Education for Chemical Engineers 34 (2021) 21–32

Contents lists available at ScienceDirect

Education for Chemical Engineers

journal homepage: www.elsevier.com/locate/ece

Teaching chemical engineering to biotechnology students in the time of COVID-19: Assessment of the adaptation to digitalization

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ARTICLE INFO

Article history:
Received 31 July 2020
Received in revised form 17 October 2020
Accepted 5 November 2020
Available online 11 November 2020

Keywords:
Biochemical engineering
COVID-19
Emergency remote teaching
Higher-order thinking skills
Collaborative learning
Diversity outreach

ABSTRACT

With the global outbreak of COVID-19 in March 2020, there was an immediate shutdown of face-to-face classes and a sudden shift to on-line learning. Confinement required finding innovative approaches to teaching and student assessment. This paper aims to share the experience of adapting the course in Biochemical Engineering, part of the Biotechnology program at Francisco de Vitoria University (Madrid, Spain), to remote learning.

A sequence of collaborative learning activities, with active student participation, was designed to replace the traditional mid-term exam. Activities were carefully implemented, considering the range of learning styles. Engineering skills, transversal competences and higher-order thinking skills were fostered through these activities.

The analysis of the teaching/learning experience was based on teacher observations, academic performance and student surveys. All indicators showed that the adopted methodology had a positive impact of student performance. Student participation, especially among those repeating the course, also improved. Furthermore, students gained a more accurate and positive perception of the link between Chemical Engineering and Biotechnology, which may have a favourable impact on the teaching of Bioreactors in the coming academic year.

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1. Introduction

1.1. Context of the study

The Coronavirus (COVID-19) outbreak was first identified in Wuhan, China, in December 2019 and spread rapidly across the globe, leading the World Health Organisation (WHO) to declare COVID-19 a global pandemic just three months later. By July 2020, over 15 million cases had been reported to the WHO and some 620,000 deaths in 213 countries and territories worldwide (WHO, 2020). In terms of its impact on education, by the end of June over 1 billion learners saw the closure of their schools, colleges and universities due to the COVID-19 outbreak (UNESCO, 2020).

As a result, conventional, in-class education was immediately moved on-line (Bozkurt and Sharma, 2020) to address the emergency. In response to this global educational crisis, teachers were forced to quickly adapt their courses and methodologies without prior training in online pedagogy and often using unfamiliar digital teaching technologies. This was a great challenge for teachers at all levels, from primary to universities (Ali, 2020). For Spanish universities, the lockdown was imposed in the middle of the second semester, raising important questions at the time:

- How will teaching/learning continue during COVID-19 pandemic?
- How to support students during COVID-19 pandemic?
- How to assess students remotely?
- How to develop transversal skills and high-order thinking skills?
- How to ensure exam authenticity?

From the very beginning, the Francisco de Vitoria University (UFV), Madrid, Spain, moved swiftly to emergency remote learning. Regular lessons were maintained with minimal disruptions or rescheduling, although flexible attendance requirements for students were implemented during the lockdown.

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https://doi.org/10.1016/j.ece.2020.11.001
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Table 1
Subjects in Chemical Engineering in the UFV Biotechnology program.

Subject	BIOCHEMICAL ENGINEERING	BIOREACTORS
Course	2	3
Term	2	1
Credit value	6 ECTS	6 ECTS
Syllabus	Enzyme kinetics	Cell culture
	Enzyme purification	Cell stoichiometry
	Mass balances	Kinetic model of bioprocess
	Transport phenomena	Bioreactor design
	Fluid dynamics	Bioreactor scale-up

The Degree in Biotechnology at UFV is a highly multidisciplinary program, which includes Microbiology, Genetic Engineering, Cell Biology, Industrial Bioprocess Engineering, Business Administration and Project Management, Bioethics, etc. with Chemical Engineering being a minor module within the syllabus. Table 1 shows the various subjects in Chemical Engineering within the Biotechnology program at the Francisco de Vitoria University (UFV, 2020), encompassing two subjects with a broad syllabus.

Biotechnology students are typically interested in the biomedical fields of Genetics and Molecular Biology, with only a passing interest in Process Biotechnology. Their interest lies primarily in biology rather than mathematics and problem-solving, finding the application of mathematical tools a challenge (Foley, 2016). However, the main difference between Biotechnology and Biology graduates are their engineering skills. Chemical Engineering, as part of the Biotechnology Degree, is a technical field and presents a particular challenge to both students and teachers. The use of active learning strategies through problem-solving is the most habitual methodology in developing students' engineering skills (Foley, 2016).

Within this context, it was essential to adapt teaching and assessment methods for the course and to capture and maintain the attention and motivation of students through remote learning. The main concern was not only that student acquire the necessary engineering skills, but also to develop transversal and higher-order thinking competences.

1.2. Course description

As mentioned above, Chemical Engineering consists of two courses within the Biotechnology degree: Biochemical Engineering and Bioreactors, 6 ECTS each with 60 h of face-to-face classroom time. However, Biochemical Engineering was delivered online during lockdown. Various information and communication technologies (ICT) were used, along with the Moodle Learning Management System™ and Blackboard Ultra Collaborate™, in place of face-to face learning.

These courses are the "Biotechnological tools" module within the Degree in Biotechnology at the UFV, with Biochemical Engineering serving as an introductory course to provide students with the foundation necessary for the Bioreactors course.

The aim of the Biochemical Engineering course is to help students (UFV, 2019) i) to interpret and apply the fundamentals of enzyme kinetics, understanding their importance and applications in industry, ii) to understand the basic fundamentals of engineering in the design of biotechnological processes, and iii) to interpret and apply relevant parameters regarding transport phenomena and mass and energy balances in bio-industrial processes.

Student assessment was as follows:

- 50 % of the final mark will be the average of the two mid-term exams. All students must take the mid-term exams as part of their continuous assessment. Students not sitting these exams will be assessed through a final exam.
- 25 % of the final mark will be the results of practical, laboratory work.
- 25 % of the final mark will be from their continuous assessment, that is:
- 15 %: the average mark from continuous assessment where 70–80 % corresponds to the best marks among the different course assignments.
- 10 %: the higher mark of the first and second mid-term exams. Students not sitting these exams will lose this part on their final mark.

