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Integration of chemical engineering skills in the curriculum of a master course in industrial engineering

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ABSTRACT

Promoting new teaching methodologies is essential to improve the participation, motivation, interest, and results of students in all educational stages. In this sense, flipped classroom and problem-based learning have emerged in the last years as fascinating options to be implemented in high education levels thanks to the students' maturity and previously acquired background. Working with motivating case studies based on real processes with their restrictions appears as an opportunity to bring future professionals closer to the industrial problems; this will capacitate engineers to solve and understand complex procedures getting tangible results. In this context, the main goal of this work is to combine flipped classroom and problem-based learning methodologies to gain the interest of students of a Master course in Industrial Engineering in the subject of Chemical Processes using real data of local companies. A survey, designed by the academics involved, will help collecting the opinion of students as well as the acquired skills in the frame of the specific subject. Results demonstrated the satisfaction of the students with the course, highlighting mainly the acquisition or improvement of self-learning skills (survey 4.0/5.0), capacity for organization and planning (survey 4.0/5.0), analytical ability (survey 4.2/5.0), and teamwork (survey 4.3/5.0). In addition, the grades accomplished during the year of implementation show that although the success rate is quite similar to preceding years, the marks achieved are considerably higher.

1. Introduction

Students in all educational stages are currently suffering lack of motivation worldwide, particularly in university studies (Da Silva Júnior et al., 2021a; Eltahir et al., 2021; Martín et al., 2021; Rodríguez-Chueca et al., 2020). For this purpose, in recent years, lecturers have been engaged in the creation and development of innovative teaching methodologies to motivate students at all levels of education. This aspect experienced a significant increment since the pandemic situation, where playschools, schools, high schools, and universities were closed, and academics had to find new strategies to educate and maintain the motivation of students online (Duggal et al., 2021; Martín et al., 2021).

The traditional lecture or teacher-centered approach is based on a methodology where professors do most of the work during the lecture. Students typically come to class without enough preparation. Thus, new educational methodologies were born to get a student-centric approach and consequently make the lectures more personal and dynamic (Munir et al., 2018). To promote active role of students during classes, the most popular and novel methodologies developed for undergraduate teaching in the last few years are i) electronic learning: employment of electronic devices as a vehicle for teaching and learning; this includes a series of methodologies such as blended, ubiquitous, and mobile learning (Díaz-Sainz et al., 2021), ii) learning-by-doing: students develop practical lessons to adapt and learn (Dominguez-Ramos et al., 2019), iii) game-based learning: to motivate students to explore and use new concepts in a stimulating and funny way, making studying a more enjoyable task (Da Silva Júnior et al., (2021a)), iv) flipped classroom: the lecturers help students instead of merely delivering information, while students become responsible for their own learning process (Akçayır & Akçayır, 2018) and, v) problem-based learning: learners can face an authentic, real-life problem scenario (Ghani et al., 2021). All the methodologies can be applied as separated or combined alternatives. For example, problem-based learning can integrate cooperative learning, which focuses on promoting effective education in and outside the class via group activities (Azizan, Mellon, et al., 2018). Although the former strategies could be applied in all different levels of education, due to the students' maturity and previous specific knowledge, the flipped

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Table 1
Case studies based on the flipped classroom and problem-based learning methodologies applied in the chemical engineering field.

University Year	Course	Main Conclusions	Reference
Flipped Classroom			
1	Chemistry	- Higher overarching concepts - Better enduring understandings	(Reid, 2020)
2	Reaction engineering and separation process II, Laboratory course, Unit Operation Lab 1	- Acquisition of more cooperative, respecting others, trust, tolerance, perseverance, empathy, and assertiveness - More independence to learn - More sociability	(Azizan, Ramli, et al., 2018)
2	Transport Phenomena	- More meaningful discussion and sensible - Reinforcing of interaction - Higher rates of motivation - Better understanding of the theory - Higher interest and value to learnt concepts	(Valero et al., 2019)
3	Unit operations	- Increase practical apprehension of concepts - Higher development of project management - More capacity of negotiation, autonomy, communication, peer-to-peer interactions, and self-regulated skills	(Ballesteros et al., 2021)
1–4	Environmental Management, Environmental Engineering and Industrial Ecology	- Enhancement of learning - Higher acquisition of theoretical concepts - Autonomous learning	(Rodríguez-Chueca et al., 2020)
3–4	Chemical Reactors, Chemical, Process Control, Process and Product Design	- Engagement in the learning process - Students more motivated, participative, and interested	(Rodríguez et al., 2020)
4	Process Control	- More proactive - Higher motivation - Better understanding - Higher participation - Enhancement of performance	(Rodríguez et al., 2018)
Senior	Unit labs	- Much more engagement - Better understanding	(Dua, 2020)
Senior	Chemical engineering design and analysis	- Effectiveness of employing student-centered activities - Higher involvement - More attendance - Online lesson engagement	(Lewin & Barzilai, 2022a)
Different years	Principles of Chemical Engineering	- Improvement in self-study	(Zeng et al., 2018)
Problem-Based Learning			
1	Reactor Design	- Activate the existing knowledge, skills, and motivations	(George et al., 2020)
1	Introduction to Engineering	- Higher empathy with more sensitivity to others, social functioning, emotionality, and self-esteem	(Nur et al., 2020)
1	Principles of Chemical Engineering and Chemical Engineering Fluid Mechanic	- A success in elevating the students' thinking capabilities - Increment in social skills such as time management, leadership, communication, and respect	(Ruslan et al., 2021)
1,2	Fundamental engineering knowledge	- Development of critical engineering thinking - Improvement in confidence	(Tsatse & Sorensen, 2021)
2	Chemical Engineering Laboratory	- Improve teamwork competency - Higher self-directed learning - Improvement in communication skills	(Ban Choon & Qingxing, 2018)
2	Reaction Engineering and Separation Process	- Improved competencies in discussions and arguments - Positive interdependence - Better Personal accountability	(Mellon & Ramli, 2017)
3	Chemical engineering principles	- Improve the selection of references - Enrich the extension of thinking - High enthusiasm - More self-directed learning - Teamwork skills	(Hu & Li, 2020)
4	Process Safety and Risk Management	- Positive student satisfaction rates - Active engagement - Enhancement of critical and problem-solving skills	(Lai et al., 2020)
4	Senior laboratory	- Improvement of the development of transferable skills in the chemical engineering field - Increase in the motivation and participation - Higher self-confidence in chemical engineering competencies	(Vaez Ghaemi & Potvin, 2021)
5	Final Degree Project	- Improvement competencies for the professional future	(Vasconcelos et al., 2022)
Junior and Senior years	Food and process Engineering	- Enriching the engineering background knowledge - Insight to solve complex problems - Strengthening teamwork skills	(Kim, 2020)
Three-year associate and a five-year undergraduate	Chemical Thermodynamics	- Improvement in understanding - Productive learning	(Mustafa, 2015)
Undergraduate and graduate students	Simulating ideal chemical reactors	- Advanced dynamism in the class - Improvement in the development of autonomy - Higher self-learning	(Sawaki et al., 2020)
Senior years	Nanotechnology	- Empowerment for studying - Encouraging social inclusion - Improvement in deep learning	(Pataquiva-Mateus & Dorantes, 2017)

