of study.
	That students know how to apply their knowledge to their work or vocation in a professional manner and possess the competencies that are usually demonstrated through the elaboration and defence of arguments and problem solving within their area of study.
	Students have the ability to gather and interpret relevant data (usually within their area of study) in order to make judgements that include reflection on relevant social, scientific or ethical issues.
	Students are able to transmit information, ideas, problems and solutions to both specialised and non-specialised audiences.
	That students have developed those learning skills necessary to undertake further studies with a high degree of autonomy.

Source: Modification report of the Degree in Industrial Chemical Engineering (2020).

The subject analysed is mainly a practical one that aims to train students in the following:

– The production of process flow diagrams.
– Classification and description of industrial scale equipment.
– Conducting experiments and interpreting and analysing the data obtained on matter transfer, chemical reactions, and environmental technology.
– Carrying out group work.
– Written communication.

The development of this course has been based on the classical methodology of practical learning. The students have a pre-established practice script in which the steps to follow during the practice are indicated, the data to be obtained after its completion and a series of questions to answer based on the data obtained. The operating conditions in each of the practical exercises are pre-established and students do not have the possibility of varying any of the process parameters. The problem-based learning methodology was proposed in a new practice in this subject that allows the active participation in the process by the students, making them the protagonists of their own learning with the manipulation of most of the key parameters that had to do with the practice. Only two parameters were set: one for purely operational reasons; the other, in order to be able to compare results between groups. In this way, when students are confronted with a real case in which they have to provide a solution to a given problem and that solution depends solely on the work they do during the course of the class, all the competencies of the order CIN 351/2009 can be covered. Specifically, the use of the PBL methodology allows the development of the ability to solve problems with initiative, decision-making, critical reasoning and to communicate and transmit knowledge, skills and abilities in the field of Industrial Chemical Engineering, in addition to all the basic competencies.

2.2 Experimental installation

The experimental plant consisted of 6 pressure tubes containing nanofiltration and reverse osmosis membranes (3 nanofiltration and 3 reverse osmosis) installed as shown in Figure 1. The pressure pipes are not identified, so that the student cannot visually distinguish the membranes of each type. The system is fed with mains water, driven by two commercial "boost" pumps. It should be noted that mains water on the Tenerife Island is generally characterised by a high ion content. For the application of the pressure required, a needle valve located in the general process outlet stream was used. The system is set to a working pressure of 6 bar and operated in a closed circuit. The performance of the process is determined by two parameters: ion removal and water recovery. The first is calculated from experimentally measured electrical conductivity data in the product water (hereafter referred to as permeate) and in the feed. The second is obtained from the experimental determination of the overall permeate and reject flows. From these values, the percentage of process water recovery or recovery (ratio of product water flow obtained to feed flow) is determined.

Fig. 1. Experimental unit

The experimental installation allowed for the versatile and agile modification of the pipes, both to characterise the membranes individually and to test all the configurations proposed by the students.

2.3 Description of the learning methodology applied

The problem-based learning methodology was implemented in the subject described above by means of the resolution of an industrial problem by the students during a practical session lasting 2 hours. The total number of students enrolled in the subject was 25. Figure 2 shows the flow chart of the teaching methodology applied.

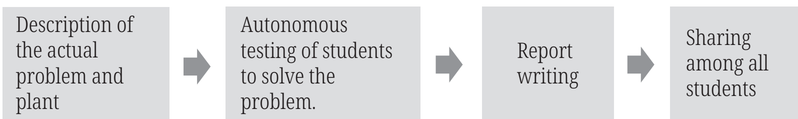

Fig. 2. Learning methodology

First, the students were tested on their prior knowledge to find out how well they had assimilated the theoretical concepts used in practice. The test consisted of 5 single-choice questions.

In the practical session, each group of three students was presented with a reverse osmosis and/or nanofiltration membrane installation already installed, the configuration of which did not allow them to obtain a product water that met the quality objectives already set by the lecturers (90% ion removal compared to the feed water).

After an orientation on the operation of the plant and a check that the students had the necessary background knowledge, they were first asked to determine the ion removal rate of the already installed configuration to know where they were starting from. Once the students found that the original process configuration did not meet the quality requirements, it was suggested that they analyse each of the membranes individually, as a starting point to come up with an alternative solution that would improve the product water performance, reach the quality target, and maximise water recovery in the process.