1.3. Underlying educational principles

1.3.1. Educational model

The course is based on a constructivist and connectivist pedagogical model. The course content and assignments are designed to expose students to a variety of tasks (problem-solving, case studies, video presentations, etc), based on a constructivist methodology; that is, through a series of tasks and assignments, students acquire new knowledge through a flexible and interactive learning process. With guidance from the teacher, students build on their previous knowledge and experiences, connecting with and learning from their fellow classmates in a process of acquiring new skills and competences (Torras, 2015). By using a broad variety of tasks and assignments, students are assessed as individuals, considering their different levels of motivation, attitudes and ways of learning (Felder and Brent, 2005).

The methodology of the course is based on a view of learning as a collective and collaborative process (Torras, 2015), incorporating a connectivist approach which understands learning as a consequence of building nodes and links between experts, knowledge repositories (databases, libraries or other information sources) and learners (Siemens, 2004; Guerrero and Flores, 2009).

1.3.2. The role of teacher/student

Within the context of the COVID-19 crisis, the teacher takes on a larger role, beyond that of a learning facilitator, instructing students in their learning objectives (Stephenson and Sangrà, 2013). The collateral effects of COVID-19 and the experience of lockdown demanded that teachers take a more active role in guiding and accompanying students along their learning path.

Students must be the protagonists of their own learning process; that is, playing an active role and making their own decisions throughout the course (Stephenson and Sangrà, 2013).

1.3.3. Pedagogical methodology

Biochemical Engineering was initially designed as a face-to-face course within the Biotechnology degree, and the conventional methodology of previous years needed to be replaced to address the realities of remote learning. Students maintained their active role in developing higher-order thinking skills, based on Bloom's taxonomy (analyse, evaluate, create; etc) (Nikolić and Dabić, 2016), given the strong connection between cooperative learning and the development of higher-order thinking skills (Davison and Majol, 2014).

Looking forward, and regarding the acquisition of practical competences, it is essential to foster the development of these higher-order skills among students, including the attitudes and habits of thought to be expected among scientists and engineers. Teachers must create and maintain the proper environment which encourages students to develop these skills (Felder and Brent, 2004a, 2004b).

Table 2
Description of the student's groups enrolled in Biochemical Engineering.

Class	First enrolled students		Repeating Students		Gender	
	Group size	Participation	Group size	Participation	Female	Male
1	34	97.1 %	7	85.7 %	54 %	46 %
2	32	100.0 %	12	100.0 %	73 %	27 %

1.4. Objectives

The present work describes how teaching and student assessment methods in the Biochemical Engineering course were adapted to the remote learning environment during the COVID-19 pandemic. This involved the development of a wide range of learning activities and a new assessment system to meet the demands of online learning.

The sequence of course activities was designed to achieve the following goals: i) to change student perception of the difficulty of Chemical Engineering and so increase student interest and engagement, ii) to motivate students to study and facilitate the understanding of concepts through constant feedback, and iii) to seize the attention and boost the participation of repeating students who often do not attend lectures and drop out of the course very early.

The activities described were designed to reinforce student knowledge, skills and competences using a practical, hands-on and collaborative methodology (Torras, 2015; Stephenson and Sangrà, 2013).

The aims of these learning activities were as follows:

1 Students were asked to work in groups, inventing a problem where the fundamentals of mass balances are applied. Collaborative learning helps students to connect their knowledge and experience in Biotechnology with Chemical Engineering, building their own knowledge working as part of a team while helping their peers to learn.
2 Participants were asked to generate a set of problems covering the main contents previously studied in the units. Learning was facilitated by working on examples about the role of Chemical Engineering within the field of Biotechnology. Thus, by designing new problems, students develop higher-order thinking skills such as abstraction, invention, organisation, teaching their peers, sharing knowledge and developing critical thinking.
3 Students were asked to complete concept quizzes in order to check their level of conceptual understanding and assess their calculation skills and knowledge.
4 Groups of 4 students were given a problem to be solved within a limited period of time, developing their ability to discuss, defend and communicate their ideas effectively, while applying appropriate mathematical methods to problem-solving.
5 Finally, students were asked to record the solution to the problem in order to assess their understanding, the application of mass balances equations and problem-solving capacity, as well as their ability to synthesise and summarise information.

2. Methodology

2.1. Participants

The participants of this work were undergraduate students of Biotechnology enrolled in the compulsory course of Biochemical Engineering during the 2019/2020 academic year. The methodology was applied in two classes (1 and 2). Class 1 consisted of students of the Degree in Biotechnology (37.5 %) and students attending a double Degree in Biotechnology and Pharmacy (62.5 %). Class 2 consisted entirely of students in the Degree in Biotechnology (100 %). A description of the classes is provided in Table 2, including sample size, student profile student (first or repeating students) and gender distribution. Participation refers to the level of student involvement, showed as percentage of student taking part in course activities. This reflects the response of students during the COVID-19 crisis to the alternative learning and assessment system.

Table 3
Student's perception of the subject's difficulty level (Sample size: 71).

Difficulty level	Relative Frequency
Very easy	1.4 %
Easy	1.4 %
Medium	9.9 %
Difficult	47.9 %
Very difficult	39.4 %

Repeating students, enrolled in the course for the second time after failing the course the year before, often have scheduling problems in attending and completing the activities part of the continuous assessment. These students are therefore able to be assessed only based on their marks in a final exam. However, despite all the educational challenges posed by the COVID-19 crisis, remote teaching was able to encourage these students to participate in these activities, improving their learning experience.

The UFV Quality Management department conducted a mid-term survey of the students to learn their opinions on the quality of teaching and the difficulty of the course. The student's perception of the difficulty of Chemical Engineering is shown in Table 3.

The survey highlighted that nearly the 90 % of the students rated the difficulty of the subject at the highest levels of the scale (difficult or very difficult). However, students attached great importance to Biochemical Engineering in their studies (Class 1: 8.0 over 10; Class 2: 7.9 over 10). This underlines the need to introduce new methodologies to make Chemical Engineering more accessible for Biotechnology students and so enhance their professional skills in related technical fields.