(*continued on next page*)

Table 1 (*continued*)

University Year	Course	Main Conclusions	Reference
Senior years	Senior Advanced Analysis Course	- Obtaining essential skills needed for their professional future	(Lou et al., 2021)
Master	Chemical plant design	- Make use of practical and experimental skills - More autonomous learning	(Vega & Navarrete, 2019)
1	Computer-aided design (CAD) laboratory	- Improvement in the perception of abilities	(Hernáiz-Pérez et al., 2021)

classroom (Admiraal et al., 2019; Galindo-Dominguez, 2021; Kwan et al., 2022; López Núñez et al., 2020; Sakti et al., 2023) and problem-based learning (Carder et al., 2001; Johnstone & Biggs, 1998) are considered the most promising methodologies to be implemented in high education levels such as Master Courses.

Flipped classroom approach has been found to be unsuitable for students under the age of 12 years due to their lack of maturity (Shao & Liu, 2021). Despite some potential drawbacks, such as limited preparation time for students and being time-consuming for both academics and students, the benefits of the flipped classroom approach outweigh these concerns. (Akçayır & Akçayır, 2018). Consequently, this methodology has become increasingly popular at the university level, as evidenced by studies conducted by Al-Samarraie et al., 2020; Colomo-Magaña et al., 2020; Divjak et al., 2022, and Flores et al., 2016.

Previous research has demonstrated numerous benefits for students who use the flipped class approach. These benefits include motivation to learn, higher academic achievement, greater flexibility in learning, improved confidence, and increased engagement(Akçayır & Akçayır, 2018; Divjak et al., 2022; Lo & Hew, 2021; Silverajah et al., 2022).

Additionally, Problem-based learning encourages creativity, deep learning, and improves teamwork skills. Besides, as Hernandez-Ramos et al., 2021 described, this methodology is considered constructive, self-directed, collaborative, and simultaneously, promotes problem-solving and contextual learning (Ghani et al., 2021; Hernández-Ramos et al., 2021). Nevertheless, when the methodology is applied in teams it is possible to find dominant facilitators and dysfunctional groups that deserve further attention (Dolmans et al., 2005). Another disadvantage previously referred to in preceding works associated to problem-based learning is the possibility of a lack of basic theoretical science (Cónsul-Giribet & Medina-Moya, 2014). In both methodologies, the efforts made by educators have to be enormous because, in many cases, learners do not have the time to access additional aides and/or are not efficient in selecting valuable references (Bains et al., 2022). However, despite new methodologies having drawbacks, the academic results and the feedback received from students and teachers demonstrate that it is worth moving forward in their implementation to engage learners and improve the academic results (Al-Samarraie et al., 2020; Gamage et al., 2022; Ghani et al., 2021).

In this context, it has been described by Fletcher et al. (2017) that Chemical Engineering is a versatile discipline that provides comprehensive solutions for a variety of challenges, including problem-solving, design, control, management, materials science, safety, economics, and environmental impact. These skills are valuable not only in Chemical Engineering education but also in employment, enabling students to acquire essential transferable skills that are required in the chemical and engineering industries. (Fletcher et al., 2017). New learning methodologies and particularly flipped classroom and problem-based learning, have been commonly used in the last few years in chemical engineering studies, both for teaching in the Chemical Engineering Degree or in the Master's Degree in Chemical Engineering or in other Chemistry or Engineering Disciplines. Thus, a huge amount of effort has focused on making friendly subjects for students. Table 1 summarizes recent case studies based on these methodologies highlighting the main conclusions reported by the authors and the year in which they are implemented.

Thus, and due to the huge efforts carried out to date focused on the flipped classroom and problem-based learning methodologies in the field of chemical engineering, this work aims to incorporate these strategies into the Master's Degree curriculum of Industrial Engineering at the University of Cantabria, Spain. Specifically, the course "Chemical Processes" implements the strategies and is taught by academics from the Chemical and Biomolecular Engineering Department. By applying these procedures, the results achieved can significantly contribute to know the strengths and weaknesses promoted in master's courses since the works reported in the recent literature based on graduate students are still scarce. This work also aims to critically discuss the outcomes achieved by students in the industrial engineering master's program after implementing the flipped classroom and problem-based learning methodologies. On one hand, it will describe and justify the students' impressions and acquisition of competencies in detail. On the other hand, this study will compare the grades of the course after having implemented the new methodology with those of the previous two years.

2. Methodology

This section presents the chemical processes course, the case of study developed, and the design of the survey for a critical review of the methodology proposed by the academics.

2.1. Chemical Processes Course

The course presented in this manuscript is delivered in the Master's Degree in Industrial Engineering during the first semester at the University of Cantabria (Spain), recognized as a European-Accredited Engineering Master Degree Programme (EUR-ACE). This subject is called 'Chemical Processes' and counts with 3-week classroom hours (1 theoretical and 2 practical), which implies 5 European Credit Transfer Systems (ECTS). The academic semester starts in September and concludes in January. The semester is marked by two mid-course exams scheduled in November and January, respectively. Students who did not pass the course are required to take a final exam. Furthermore, students who

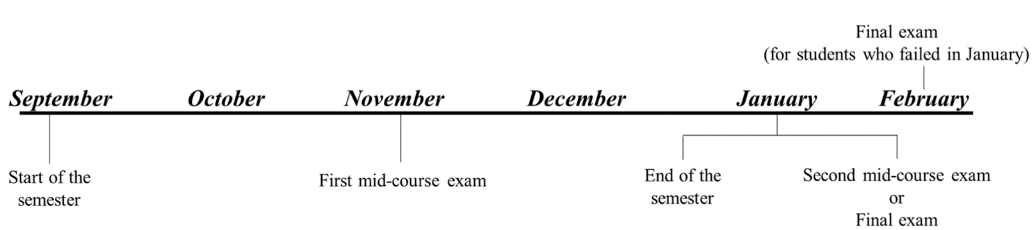

Fig. 1. Calendar of the course 'Chemical Processes' delivered in the Master's Degree in Industrial Engineering at the University of Cantabria.

Table 2
Lessons delivered in the course 'Chemical Processes' in the Master's Degree in Industrial Engineering at the University of Cantabria.