To reach the possible solutions, the students should select, according to their criteria, both the membranes to be used and the order of the membranes, analysing in each case the results obtained, and progressively orienting themselves towards the optimal configuration. On average, the working groups tested 4 configurations.

After recording the values obtained in the laboratory, the working group produced a report detailing the process followed, the identification of the membranes and the justification, based on experimentation and supported by theoretical knowledge, of the configurations chosen to arrive at the optimal solution, such as the phenomena that prevented certain tested configurations from not giving an acceptable result.

Finally, in a collective session, each of the working groups presented the configuration they considered optimal among those tested, justifying their decision in a reasoned manner. After presenting all the solutions, the students repeated the initial test to find out the degree of assimilation of the same concepts after carrying out the practice. The difference in the score of this test was used as an indicator of the effectiveness of this type of teaching methodology.

3 RESULTS AND DISCUSSION

3.1 Evaluation of acquired knowledge

The purpose of the practical course is not to provide new knowledge since this knowledge is developed in theoretical subjects of the syllabus of the Degree in Chemical Engineering at the University of La Laguna. The practical course aims to apply this knowledge and to transmit other competencies to the students. However, it was considered appropriate to assess the previous knowledge acquired by the students in a traditional theoretical class and the knowledge assimilated through the alternative system of problem-based learning.

The assessment of the knowledge acquired was developed by means of a multi-choice test questionnaire with a single correct option where the student is asked simple questions on how they should modify operating conditions to achieve a desired objective. Figure 3 shows the percentage of correct answers to each of the questions before and after the laboratory practice. In the pre-questionnaire, the students' results were rather low, as the percentage of correct answers shows. In the first 4 questions, more than half of the students answered incorrectly, showing that they had not internalized basic knowledge from previous theoretical subjects. Once the laboratory practice had been carried out by means of problem-based learning, the results improved notably, with a high percentage of correct answers exceeding 50% in all cases.

The results highlight the importance of practical subjects as they help students to assimilate knowledge better by being able to understand the concepts taught in a theoretical way. Furthermore, the results show that the problem-based methodology allows students to transfer theoretical knowledge to practical cases and to interrelate concepts taught in different theoretical subjects in order to prepare students for their professional exercise. The concepts assimilated when students are confronted with a case study in which they have to propose a solution are internalised more deeply, allowing for greater assimilation because they are made to "think outside the box" [20]. Moreover, since it is a real problem where there is no single solution, or at least no obvious solution, it encourages critical analysis by students and collaborative learning where the solutions of classmates help to support global knowledge. In the development of the practice, critical debates were established between the members of the working group, allowing each of them to present their knowledge and reflections on the process to the rest of the group members in order to find an optimal solution to the problem posed. The pedagogical exercise carried out by the participants themselves allows them to assimilate and internalise the knowledge acquired.

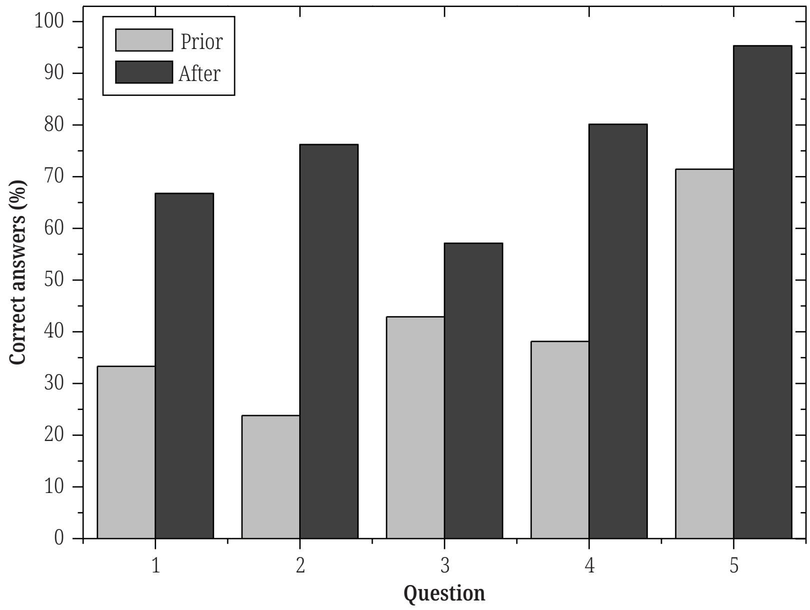

Fig. 3. Results of the test evaluation carried out prior to and after the practical sessions