2.2. Teaching methodology

Looking to adapt teaching and assessment to the lockdown situation, an innovative approach was designed for the second mid-term exam on mass balance. This methodology was based on cooperative learning, with students taking an active role and taking into account the diversity of learning styles. A sequence of learning activities was designed to assess not only student's knowledge, but also to improve their transversal competences and higher-order thinking skills. The complete sequence of learning activities, assessment and weighted grades are shown in Table 4.

Step 0 *Attending lectures and problem-solving lessons*

The mass balances unit was taught over 5 weeks of which 3 were remote learning. To facilitate independent learning adapted to student's particular circumstances during lockdown, each lecture was recorded. Videos of problem-solving were also recorded.

Step 1a *Creating a problem in cooperative learning groups*

Step 1a consisted of building a problem for the mass balances unit. Students worked in teams of 4 and were allowed to choose

Table 4
Sequence of learning activities developed for teaching mass balance.

Step	Learning Activities	Type of activity	Student's role	Duration	Assessment system	Weight (%)
0	Attending lectures and problem-solving lessons	Face-to-face Remote	Passive	2 weeks 3 weeks	–	–
1	**a)** Creating a problem based on cooperative learning groups	Cooperative (4 people)	Active	1 week	Grading through rubric	30
	b) Using the created problem set for learning	Individual	Active	1 week	–	–
2	Concept quiz	Individual	Active	40 min	Points based grading	30
3	**a)** Finding the solution to a given problem	Cooperative (4 people)	Active	90 min	–	–
	b) Recording the solution to a given problem	Individual	Active	30 min	Grading through rubric	40

Table 5
Specifications for each team to create a problem based on cooperative learning.

	SPECIFICATIONS			
Team	1 Operational Mode	2 Operation units	3 (Bio) chemical reaction?	4 Other requirements
1	Continuous (steady state)	3	No	The process must be focused on separation operations for product purification
2	Continuous (steady state)	3	No	Stream data must include changes in volumetric flow and density
3	Continuous (steady state)	3	No	Efficiency of any separation unit must be provided
4	Continuous (steady state)	3	Yes	A splitter must be included in the process
5	Continuous (steady state)	3	Yes	Reactor size and rate must be provided so that generation can be established.
6	Continuous (steady state)	3	Yes	Productivity data must be provided so that generation can be established.
7	Batch	3	No	Efficiency of any separation unit must be provided
8	Batch	2	No	Kinetic equation of any physical operation must be included
9	Batch	3	Yes	Reaction time must be provided as data
10	Batch	2	Yes (at least 2)	Reactor size and rate must be provided so that generation can be established.
11	Continuous	2	No	The process does not work under steady state

their own team. The proposed problem had to meet the specifications of the teacher and also be related the field of Biotechnology. These specifications are summarised in Table 5. After week 1, each group submitted their assignment, including a description and solution to the problem. The teacher was available to clarify student's questions during the assignment, addressing misconceptions and providing additional information.

The task focused on developing hands-on learning, with students working in small-groups toward the same goal. Creating a problem using cooperative learning groups was an exploratory task. Students were encouraged to contribute examples and discover connections between Chemical Engineering and their specific experience in Biotechnology. The proposed methodology invited students to build their own knowledge collectively. As noted above, the aim was to apply a practical, hands-on and collaborative approach (Torras, 2015; Stephenson and Sangrà, 2013). Thus, students were asked to produce the content to be taught to their classmates. It is also an opportunity for students to internalise concepts, understanding and helping others to learn.

The assessment system consisted in a rubric, providing a specific guide about the assessment criteria and expectations and criteria. The rubric for the evaluation of the activity is shown is Table 6.

Step 1b *Using the created problem for learning*

The specifications were designed to provide a wide-ranging set that addressed the main types of problems studied previously in the unit. The set was available in the virtual classroom immediately after the submission deadline for the assignment in step 1a.

Biotechnology students tend to find the mass balances unit particularly abstract and confusing. For this reason, some of them opt to memorise solutions rather than truly understand them for future application. The objective of step 1b is to provide students a useful tool to facilitate learning by presenting Chemical Engineering through familiar examples. A forum was also included in the virtual classroom to provide students with a tool to chat and discuss the proposed problems.

Step 2 *Concept quiz*

Step 2 was an individual test consisting of 12 questions on the various topics in the unit. During the 2019/2020 academic year, the virtual platform at UFV was Moodle™. A questionnaire module was employed to create a bank of questions with similar content for each category. The concepts, types of question and weighting is shown in Table 7.

Multiple choice questions allowed a single answer (only one answer could be chosen). Correct answer got full marks (100 %) and wrong answers were penalised with negative mark (25 %). Numer-

Table 6
Rubric for the evaluation of the problem based on cooperative learning.

CRITERIA	Points
1 About the wording of the problem	
1.1 Is it scientifically consistent?	– / 3
1.2 Is it innovative and creative?	– / 3
1.3 Is the wording expressed clear and proper?	– / 3
1.4 Is the required information provided?	– / 3
1.5 Does the problem fit for an exam's difficulty?	– / 3
2 About the specifications	
2.1 Is the specification 1 included?	– / 3
2.2 Is the specification 2 included?	– / 3
2.3 Is the specification 3 included?	– / 3
2.4 Is the specification 4 included?	– / 3
3 About the resolution	
3.1 Does the resolution apply the methodology?	– / 3
3.2 Is the resolution correct?	– / 3
3.3 Is the resolution easy to understand?	– / 3
Total	**– / 36**

Table 7
Structure of the concept test.