	Lectures	Contents	Weeks
First mid-course exam	1	Introduction to Chemical Processes: Process Variables, Diagrams, and Chemical Kinetics - Practical case: Kinetic problems	1–2
	2	Fundamentals, design and applications of homogeneous chemical reactors. Resolution of mass and energy balances. - Practical case: Batch reactors - Practical case: Continuous stirred-tank reactors - Practical case: Plug flow reactors	3–8
Second mid-course exam	3	Fundamentals, design, and applications of heterogeneous chemical reactors. - Practical case: Resolution of mass, energy, and momentum balances in fixed bed reactors - Practical case: Fluidized Bed Reactor Design - Practical case: Modelling and simulation of a fixed bed reactor for the catalytic oxidation of ethylene.	9–12
	4	Fundamentals, design, and applications of fluid-solid separation processes. - Practical case: Adsorption - Practical case: Ion exchange - Practical cases: i) Modelling and simulation of styrene dehydration by activated alumina, ii) Modelling and simulation of a water softening process through ion exchange.	13–15

failed in the previous semester are granted an opportunity to retake the course before the start of the second semester, which begins in February. To aid in comprehending these critical dates, Fig. 1 provides a schematic calendar of the course.

All the lectures of this course, as well as the weeks dedicated, are summarized in Table 2. Thus, lectures 1 and 2 (before the mid-course exam) are developed during the first 8 weeks, while lectures 3 and 4 are given during the last 8 weeks of the course.

The course 'Chemical Processes' brings learners different competencies that can be classified as a function of the typology, generic, specific, basic, and transversal, as shown in Table 3. Regarding generic competencies, the implementation of the flipped classroom model facilitates the development of critical thinking skills among students. This approach encourages them to seek accurate and reliable information, fosters autonomy in learning, and promotes advancements in modelling. Similarly, problem-based learning will contribute to the enhancement of critical analysis and the design of chemical processes, as both strategies inherently prioritize these aspects.

Moreover, the adoption of the flipped classroom and problem-based learning approaches will significantly improve basic competencies. By emphasizing active participation and self-directed learning, these methodologies create an environment where students are encouraged to put forth effort and focus on the solve real engineering problems.

Furthermore, problem-based learning plays a crucial role in promoting problem-solving skills and fostering teamwork among students. It will also inspire originality in developing and applying ideas, particularly within the context of research-oriented activities.

Table 3
Competence acquired by the students.

Typology of competencies	Competencies
Generic	Having adequate knowledge of the scientific and technological aspects of mathematical, analytical, and numerical methods in engineering. Carrying out research, development, and innovation in products, processes, and methods. Projecting, calculating, and designing products, processes, installations, and plants.
Specific	Ability to analyze and design chemical processes.
Basic	Possessing and understanding knowledge that provides a foundation or opportunity to be original in the development and/or application of ideas mainly in a research context
Transversal	Problem resolution Teamwork

2.2. Case study

The course "Chemical Processes" teaches in detail different important concepts related to processes engineering. Transmitting this course is an already complex challenge for chemical engineering undergraduates or postgraduates, but teaching this branch of knowledge is undoubtedly more complex in other degrees or master's programs due to students' lack of engagement. Thus, this course delivered in the Master's Degree in Industrial Engineering was supported by case studies, preferably based on a real-international company in the Autonomous Community of Cantabria (Spain). Motivating students requires the selection of cases enabling versatility, meaning, the existence of a flowsheet with multiple decision and options in terms of reactor or equipment selection, different purity or quantity requirements allowing to favour the discussion and the study of different alternatives. In this sense, to offer realistic problems, the academics contacted several chemical companies to know inputs, outputs, flow diagrams, fluxes, and the type of reactor employed, among other information that could be useful. Finally, the academics chose chemical plants located in Cantabria, such as a rubber plant, and provided students with a portfolio containing the current flowsheet. The information also included the layout of different plant areas, such as raw materials reception, raw materials pre-treatment, process area, cylinder and gases area, and finally the packaging section before transportation. All parts of the plant were well-described, providing information not necessarily essential to use during the course but relevant to mass or molar fluxes, temperatures, pressures, concentrations, security measurements, among others. An example of the extracted information provided is shown in Table 4. This company was chosen due to its international character and its appearance in the European Union Best Available Techniques reference documents (BREFs) and European Union Emissions Trading System (EU ETS) and both concepts were introduced and explained.

In addition, the students had the opportunity to visit the plant, see with their own eyes the facilities and solve their doubts with professionals of the abovementioned industry. The general objective proposed to the students was the improvement in terms of the product purity and sustainability of the process. To achieve these objectives, the following actions were proposed: i) to analyse the current main reactor to determine if it is the best option, studying the volume and time required to decide new strategies; ii) to propose improvements to increase the current product purity by at least 10%; and iii) to design measures to improve the sustainability of the plant (such as utilizing residual heat from the reactor in other parts). In some cases, based on other companies, students also analyzed the feasibility of implementing different configurations connecting the reactors in series, parallel, or recirculation, depending on the disposal of raw materials. This approach helps students understand how to apply their knowledge in industrial settings, while academics strive to create a more engaging learning environment.

Additionally, the approach employed in this course plays a vital role in the development of student competencies, including both generic and specific competencies. This methodology not only improves students' comprehension of scientific and technological aspects but also stimulates innovation in product development and enhances their project management, calculations, and design abilities for new products and processes. On the other hand, the methodology proposed here contributes to analyse and design processes and promotes the development of ideas in a research context. Furthermore, the methodologies chosen to carry out the case study facilitate problem-solving and teamwork. The graphical representation of both theoretical classes and the resolution of the case study lessons can be found in Fig. 2. This scheme visually illustrates the step-by-step process followed in these lessons.

All the materials were uploaded to Moodle learning platform each week before the lessons. Besides, the different challenges to be solved during the week were submitted to the same application. In addition, when the softwares, Polymath™, Aspen Custom Modeler, or Aspen Plus were introduced, 15-minutes-video tutorials were prepared to be used as a starting guide explaining in detail the tools, possibilities of use, interpretation of results, outcome management; furthermore, a simple problem was defined and solved. Fig. 3 illustrates screenshots of the tools used; it is possible to appreciate the significant interface differences between the softwares: (i) Polymath™, (ii) Aspen Custom Modeler, and (iii) Aspen Plus. Finally, selected-complimentary references were suggested to allow learners to strengthen and expand their knowledge.