3.2 Evaluation of acquired knowledge

The quantification of the skills acquisition by the students is not a simple task since many of them are not directly quantifiable. In order to evaluate the competencies, the students carried out a survey on their perception of the acquisition of competencies, in which they had to respond on a Likert scale of 1 to 5 (1 is not very satisfied and 5 is very satisfied). Table 2 summarizes the percentages of student responses to each of the questions. A fairly high degree of satisfaction was obtained for most of the questions, with an average of 4.5 out of 5 for all questions.

Table 2. Survey results

Question	% Answer According to Rating				
	1	2	3	4	5
The development of the internship has helped me to learn how to deal with a real case.			8	16	76
The material in the practice script was sufficient to solve the problem.	12		8	40	40
The sharing has helped me to understand the problem and to propose a solution.				24	72
I consider that for this type of practice it is better to do it in a group.				8	92
I consider it appropriate to use this type of methodology to learn by solving real cases.				24	76
I prefer this type of laboratory practice to more conventional ones.			4	20	76
The knowledge acquired in previous subjects has helped me to solve the initial questionnaire without any problems.	4	16	24	40	16
My knowledge in previous subjects has helped me to solve the problem solved.	4	12	28	40	16
This methodology has increased my motivation to carry out the practice.				20	80
The teaching staff involved has served as a guide for the resolution of the proposed problem.				24	76

The majority of students consider that the development of the internship has helped them to learn how to deal with a real case and that the shared session has helped them to understand the problem and propose an optimal solution. Reflecting that, according to the opinion of the students, the development of the internship has allowed them to acquire methods that provide them with versatility to adapt to new situations, bringing them closer to their professional practice. The results are consistent with what was described in the previous section regarding "thinking outside the box" and the internalisation of knowledge when presenting their ideas and findings.

It is remarkable how some students, around 20%, indicate that the theoretical knowledge acquired in previous subjects has not made it easier for them to solve the proposed case or the previous questionnaire. This is one of the main challenges of university education today, as some students memorise theoretical concepts without being able to transfer these concepts to their professional practice. A percentage of students (12%) considered that the practice guide was not sufficient to solve the problem, when it was a brief summary of the basic concepts. The students expected a detailed guide to help them solve the proposed case, as is done in traditional laboratory practical. However, providing such information would have slowed down the critical thinking and self-learning process as reflected in the results in Figure 3.

One of the objectives set in the achievement of the laboratory practice is the development of the students' group work and their collective self-learning. The results of the survey show that students value positively the development of the practice in working groups and their preference for this type of laboratory practice as opposed to traditional systems based on following a written procedure and collecting data to produce a final report. The problem-based methodology applied in the laboratory practice has allowed them to develop decision-making skills with critical reasoning, encouraging creativity to reach a solution that they had to communicate and transmit to their classmates.

The proposed methodology allowed students to acquire skills in the design and management of experimentation procedures, as they themselves had to propose the methodology to be followed within a given time. Obviously, the teacher had to channel these ideas and act as a guide, this being a key role in the process. The students valued very positively the work of the teacher in the development of the practice.

In summary, the development of this new methodology enables students to acquire and internalize practically all the competencies described in the CIN Order 351/2009, which are summarised in Table 1.

3.3 Student evaluation of the methodology used

Problem-based methodology is a powerful pedagogical tool that teachers can use for the acquisition of new skills [2]. However, it is appropriate to know the students' opinion about this methodology since it represents a break from the traditional systems that are highly implemented in educational systems. In order to evaluate the proposed methodology, the students completed a survey in which they had to rate different aspects of the development of the practice on a Likert scale from 1 to 5. The results are shown in Figure 4.