Type of question	Evaluated concept	Number of questions	Weight (%)
Multiple choice question	Theoretical concepts	4	33.3
Numerical question	Continuous physical process	3	25.0
Numerical question	Continuous process with chemical reaction	2	16.7
Numerical question	Batch physical process	2	16.7
Numerical question	Batch process with chemical reaction	1	8.3

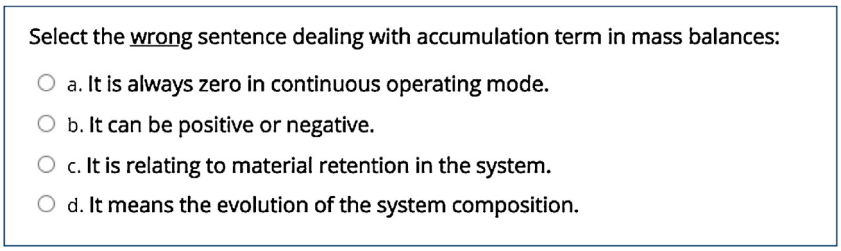

Fig. 1. Concept quiz example of multiple-choice questions for the topic theoretical concepts.

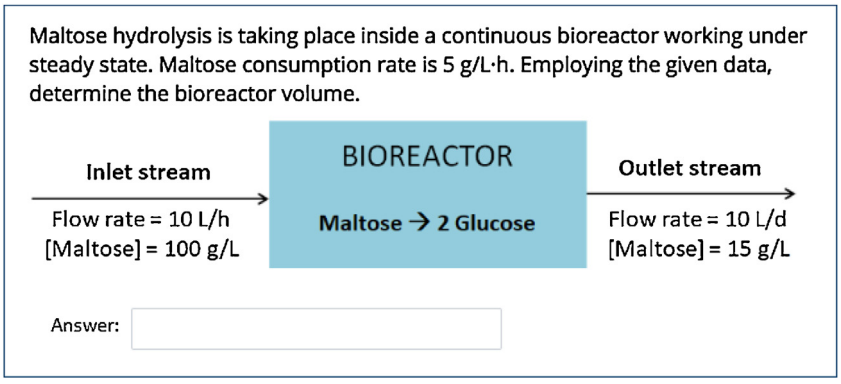

Fig. 2. Concept quiz example of numerical questions for the topic continuous process with chemical reaction.

ical questions accepted numerical answers with an error of 5 %. Units also needed to be specified. Numerical questions were used to grade the number (90 %) and the unit (10 %). Figs. 1 and 2 show examples of multiple-choice questions and numerical questions, respectively.

To avoid cheating or copying between students, each student was given a different quiz. Tests were designed so that questions in different categories were randomised. Moreover, questions were arranged on separate pages and browser's back button was deactivated.

The aim of the concept quiz was to evaluate student comprehension and the test was at low-intermediate level. However, the short duration, 40 min, raised the difficulty to score high marks. Therefore, students needed to have competent calculation skills and applicable knowledge to pass the test.

A points-based assessment system was employed, with each question scoring 1 point. The final mark was the sum total of points divided by the total points (12).

Step 3a *Finding the solution to a given problem*

Finally, the teams of 4 students were required to solve a given problem in 90 min. Each team received a different problem but all at the upper intermediate level of difficulty. The teacher prepared a Blackboard UltraCollaborate™ session per group. Students joined their session to discuss how to solve the problem, draw a process flow diagram, apply and resolve mass balances while answering the questions provided. During the execution period, the teacher was available to clarify any questions. The aim of this activity was to create a forum for debate about the problem and to find a solution through collaborative learning.

Step 3b *Recording the solution to a given problem*

Immediately after step 3a, students were assigned activity 3b: recording the solution to the given problem. Each student had previously checked the proper functioning of their recording device (mobile, tablet or webcam). Students were given 30 min to record their videos and an additional 30 min to prepare and submit the assignment.

Table 8
Rubric for the evaluation of problem-solving video.

CRITERIA	Points
1 About the digital content	
1.1 Is the recording duration suitable?	– / 3
1.2 How is the design-quality of the recording?	– / 3
2 About oral skills	
2.1 Does the student introduce themselves?	– / 1
2.2 How is the oral communication?	– / 3
2.3 Is the speech consistent?	– / 3
3 About the resolution	
3.1 Does the student understand the wording?	– / 3
3.2 Does the student apply the mass balance equations?	– / 5
3.3 Does the student calculate the unknowns?	– / 5
3.4 Does the student answer the exercise's questions?	– / 5
Total	**– / 31**

For student identification, a short introduction was required at the beginning of the video. The recommended length of the video was 10–15 min. Videos that were too short or too long were penalised. The assessment system was outlined in a rubric previously provided to students, shown in Table 8. Understanding processes, applying mass balances equations and solving the proposed problem accounted for 60 % of the mark. Digital content production and oral communication were also assessed (20 % each item).

2.3. Competences

The Biochemical Engineering course in the 2019/2020 academic year (UFV, 2019) encompassed the main competences students should acquire. Basic, general competencies are common to most degrees, but adapted to their contexts, whereas certain competencies are specific to each degree with a specific graduate profile. The following is a description of the specific competences developed in the mass balances unit and learning activities:

Table 9
Transversal competences and higher-order thinking skills developed in learning activities.

	LEARNING ACTIVITY				
TRANSVERSAL COMPETENCES	1a	1b	2	3a	3b
Oral communication skills	X			X	X
Teamwork	X			X	
Digital skills					X
Creative and innovative thinking	X				X
Critical thinking	X	X	X	X	
Knowledge transfer	X	X		X	X
Time management			X		X
Organizational skills					X
HIGHER-ORDER THINKING SKILLS	1a	1b	2	3a	3b
Create an original work	X				X
Evaluate and make judges		X			
Analyse and make connections		X		X	
Apply information in new situations	X	X	X	X	X

2.3.1. Basic competences

- The integration of knowledge from various sciences and an understanding of social and ethical responsibilities in the application of this knowledge.
- The ability to communicate clearly and concisely opinions and conclusions to both specialists and non-specialists.
- The learning skills necessary for effective, autonomous learning.

2.3.2. General competences

- The collection and analysis of information; the capacity for problem-solving and decision-making.
- The capacity for analytical, synthetic, reflective, critical, theoretical and practical thinking.
- An understanding the fundamental principles and laws of physics, mathematics, chemistry, and biology as the basis of Biotechnology.

2.3.3. Specific competences

- The ability to calculate and interpret relevant parameters about transport phenomena, mass and energy balances in bio-industrial processes.
- The acquisition of essential technological and engineering knowledge for the design of processes.
- The application of theoretical knowledge to problem-solving and practical cases.