2.3. Surveys

After the semester ended, a meticulous survey was created to assess the opinion of students on the quality of the materials provided, the level of enjoyment, and the overall satisfaction with the course. The academics were mindful that industrial engineering master students often lack interest in chemical engineering processes, and thus they made a concerted effort to ensure that the survey was thoughtfully designed to elicit honest feedback. Table 5 shows the survey, where four groups of queries (Q) are presented and the punctuation was from 1 (Much lower than expected) to 5 (Much higher than expected); i) regarding only the subject and the contents delivered in the course (Q1-Q3), ii) focusing on the novel methodologies applied (flipped classrooms and problem-based learning) (Q4-Q8), iii) based on their perception of chemical engineering and the utility of the course for their professional career as industrial engineers (Q9-Q11), and iv) about the preference of the software tools employed to work the case studies (Q12). In addition, the results obtained in the first three questions have been compared with the feedback received in the precedent years (courses 2019/2020 and 2020/2021).

For this purpose, the score scale achieved by the students was divided into five categories following the ECTS system none (the students did not go to the exam), fail (0–4.9), sufficient (5.0–6.9), good (7.0–8.9), very good (9.0–9.9), and excellent (10).

Table 4
Information provided by the lecturers.

		Value
Raw materials	Butadiene	92,169 t/year
	Styrene	45,660 t/year
	Solvent	2340 t/year
	Paraffin oil	9124 t/year
Reaction	Maximum Temperature	115–120 ºC
	Pre-heating temperature	80 ºC
	Recommended pressure	Above 20 bar
Other important features	Tap water consumption	156,095 m3
	Steam necessary	1620,377 GJ per year

3. Results and discussion

This section is divided into two main parts according to the methodology explained to carry out the case of study and with the aim of assessing: (i) the students' opinions based on their impressions and answers to the survey designed by the lecturers, and (ii), a critical comparison between the results obtained in the grades during the last three academic courses (2019/2020, 2020/2021 and 2021/2022). A comparison between the rates of the three courses provides an in-detail study of the learning methodologies' impact on the students because the two first courses lacked the implementation of both teaching methodologies.

3.1. Students' Outputs

This section presents the results collected from the survey provided to students of the Master's Degree in Industrial Engineering together with a critical discussion of the outputs received. As described previously, several case studies focused on problem-based learning combined with the flipped classroom were used to teach the course. A total of 22 students completed the survey in the course 2021/2022, where the new methodologies had been implemented, answering the ten questions from 1.0 (much lower than expected) to 5.0 (much higher than expected). Fig. 4 depicts the average of each respondent, taking into account the inputs. It is noteworthy that only one respondent reported a score below 3 (2.6). As a result, it can be inferred that the overall perception of the course was high and, consequently, the student trainees were moderately satisfied with the course content. Another important issue to highlight is the average of all the answers that is close to 4.0/5.0, demonstrating that Students of the Master's Degree in Industrial Engineering are interested in chemical engineering, particularly in the subject reported in this manuscript, Chemical Processes. This can be attributed to the effectiveness of the innovative approaches utilized throughout the course. These strategies have played a crucial role in capturing and sustaining students' attention, stimulating their curiosity, and fostering a deeper engagement with the content. Thus, by emphasizing learner-centered approaches, hands-on experiences, and real-world applications, the innovation strategies employed have successfully heightened students' enthusiasm for chemical engineering, particularly in the context of the Chemical Processes subject discussed in this manuscript.

The first point in-depth to analyze is the satisfaction of the students with the overall subject. In this context, three questions in the survey were based on the opinion of the surveyed related to the academics and their educational organization i) if the course was friendly to them, ii) if they had felt motivated to study, and iii) if the different chapters of the course were coordinated during the semester. In this sense, Fig. 5 depicts the feedback received, and as can be observed, only the answer of two participants corresponded to the category 'much lower than expected' (2 respondents) or 'lower than expected' (1 respondent). Specifically, the question 'I liked the subject' received twice a punctuation of 2 but, in contrast, up to 7 students pointed out that they liked it very much, obtaining an average value of 4.0/5.0. Regarding motivation, despite the academic emphasis on transferring knowledge and enthusiasm, it is evident that more effort is still necessary, as the average rating was only 3.2 out of 5.0. However, these results make sense since the course contents are, in many cases, far from the Industrial Engineer grade curriculum. In this way, Bancroft et al. reported the necessity of inspiring students to engage them with learning (Bancroft et al., 2021). Similarly, da Silva Junior et al. described the gap between the high demands that learning requires and the students' low efforts due to the lack of motivation in the United States of America (da Silva Júnior et al., 2021b). Therefore, it is necessary for professors to enhance their communication skills in the near future to better connect with students and improve the academic outcomes at the university level. The other key important point to evaluate a subject is the perception of the structure by the learners. In this framework, the punctuation obtained

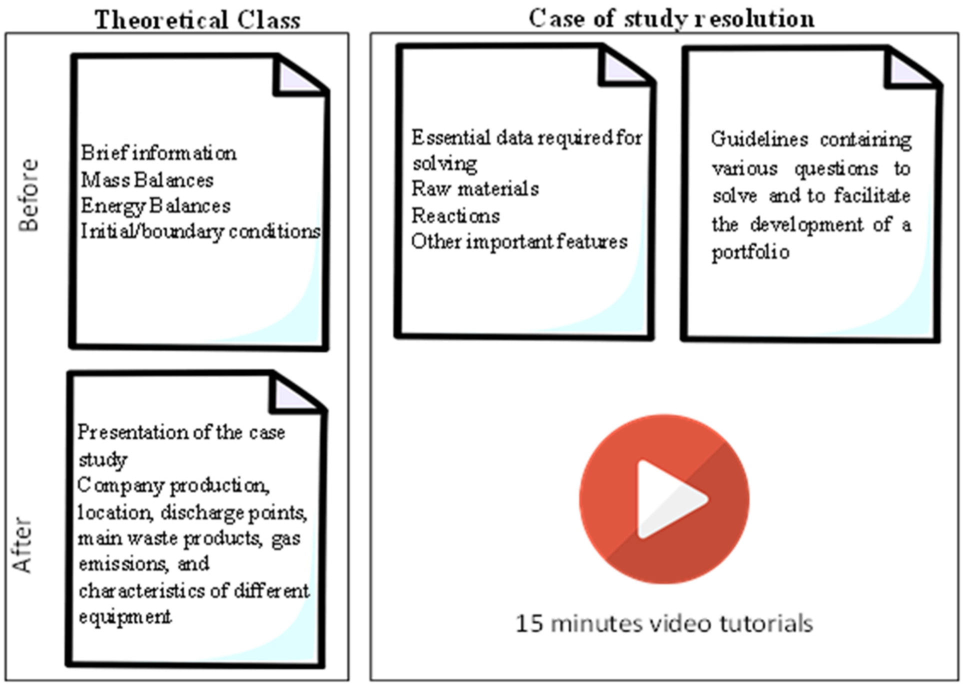

Fig. 2. The scheme followed during both theoretical classes and the resolution of the case study lessons.