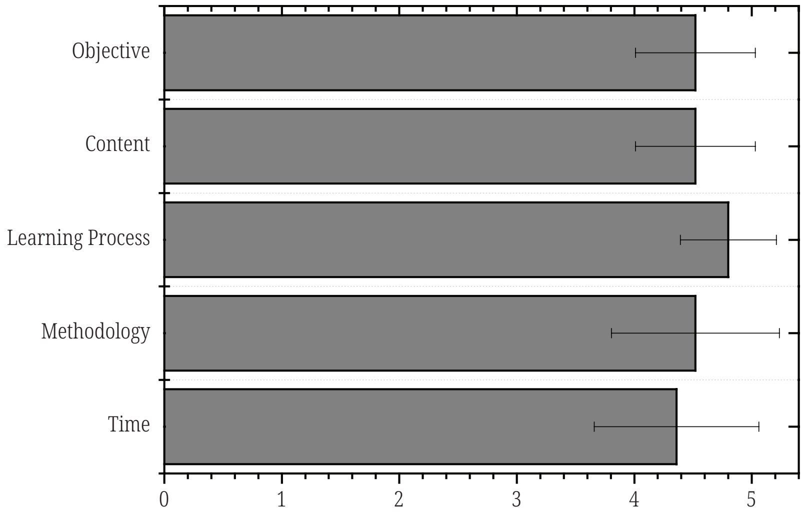

Fig. 4. Student evaluation of the methodology applied

Students rate the proposed methodology very positively, giving it an average score of 4.47 out of 5. The results reveal that students prefer this type of methodology to traditional systems when carrying out laboratory practicals.

In the same survey, the students could add comments regarding their impressions of the proposed methodology. The results mostly value positively the group work and the possibility of facing a real case that has allowed them to know the degree of assimilation of concepts acquired during their learning stage. Furthermore, it is emphasised that the system seems to them to be novel and highly dynamic, which generates a high level of motivation. It should also be noted that the students were unaware of the Problem-Based Learning methodology. In order to analyse the students' impression of the new methodology, they were asked to choose from a total of 8 concepts/adjectives (positive and negative) those with which they would qualify the methodology used in practice. Figure 5 shows the number of times students chose each of them.

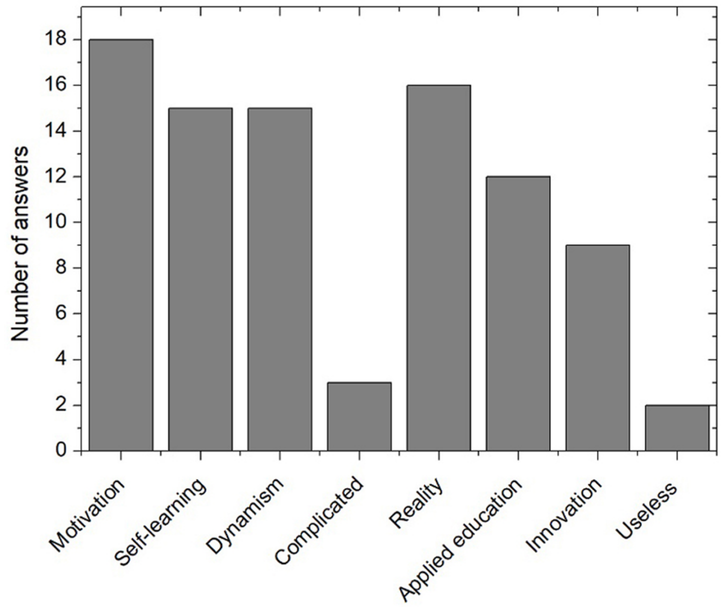

Fig. 5. Adjectives/concepts proposed for the description of the methodology followed according to the students' vision

"Motivation" is the concept most frequently chosen by students, followed by "Realism". "Self-learning", "Dynamism", "Applied teaching" and "Innovative" also stand out. The adjectives "Complicated" and "Useless" were the least chosen. These results show that the pupils consider this methodology to be clearly positive, enabling them to achieve self-learning in a motivating and dynamic way.