These basic, general and specific competences should be acquired and consolidated by the end of the course.

2.3.4. Transversal competences and high-order thinking skills

Transversal competences can be considered generic and applicable skills that students acquire throughout their degrees. The development of transversal competencies complements technical-scientific skills and ensures graduates have the profile to act as competent professionals in the future (Sa and Serpa, 2018). However, course programs at the UFV do not specifically include these competences. Given their importance to student learning, the chart of learning activities provided below indicates the transversal competences and higher-order thinking skills which may be difficult to impart through remote learning. Table 9 summarises the main competences developed at each step.

The activities described in steps 1 and 3 encompass a number of transversal competences, such as oral communication, teamworking and digital literacy. Additionally, both steps were designed to develop higher-order thinking skills. According to Bloom's taxonomy, creating, evaluating and analysing involve complex cognitive skills. However, understanding and applying are lower-order thinking skills. These proposed activities encourage students to think "out-of-the-box", to be creative and innovative. To achieve this, activities involve projects which assess the synthesis of knowledge and creation of new understanding. Step 2 is a more conventional teaching approach, assessing primarily lower-order levels of thinking.

2.4. Assessment of the learning experience

An online survey was conducted to evaluate the experience of the second mid-term exam and student's view of the teaching approach, their development of transversal skills and other relevant aspects. The survey was constructed using Google Forms®. Students were given 9 statements, indicating their level of agreement using a Likert scale (1 strongly disagree; 2 disagree; 3 neutral; 4 agree; 5 strongly agree). The survey structure is shown in Table 10. All enrolled students were invited to take the survey at the end of the term.

3. Results and discussion

3.1. Instructor observations

Recorded lectures and problem-solving videos were available to students during the semester. As there is a record of the views and reviews of these videos, the availability of these recordings was considered to have a positive effect on students learning. Videos were a useful tool allowing students to view them at them at any time. In fact, few students requested teacher support to resolve their questions dealing with mass balances, whereas, in previous years, most students asked teachers help several times throughout the semester.

Student results on the second mid-term exam was more successful and higher than expected. The majority of repeating students took part in the activity, indicating that the aim of encouraging their participation had been achieved.

Regarding problem-creation and cooperative learning, all the students completed the task properly. Some teams formulated

Table 10
Survey structure to evaluate student's opinion.

Code	Choose your level of agreement with the following statements:	Rating scale				
		1	2	3	4	5
1.a	Teamwork activities enhanced my learning in *Biochemical Engineering* course.					
1.b	Teamwork activities improved my oral communication skills.					
1.c	Collaborative assignments helped me to cope with lockdown.					
2.d	Scientific video recording enhanced my digital skills.					
2.e	Scientific video recording helped me to organise concepts in mass balances problems.					
2.f	Scientific video recording improved my oral communication skills.					
3.g	Seeking my own problem based on cooperative learning had a positive effect on integrating mass balances concepts.					
3.h	Seeking my own problem based on cooperative learning helped me to link Chemical Engineering to Biotechnology.					
3.i	The created problem's set was a useful tool in the study of the subject.					