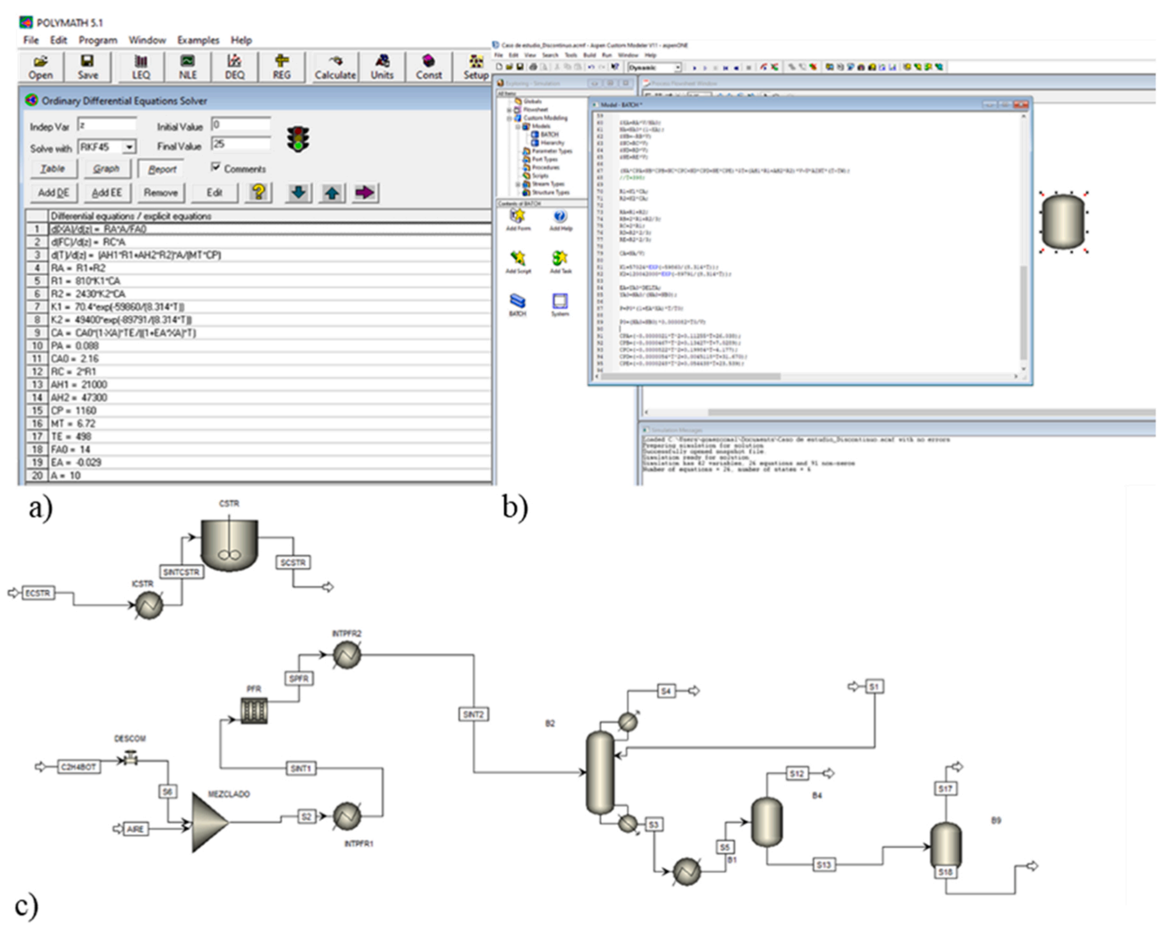

Fig. 3. Solver-tools screenshots of the tools used in Chemical Processes course. a) Polymath™, b) Aspen Custom Modeler, c) Aspen Plus.

Table 5
Survey provided to the Chemical Processes course of the Master's Degree in Industrial Engineering at the University of Cantabria.

		Much lower than expected	Lower than expected	As same as expected	Higher than expected	Much higher than expected
		1	**2**	**3**	**4**	**5**
Q1	I liked the subject					
Q2	I have been motivated to study					
Q3	The contents of the subject are coordinated					
Q4	Having notes before class favours learning					
Q5	Video tutorials help learning					
Q6	The use of computer tools favours learning					
Q7	Working with real-world case studies is attractive					
Q8	Group work promotes learning					
Q9	The course has improved my perception of chemical engineering					
Q10	The subject will be useful for my professional future					
Q11	What computer tool did you find most useful for your professional future?	☐ Polymath ☐ Aspen Custom Modeler ☐ Aspen Plus				

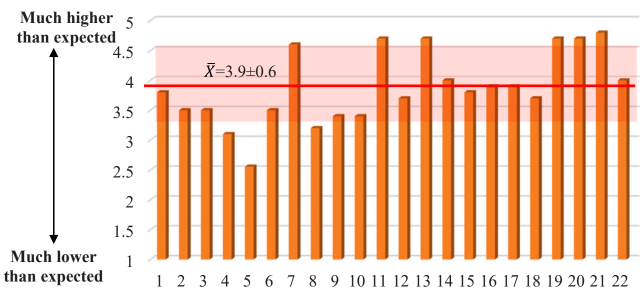

Fig. 4. Average punctuation of Q1-Q10 questions of each student. Redline: Average mean value.

increased with respect to the motivation, achieving 4.2/5.0, which can be considered a significant success. In this regard, Carbonell et al. communicated the importance of developing a high level of vertical/horizontal coordination between and inside the different courses to improve the quality of degrees and master's programs (Carbonell et al., 2021).

The average mark for these three questions was 3.8. Compared to the two previous academic years (2019/2020 and 2020/2021) where only the average mark was available, the increase of 0.4 can represent a positive step forward.

Focusing on the results related to new teaching methodologies explained through this work, problem-based learning, and flipped classroom, Fig. 6 illustrates the evaluation of the five key questions (Q4-Q8). The average punctuation is as highest as 4.1/5.0, obtaining the maximum evaluation in 11 (50%) answers in the question related to the learning based on real-world cases of study. Preceding works such as Borreguero et al. pointed out the importance of using real cases to link concepts and contents and give students a vision of their possible future profession (Borreguero et al., 2019). Besides, through this approach, the learners know the reality and see for themselves their capability to solve real industry problems, particularly, case studies associated with the region.