4 CONCLUSIONS

The manuscript evaluates the methodology of problem-based learning in the development of a laboratory practice in the last year of Industrial Chemical Engineering. The results show that this methodology improves the acquisition and internalisation of theoretical knowledge and its applicability to the resolution of real problems in the case of fourth-year students of the Degree in Industrial Chemical Engineering at the University of La Laguna. In addition, the proposed learning system in which students were faced with a real problem, without an obvious solution, encouraged critical analysis by the students and collective learning, allowing them to acquire knowledge in a more profound way. The students' assessment of this methodology is positive, and they even propose that it should be implemented in the rest of the practical subjects in the current degree program, as they consider it to be a way of encouraging student motivation and interest.

5 ACKNOWLEDGEMENTS

This manuscript has been produced thanks to a grant from the project "El alumnado ante un caso real: Análisis de un proceso de desalación de agua salobre" awarded to the authors in the call for Innovation and Educational Transfer Projects (PITE) to be developed in the academic year 2022–2023 promoted by the Vice-Rectorate for Teaching Innovation, Quality and Campus Anchieta (VICINCAL) of the University of La Laguna for the academic year 2021–2022.

6 REFERENCES

[1] F. Vega and B. Navarrete, "Professional design of chemical plants based on problem-based learning on a pilot plant," *Education for Chemical Engineers*, vol. 26, pp. 30–34, 2019, https://doi.org/10.1016/j.ece.2018.08.001

[2] R. Vaez Ghaemi and G. Potvin, "Experimenting with labs: Practical and pedagogical considerations for the integration of problem-based lab instruction in chemical engineering," *Canadian Journal of Chemical Engineering*, vol. 99, no. 10, pp. 2163–2172, 2021, https://doi.org/10.1002/cjce.24136

[3] Y. Hu and C. Li, "Implementing a multidimensional education approach combining problem-based learning and conceive-design-implement-operate in a third-year undergraduate chemical engineering course," *J Chem Educ*, vol. 97, no. 7, pp. 1874–1886, 2020, https://doi.org/10.1021/acs.jchemed.9b00848

[4] J. Uziak and V. P. Kommula, "Application of problem-based learning in mechanics of machines course," *International Journal of Engineering Pedagogy*, vol. 9, no. 1, pp. 68–83, 2019, https://doi.org/10.3991/ijep.v9i1.9673

[5] W. Chen, U. Shah, and C. Brechtelsbauer, "The discovery laboratory – A student-centred experiential learning practical: Part I – Overview," *Education for Chemical Engineers*, vol. 17, pp. 44–53, 2016, https://doi.org/10.1016/j.ece.2016.07.005

[6] H. Ju, I. Choi, B. Doo Rhee, and J. Tae-Lee, "Challenges experienced by Korean medical students and tutors during problem-based learning: A cultural perspective," *Interdisciplinary Journal of Problem-based Learning*, vol. 10, no. 1, 2016, https://doi.org/10.7771/1541-5015.1565

[7] J. R. Savery, "Overview of problem-based learning: Definitions and distinctions," *Interdisciplinary Journal of Problem-Based Learning*, vol. 1, no. 1, 2006, https://doi.org/10.7771/1541-5015.1002

[8] A. M. Ruiz-Ortega, J. J. Gallardo-Rodríguez, E. Navarro-López, and M. del C. Cerón-García, "Project-led-education experience as a partial strategy in first years of engineering courses," *Education for Chemical Engineers*, vol. 29, pp. 1–8, 2019, https://doi.org/10.1016/j.ece.2019.05.004

[9] R. Wood, A. McGlashan, C. B. Moon, and W. Y. Kim, "Engineering education in an integrated setting," *International Journal of Engineering Pedagogy*, vol. 8, no. 3, pp. 17–27, 2018, https://doi.org/10.3991/ijep.v8i3.7857

[10] J. Castelan and R. D. Bard, "Promoting PBL through an active learning model and the use of rapid prototyping resources," *International Journal of Engineering Pedagogy*, vol. 8, no. 4, pp. 131–142, 2018, https://online-journals.org/index.php/i-jep/article/view/8281/5013

[11] B. D. Jones, M. K. Byrnes, and M. W. Jones, "Validation of the MUSIC model of academic motivation inventory: Evidence for use with veterinary medicine students," *Front Vet Sci*, vol. 6, 2019, https://doi.org/10.3389/fvets.2019.00011