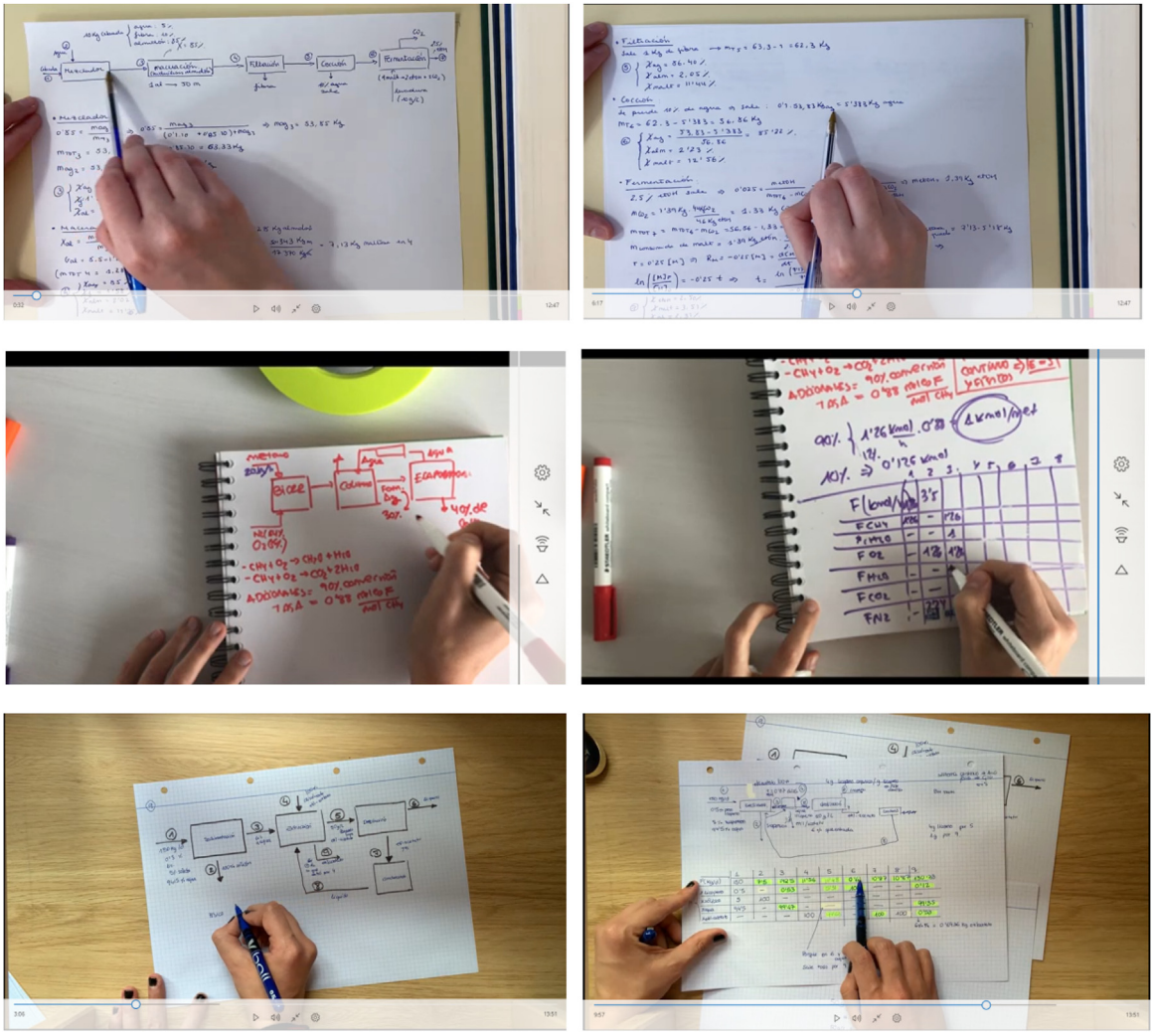

Fig. 3. Frames of problem-solving videos by various students.

highly creative problems while others found excellent examples within the field of Biotechnology. Problem-solving was also required in the assignment, but the format was not fixed. Some teams decided to record a video explaining the solution, often producing engaging, high-quality work.

With regards to the forum provided step 1.b, this was not widely used; only by 2 students from Class 2. The forum was created as a support tool, but students did participate, perhaps because this activity did not count towards their final mark.

After the concept quizzes, students reported they were not given enough time to finish the task. They also complained about calculation questions because only the final results were marked. However, most students passed the concept quizzes and a few scored outstanding marks. Calculation questions were new to the students and they reported a lack of confidence in this area. The final exams also included this type of questions relating to other units and there were no significant complaints about the marking system.

All the students joined the Blackboard Ultra Collaborate™ session to work on finding the solution to a given problem in groups. They worked on this task for 90 min without incident. However, several students experienced some difficulties in completing the exercise. Submitting video recordings was a difficult assignment for some students, as they had several technical problems (sounds failures, not enough available memory, mobile/tablet connection failures, etc). File uploading took longer than expected. In addition, 3 students in Class 1 did not submit their recording although they had done previous learning activities.

Lockdown was a stressful experience in terms of isolation and deprivation and students needed to adapt using the resources they had available. In the 2019/2020 academic year, the virtual platform did not offer an embedded video recording application. Fortunately, this will be available from the current academic year and will certainly be a useful tool to develop innovative learning activities.

The overall instructor perception was that video recordings are a good formative activity. Students were asked to organise and communicate their knowledge, developing a deeper level of thinking. In spite of the stressful situation, student's final results were good. A series of frames the problem-solving videos of different students are provided in Fig. 3.

3.2. Results in learning activities

The results of students in Class 1 were quite similar to those of students in Class 2 in terms of average marks and standard deviation. Therefore, the outcomes of learning activities have been addressed and discussed jointly as a single class.

The results of problem-solving through cooperative learning (step 1.a), based on the assessment rubric (Table 6), are provided in Fig. 4. The sample size was 83 participants. All students passed

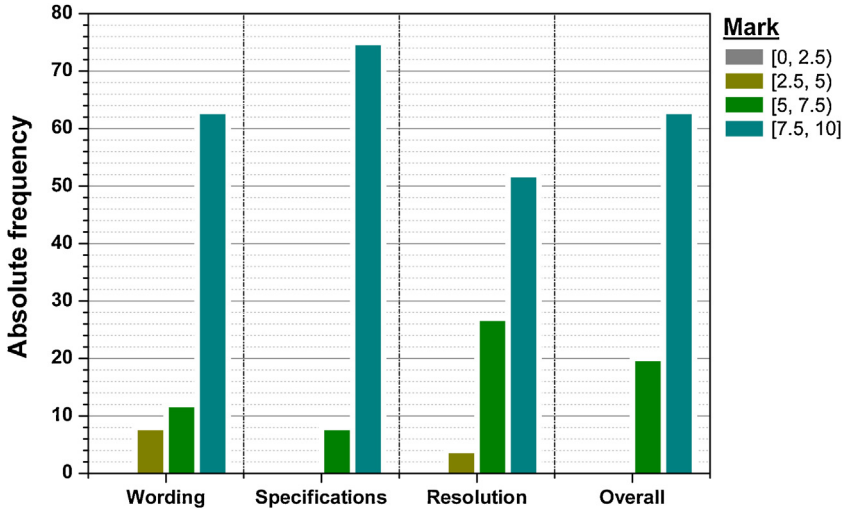

Fig. 4. Results in problem-solving through cooperative learning (step 1.a) according to evaluated topics in the rubric (Sample size: 83).

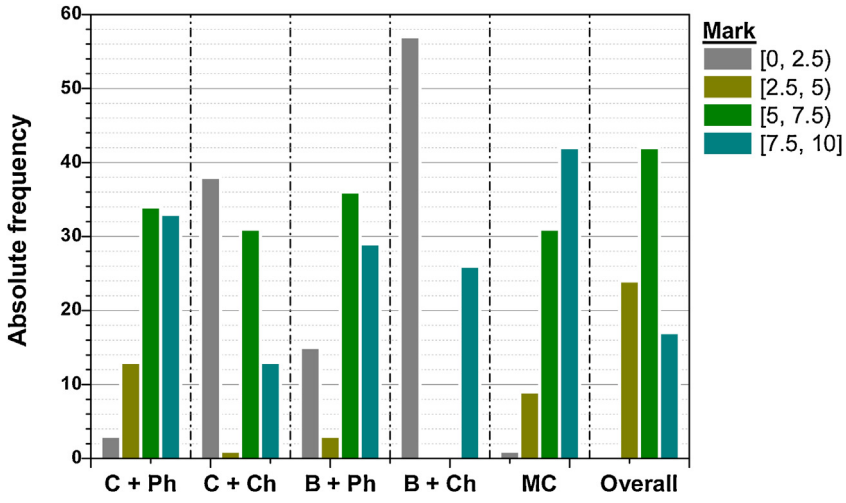

Fig. 5. Results in concept test (step 2) by question categories (Sample size: 83). **Key:** C + Ph: Continuous physical process; C + Ch: Continuous process with chemical reaction; B + Ph: Batch physical process B + Ch: Batch process with chemical reaction; MC: Multiple choice questions about theoretical concepts.

step 1.a, obtaining a mark higher than 5. Around 75 % of students scored higher than 7.5 points. The average mark for this learning activity was 8.2 ± 1.5.