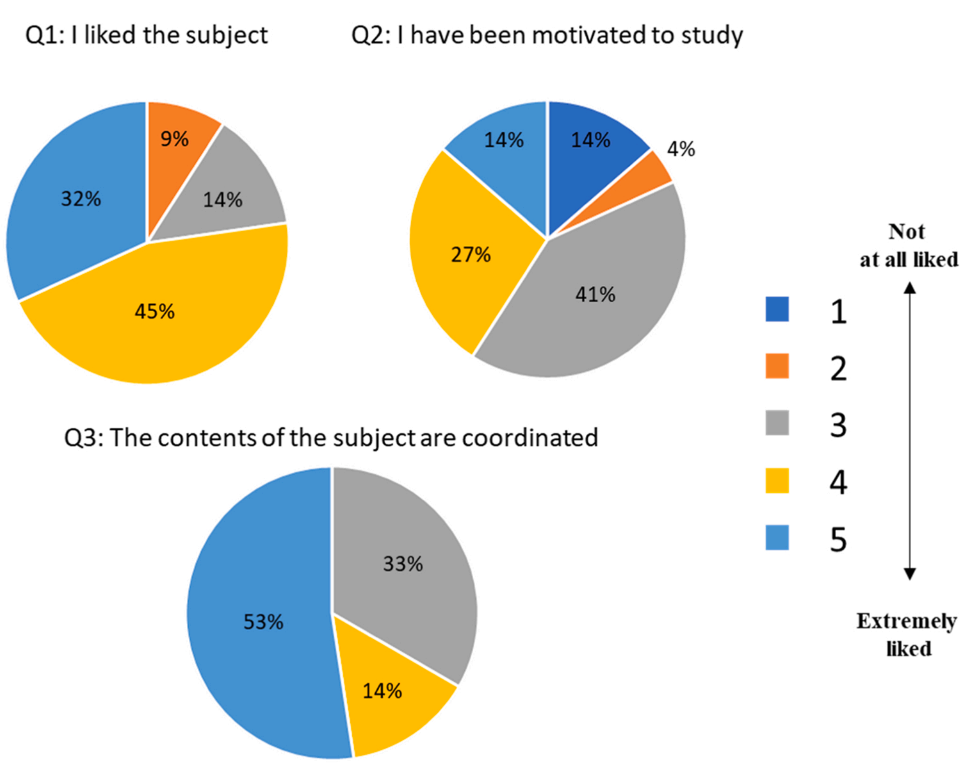

Fig. 5. Survey results of Q1-Q3 achieved relating to the diverse courses.

To discuss more in-depth these answers, Fig. 7 shows the average and the standard deviation of each question. All the items have average values of at least 4, except the opinion of the usefulness of video tutorials (3.8/5.0). However, almost 50% of the students (9/22) answered that this learning tool complied much higher than expected. The use of videos is inherent to the flipped classroom model, where instructors record instructional videos for students to watch before class, providing opportunities for independent learning and increasing time for practice during in-person lessons (Lin et al., 2021). The tutorials consisted of 15 recorded minutes of the different solver tools (Polymath™, Aspen Plus, and Aspen Custom Modeler) used along the course. The contents were a step-by-step solution to a problem. The first few minutes were dedicated to describing the resolution tool, including its advantages and disadvantages, language, and interface. Then, the approach to addressing the problem was presented, including the introduction of input data, followed by a detailed explanation. The lecturers noticed that the success of these videos is strongly connected to the interest of students. In this sense, recent works demonstrate the clear discrepancy between the convenience and utility of video tutorials or their inefficiency. Professor Belton reported a work describing a case of study teaching process simulation supported by video tutorials, among other strategies. The results indicated only a marginal preference by the students for video tutorials instead of demonstration/explanation from the front (Belton, 2016). In this context, Lewin and Barzilai noted that frequently learners watch video lessons passively, just listening without taking attention (Lewin & Barzilai, 2022a). On the other hand, Meunier and Hudon bet by the use of video tutorials since students can pause and re-watch the videos at their leisure, which helps them understand the problem-solving approach (Meunier & Hudon, 2019).

In the case of having notes before class, another characteristic of flipped learning, students welcomed the initiative, having this question an average 'higher than expected' (4.0/5.0), with 9 surveyed answering 'much higher than expected'. In this case, professors provided students with materials that enabled self-directed learning. Besides, 5 students, answered 'as same as expected', this could be probably related to the fact that this methodology cannot be uniformly applied due to differences in environment, capability, and culture of each educational institution (Kwon, 2021) because the students enrolled in this Master's program originate from diverse regions across Spain. Regarding the work in teams, learners were in favour although they found difficulties coordinating schedules, or in some cases, some groups faced the issue that a member was doing less work than the others. The punctuation obtained was 4.3/5.0, implying that the surveyed felt comfortable with the group's work. However, Ghani et al. developed a scoping review that claimed the need to design the groups and the role of lecturers during problem-based learning correctly (Ghani et al., 2021), or in other cases, learners could be frustrated.

Finally, the use of computer tools was also highly valued (4.3/5.0). This question was complemented by others where academics asked for the most attractive program used. Three informatic solvers were employed in this subject, two of them widely used in the chemical industry: Aspen Plus and Aspen Custom Modeler. The former is the primary Process Simulation tool in the market in this field, permitting the modelling of properties and phase equilibria. The second one allows the creation of customized high-fidelity models for process equipment and optimization processes. The third tool, employed in this course is Polymath, which permits the user to apply effective numerical analysis techniques during interactive problem-solving. The respondents' opinions are illustrated in Fig. 8, where the strong preference for both Aspen software's versus Polymath can be seen. Specifically, the majority of students chose as the first simulator Aspen Plus (71%), being Aspen Custom Modeler the second option (25%). This selection may be related to the user interface of the software programs. While Aspen Plus has a more visual interface that allows students to construct flow diagrams and input specific parameters based on the equipment selected, Aspen Custom Modeler requires more programming and equation writing skills. Additionally, the screens are less user-friendly than those of Aspen Plus. Nevertheless, Polymath control is easier and more intuitive than Aspen programs but it was only the selected option by 4% of the students. Therefore, it is possible to conclude that the learners perceived the usefulness of knowledge of these chemical engineering tools for their professional future.