[12] L. A. Jesper, J. F. D. Nielsen, and C. Zhou, "Motivating students to develop satellites in problem and project-based learning (PBL) environment," *International Journal of Engineering Pedagogy (iJEP)*, vol. 3, no. 3, p. 11, 2013, https://doi.org/10.3991/ijep.v3i3.2529

[13] S. Fernandes, M. A. Flores, and R. M. Lima, "Students' views of assessment in project-led engineering education: Findings from a case study in Portugal," *Assess Eval High Educ*, vol. 37, no. 2, pp. 163–178, 2012, https://doi.org/10.1080/02602938.2010.515015

[14] S. Fernandes, D. Mesquita, M. A. Flores, and R. M. Lima, "Engaging students in learning: Findings from a study of project-led education," *European Journal of Engineering Education*, vol. 39, no. 1, pp. 55–67, 2014, https://doi.org/10.1080/03043797.2013.833170

[15] R. M. Lima, D. Mesquita, and L. Coelho, "Five years of project-based learning training experiences in higher education institutions in Brazil," in *6th International Research Symposium on PBL (IRSPBL' 2017)*, 2017, pp. 470–479.

[16] I. Syamsuddin, "Problem based learning on cloud economics analysis using open source simulation," *International Journal of Online Engineering*, vol. 12, no. 6, pp. 4–9, 2016, https://doi.org/10.3991/ijoe.v12i06.5147

[17] Darmaji *et al.*, "E-module based problem solving in basic physics practicum for science process skills," *International journal of online and biomedical engineering*, vol. 15, no. 15, pp. 4–17, 2019, https://doi.org/10.3991/ijoe.v15i15.10942

[18] T. T. D. Susanto, P. B. Dwiyanti, A. Marini, J. Sagita, D. Safitri, and E. Soraya, "E-book with problem based learning to improve student critical thinking in science learning at elementary school," *International Journal of Interactive Mobile Technologies*, vol. 16, no. 20, pp. 4–17, 2022, https://doi.org/10.3991/ijim.v16i20.32951

[19] M. (John) Zhang, C. Newton, J. Grove, M. Pritzker, and M. Ioannidis, "Design and assessment of a hybrid chemical engineering laboratory course with the incorporation of student-centred experiential learning," *Education for Chemical Engineers*, vol. 30, pp. 1–8, 2020, https://doi.org/10.1016/j.ece.2019.09.003

[20] A. T. Harris and S. Briscoe-Andrews, "Development of a problem-based learning elective in 'green engineering,'" *Education for Chemical Engineers*, vol. 3, no. 1, 2008, https://doi.org/10.1016/j.ece.2007.12.001

7 AUTHORS

Oliver Díaz. Since January 2017 to 2022, Plant manager to SUEZ WTS in the "Sistema Comarcal de Abastecimiento Urbano del NorOeste de Tenerife". Since 2023, Assistant Professor of Department of Chemical Engineering at the Chemistry Section of Faculty of Science, La Laguna University. Key research topics have concerned biological and membrane processes applied to tertiary wastewater treatment. Most research papers have been focused on developing membrane bioreactor technology, through the development of new operating strategies and advanced understanding of fouling mechanisms (email: odiazlop@ull.edu.es).

Elisabet Segredo-Morales. Teaching in the Chemical Engineering and Environmental Sciences degrees at the University of La Laguna since 2023. Key research topics have concerned biological and membrane processes applied to tertiary wastewater treatment. Most research papers have been focused on developing membrane photobioreactor technology, through the development of new operating strategies. She has also been focused on the field of formulation of injectable systems for the improvement of bone regeneration in osteoporotic conditions and in the release of bioactive substances (marked with radioactive isotopes or not) inside these systems (email: esegredm@ull.edu.es).

Enrique González is an Assistant Professor in Chemical Engineering at the Chemistry Section of Faculty of Science, La Laguna University since February 2017. 10 years of post-doctorate experience in academic and industrial research in wastewater treatment technology. Co-investigator on two Spain research council-sponsored programs on membrane bioreactors. Research member in 7 contracts or research agreements with other local institutions or water companies. Key research topics have concerned biological and membrane processes applied to wastewater treatment and reuse. Most research papers have been focused on developing membrane bioreactor technology, through the development of new operating strategies, advanced understanding of fouling mechanisms and application of rotating membranes (email: eglezc@ull.es).