More specifically, the results obtained in the wording of the problem were between 5–10 points, mostly between 7.5 and 10 (63 out of 83 students), and only 8 students scored below 5. The results for the specifications followed the same trend. However, the results for problem resolution were different. All but 4 students scored higher than 5, and 63 % scored between 7.5 and 10 points.

These results suggest that students were able not only to correctly formulate their proposed systems, but also to successfully identify and apply the instructions in order to create the problem to be solved, drawing on working in cooperative learning groups (as shown in Table 5). Higher-order thinking skills were put into practice; most student properly formulated and explained their proposal, extracted information and solved the problems. However, difficulties in systematic organisation and applying mathematics were detected. This may be related to the need for students to master not only concept regarding mass balances, but mathematical tools and calculus skills as well.

The overall results and the results in each category of the quiz (step 2) are summarised in Fig. 5. Approximately 75 % of students passed the test. Specifically, 43 students, out of 83, scored between 5 and 7.5, while 17 students obtained a mark higher than 7.5. A total of 24 students failed the test. The average grade of this activity was 5.9 ± 1.8.

The results in each category clearly reveal the most difficult issues for participants. Broadly speaking, systems involving deeper mathematical skills proved most difficult for students. Particularly, changes in system composition due to transformation (chemical, enzymatic, biological, etc.) increase complexity. Likewise, if the problem also involves a batch system, the difficulty is higher, requiring the integration of kinetic expressions. This is consistent not only with a lack of a mathematical foundation within the degree syllabus, but also with a general prejudice or fear of engineering subjects in general, as previously mentioned.

The results of step 3b (recording the solution to a given problem) were evaluated using the rubric shown in Table 8. Grades obtained are provided in Fig. 6. The marks obtained in two of the three items of the rubric (digital content and oral skills) followed the same trend. Some 88 % of the students scored higher than 5 in all the items indicated. Additionally, 71 % of students scored between 7.5 and 10. However, 23 % of students did not pass the resolution item, which slightly deviated the observed trend. Consequently, for the final grades of students, shown below, 93 % attained positive results, higher than 5 (as shown on the right side of Fig. 6). There-

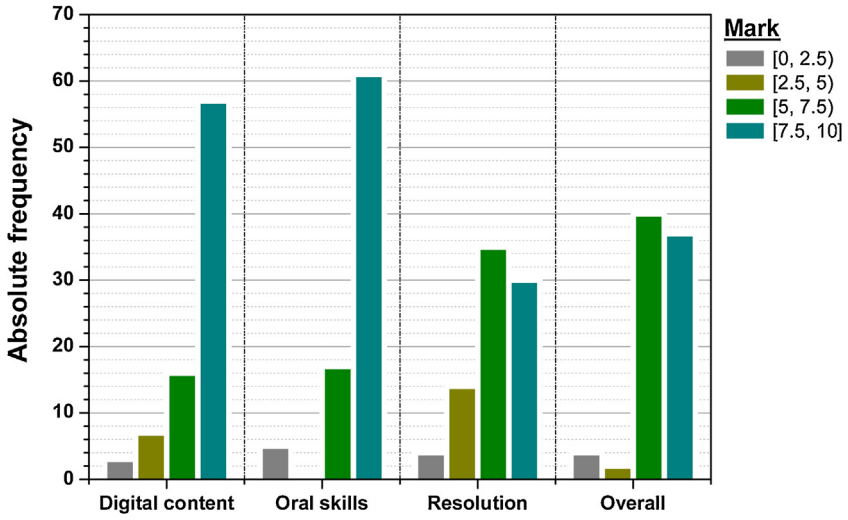

Fig. 6. Results in problem-solving recording (step 3.b) according to evaluated topics in the rubric (Sample size: 83).

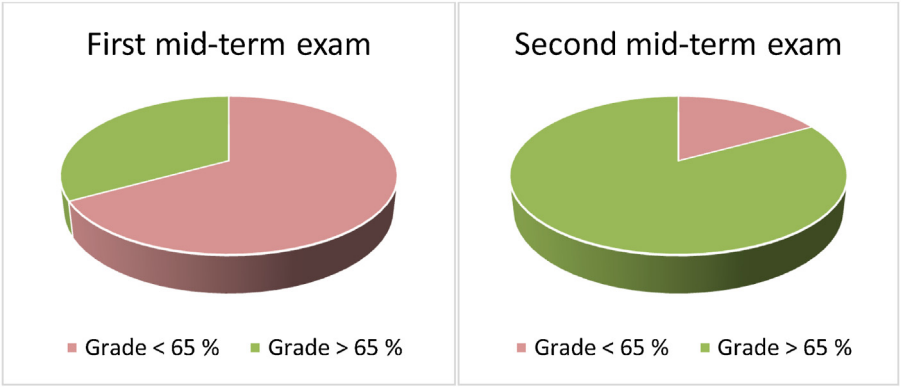

Fig. 7. Obtained final grade in the first and second part of the continuous assessment (Sample size: first mid-term exam 80; second mid-term exam 83).

fore, only 7% of students failed the step which consisted in recording the solution to a given problem. The average mark for this learning activity was 7.1 ± 1.5.

Students have been acquired oral and digital skills as well as the ability to synthesise and abstract information. However, the application of theoretical knowledge and performing the right calculations are the main difficulty for students.

3.3. Final marks overview

In order to determine the effectiveness of innovative methodologies, the final results of the second mid-term exam were compared to the first mid-term exam (Fig. 7). Firstly, overall participation in mid-term exam 2 increased compared to participation in mid-exam 1. The number of students who passed increased noticeably when the proposed methodology was applied. The percentage of students being exempted from the respective units in the final exam increased from 33 % (first mid-term exam conducted with a conventional methodology) to 83 % (second mid-term exam using the innovative methodology).