In this framework, the analysis of the students' competencies and perceptions has been performed. The two methodologies implemented and discussed in this manuscript can promote specific capacities, which are closely correlated with improving their skills. Besides, employing the flipped classroom, the competencies obtained or improved were self-learning and capacity for organization and planning (answered in Q4),

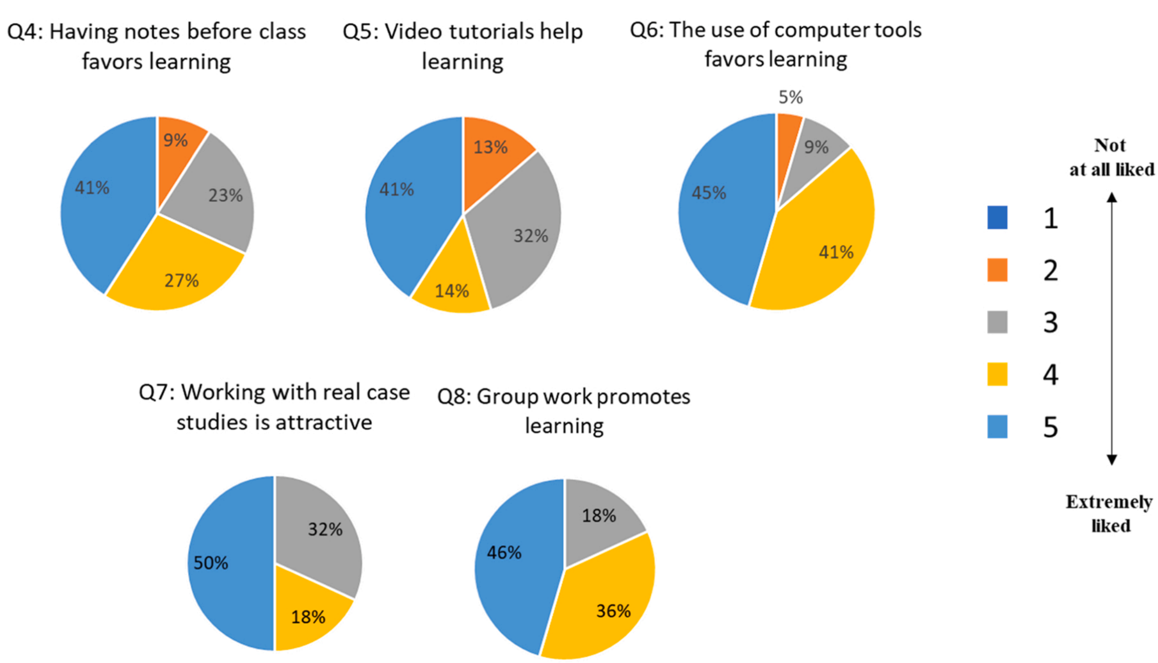

Fig. 6. Survey results of the questions (Q4-Q8) regarding the new teaching methodologies applied in the academic course 2021/2022.

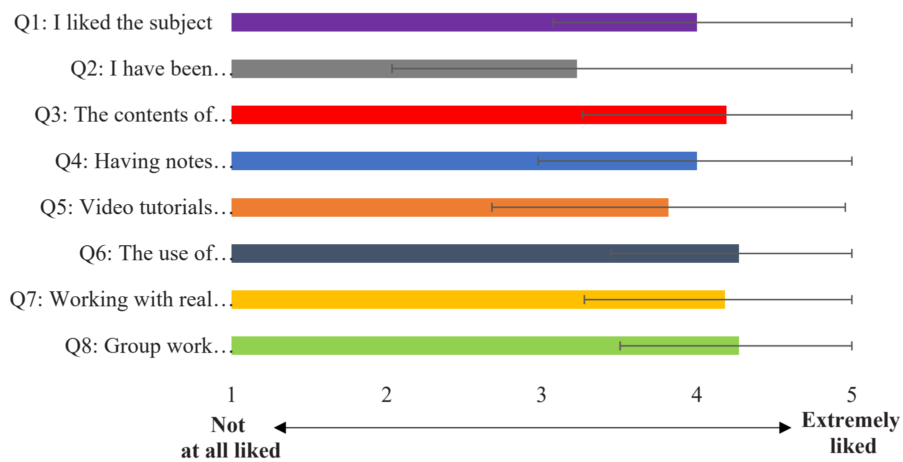

Fig. 7. Average and standard deviation evaluations regarding the questions related to flipped classrooms and problem-based methodologies.

autonomous workability, and independent learning (answered in Q5). On the other hand, problem-based learning and group problem-solving facilitated the attainment of computer science knowledge relevant to the field of study (answered in Q6). Moreover, it led to the development of positive attitudes towards problem-solving and critical analysis (answered in Q7). Additionally, the approach fostered teamwork skills and promoted positive interpersonal relations among the students (answered in Q8). All the competencies reinforced by the learners, together with their valuation, are summarized in Table 6.

The third block of questions focused on the perception of chemical engineering in industrial engineers and if the contents learned through the subject will benefit their careers. Fig. 9 illustrates the results obtained in percentage, indicating that although the perception did not change in the majority of cases (54%) an overwhelming proportion of respondents acknowledged the usefulness of the acquired knowledge for their near future. In this way, approximately 41% admitted that the course resulted in higher than expected, and 27% expressed that the subject will be helpful much higher than expected in their future professional enrolment. This can be translated into the learners who are aware that they should probably adapt their skills in different work positions since, in this globalized world, the ability to get familiar with diverse disciplines is highly valued.

The lecturers have made several observations that are mentioned below. Firstly, from their perspective, programming-based instruction requires greater preparation compared to traditional teaching methods. This entails the need for more extensive documentation and ensuring that the material is comprehensible for students. Secondly, the development of instructional videos demands a significant investment of time to condense the maximum useful information within the limited duration of the videos. Thirdly, the incorporation of real-world data and case studies necessitates substantial effort in searching for relevant data and establishing connections with companies.

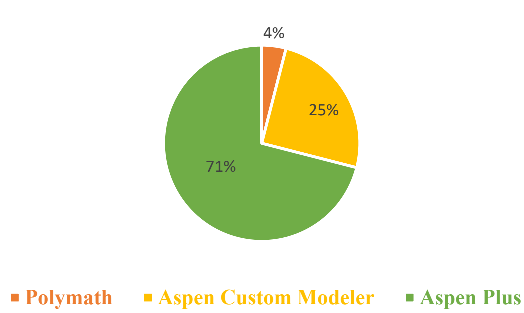

Fig. 8. Solver-tool preference among students of the Master's Degree in Industrial Engineering.

However, the lecturers also noticed several positive aspects. Firstly, they observed a higher level of interest and motivation among students compared to previous years. Secondly, a larger number of students displayed a commitment to staying updated on the subject matter. Thirdly, the students demonstrated a remarkable inclination towards independent research, actively seeking out additional information, indicating an increase in autonomous work. Finally, noteworthy is the students' enjoyment of working in teams, highlighting the positive impact of collaborative work on their learning experience.

3.2. Grades obtained by the students

This section discusses the overall final grade accomplished by the students. Three academic years have been selected for the comparison because the academics involved in the subject were the same. Besides, and as mentioned previously, only the latest course counted with the implementation of flipped-classroom and problem-based learning methodologies. Thus, a critical comparison between the value of implementing new methodologies is discussed in depth in this section.

The evaluation consisted of two partial exams or a final one in case of fail the continuous evaluation. This mark counted 90 points (45 +45 in the case of partials), and the remaining points correspond to the delivery of exercises carried out in group. The exams were distributed by a theoretical part and a practical part based on similar real exercises and study cases developed during the class and supplementary activities.

Fig. 10 presents the distribution of grades in accordance with the ECTS system, where the bars show the percentage of students who received each grade. In the academic course 2021/2022 a greater proportion of students (89.1%) attended the examination, with only 10.9% being absent (Fig. 10a). However, this academic year exhibited the highest failure rate compared to the previous years. These course evaluations comprises two assessments, one at the end of the semester and another, the extraordinary exam, scheduled a month later, solely for

Table 6
Competencies acquired by students and the evaluation.

Question	Competence	Punctuation*
Q4	- Self-learning - Capacity for organization and planning	4.0
Q5	- Ability for autonomous work - Capacity for autonomous learning	3.8
Q6	- Knowledge of computer science in the field of study	4.3
Q7	- Developed problem-solving - Analytical capacity	4.2
Q8	- Teamwork - Interpersonal relations	4.3

* (average/5.0)

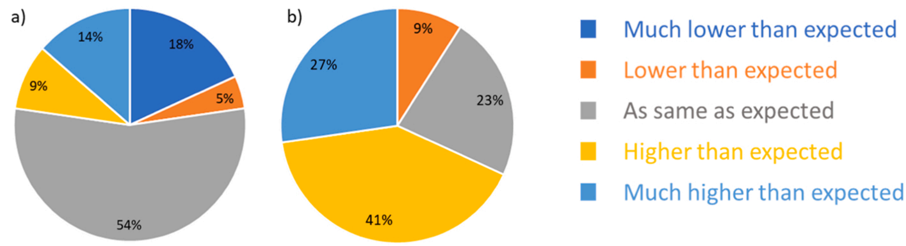

Fig. 9. Perception and usefulness of the course by the students of the Master's Degree in Industrial Engineering. a) The course has improved my perception of chemical engineering. b) The subject will be useful for my professional future.

students who failed in January. Fig. 10b compares the grades obtained in January after the regular assessment across the three academic years. In this case, the percentage of students that passed the course (pass, good, or very good) is quite similar, close to 50% of the enrolled people in each case. Nevertheless, the grades obtained by the students are significantly higher in the last year. Learners with good scores are 28% in contrast with 17.5% and 14.0% in the 2019/2020 and 2020/2021 courses, respectively. Thus, the implementation of new methodologies, specifically flipped classroom and problem-based learning, has been found to contribute to increasing the preparation and, therefore, the grades obtained by the students. In contrast, students who did not participate regularly in the course experienced more difficulties in passing the exam. This is likely due to the fact that the course contents provided by the academics required more effort to be understood if the learner was absent from the class or did not spend the recommended daily time for the course contents.

Moreover, the course's proposed activities facilitated and fostered the development of the subject's ultimate goals in terms of competencies. Students who passed the exam exhibited enhanced understanding of scientific and technological aspects of engineering, as they were able to apply and discuss diverse numerical methods to solve chemical process problems. In this regard, many students demonstrated the ability to propose innovative strategies for improving the industry's supply chain through research and by projecting, calculating, and designing novel approaches. Consequently, they acquired the capability to analyze and design chemical processes. In this sense, the learners increased their knowledge to be autonomous and original in the application of ideas. Finally, the problem resolution capacity and teamwork adaptation were encouraged promoting new capacities for the work world.

4. Conclusions

This work combines two teaching methodologies, flipped classroom and problem-based learning to teach the Chemical Processes course in the Master's Degree in Industrial Engineering at the University of Cantabria (Spain). In this framework, the subject was planned, including two strategies typical of the flipped classroom, i) the delivery of the materials to the students before the classes and, ii) the recording of video tutorials introducing the different software and tools used during the course. Besides, in the context of problem-based learning context, an effort was made to bridge the gap between theoretical concepts and real-world practical practices. To achieve this, practical cases based ona rubber international company in the Autonomous Community of Cantabria were presented and solved in class, with a focus on teamwork to simulate real-world work environments. The results discussed here demonstrate that students prefer the student-centric approach and particularly, the implementation of new teaching methodologies with respect to the traditional classes. For this purpose, the opinion of the learners has been evaluated by a survey which has been carefully designed, including different points related to i) the opinion of the subject and of the academic's evaluation, ii) the development of the new methodologies, and iii) the usefulness of a chemical engineering course in the professional future of the graduates. According to the survey results, students generally confirmed that: i) they consider the use of software as a tool to enhance their learning (rated 4.3/5.0), ii) teamwork highly contributes to their learning (rated 4.3/5.0), and iii) they prefer having notes before classes (rated 4.3/5.0). In addition, the implementation of these methodologies promoted the acquisition of various competencies, such as flexibility, self-learning, interpersonal relations, and analytical capacity. On the other hand, the grades obtained by the learners have been compared with previous academic courses where the new methodologies were not applied. The analysis revealed that while the percentage of students who failed the exam remained similar, those who were taught using the new methodologies achieved higher grades in the ordinary call compared to the results when these strategies had not been implemented. Therefore, these results confirm that incorporating new teaching methodologies, such as flipped classroom and problem-based learning, can enhance chemical engineering education in other programs, including the Master's in Industrial Engineering. This approach must be considered in the near future to motivate students and improve their skills.

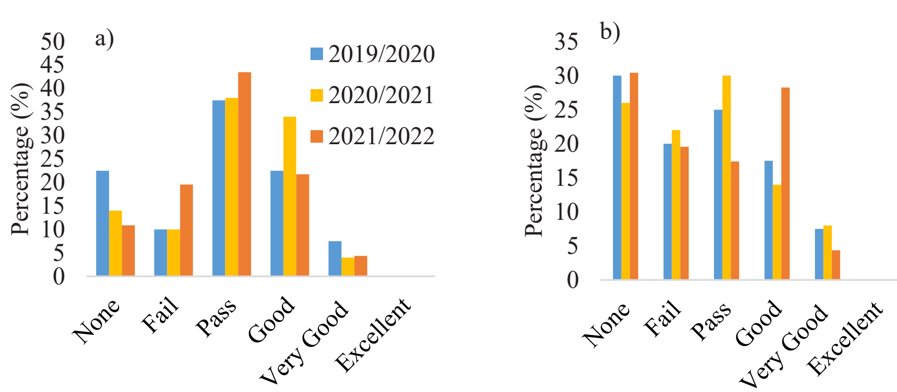

Fig. 10. Grades achieved by the students of the Master's Degree in Industrial Engineering a) overall course, b) taking into account only the results in the first examination period.

Declaration of Competing Interest

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

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