In conclusion, the results show that the innovative learning methodology employed led to a slight increase in the student participation. Moreover, there was a significant increase in the number of participants passing the midterm exams, being exempted from the respective units in the final exam (with marks higher than 65 % of the scale). This improvement can be explained by a number of factors, including greater motivation among students with the use of new methodologies, a significant improvement in student accompaniment, monitoring and feedback, a better continuation of learning processes, an improvement in student autonomy, the reduction in the perceived difficulty of the subject, variability in learning tools and assessment.

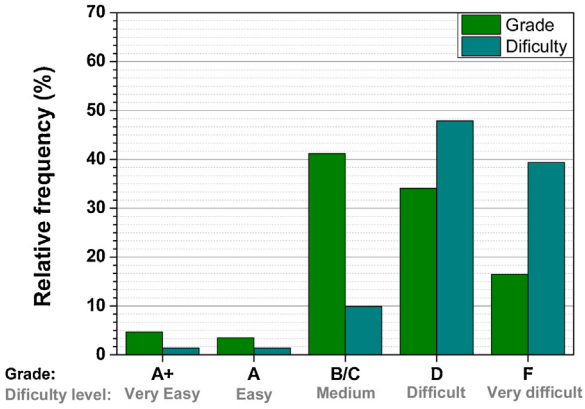

Fig. 8. Comparison between final marks (Sample size: 85) and perceived difficulty by students (Sample size: 71). **Key:** A+ (outstanding grade); A (100-90 %); B/C (89-70 %); D (69-50 %); F (<50 %).

Table 11 shows the results from the last four academic years. It should be noted that the percentage of first enrolled students passing the subject increased significantly in the last academic year.

Table 11
Results obtained in the last four academic years.

	First enrolled student			Repeating enrolled student		
Academic year	Passed (%)	Failed (%)	Students	Passed (%)	Failed (%)	Students
2019/2020	89.3	10.6	66	68.4	31.6	19
2018/2019	70.8	29.2	48	56.2	43.8	16
2017/2018	79.3	20.7	92	62.5	37.5	16
2016/2017	75.0	25.0	76	66.7	33.3	9

However, the improvement of results obtained by repeating students was less noticeable due to the lack of connection of this group of students to the subject.

Comparison between final marks and perceived difficulty by students is shown in Fig. 8. Around 90 % of the students indicated that Biochemical Engineering is a difficult or very difficult subject. Only 3% of the students perceived the subject as easy or very easy. However, final marks show that around 70 % passed the course. In addition, 41 % of the students obtained a final mark ranging from 7 to 8.9. Thus, there is no relationship between both trends. This confirms that Biotechnology students are often conditioned negatively towards the engineering field. To change student perceptions of the subject's difficulty, Fig. 8 was shown at the end of the term. Thus, reaching open-minded students about Bioreactors will also lead to improved outcomes and motivating students to change their opinions may result in better student performance.

3.4. Online student survey

The online survey created to assess the learning experience was divided into the following evaluable parts: i) teamworking activities, ii) scientific video recording, and iii) problem-solving through cooperative learning. Some 80 % of students (68) completed the online survey. The results are show in Fig. 9.

In general, it can be seen that students have a positive perception of the three items surveyed. Specifically, a positive trend can be seen relating to teamworking activities. However, in questions dealing with video recording, this positive trend is lower when students were asked about any improvement in their digital skills. Some 50 % of the students perceived an improvement in digital skills due to the activity, 25 % of the students were neutral and the remaining 25 % concluded that their digital skills had not improved. A positive trend can also be seen in the question regarding problem-solving through cooperative learning. This positive perception increases when students were asked about the effect of these activities on integrating mass balances concepts and finding a link between Chemical Engineering and Biotechnology. However, some students (around 35 %) did not consider this a useful resource to study the subject.

3.5. Limitations of this study

The present work describes the experience of using new learning methodologies for Biochemical Engineering in response to the disruptions caused by the COVID-19 crisis. The student perceptions and learning outcomes of these methodologies were evaluated.

However, designing the survey is a complex process to accurately measure the opinions, experiences and behaviour of students. Inexperienced surveyors may lead to ambiguous or biased questions. In future, surveys of student perceptions should be carefully reviewed to avoid any potential question bias. The authors highlight the importance of paying attention to open and closed questions, question wording, order, etc.

It should be noted that the methodology was only applied to Biotechnology students at a single university. The results may differ based on institutional context and participants' academic background.

Finally, the data collected related to student impressions and academic results were handled anonymously and separate from any personal data. As a consequence, only global conclusions can be extracted; obtaining individual results inferring personal motivations and situations was neither possible nor the aim of this work.

This study offers a comparative analysis of results over the last two years. Although a longer study would provide more robust results, the substantial differences observed allow conclusions to be drawn regarding the hypothesis of this work. An alternative learning methodology, taking advantage of Information and Communications Technologies succeeded in overcoming the direct consequences of the COVID-19 lockdown, motivating students and improving participation for successful learning outcomes both in student performance and perception of Biochemical Engineering.

4. Conclusions and future perspectives

An innovative methodology based on cooperative learning, focused on the active role of students and considering different learning styles, was proposed in response to the COVID-19 crisis. Students were provided, not only with remote lectures and problem-solving assignments, but other activities as well. For instance, the creation of a problem, working collaboratively, building a set of significant problems covering the course contents, answering a quiz on relevant concepts in Biochemical Engineering, and, finally, finding the solution to practical problems and recording the solution, fostering collaborative learning using created videos.

Although there was a dramatic change in learning due to COVID-19, the application of these innovative methodologies succeeded in aligning course competences and skills, while responding rapidly to student needs, maintaining class dynamics and motivating learning. Collaborative learning, including working as part of a team, discussing information, extracting relevant data, and building knowledge together within a common repository, are a great help in building autonomy, effective knowledge assimilation and the acquisition of key competences. This connected and cooperative learning enhanced student participation significantly, despite the challenges of the COVID-19 lockdown, the unfamiliar use of remote learning and often difficult personal circumstances. Student participation also increased significantly among repeating students. As noted above, a collaborative approach helped students develop creative solutions and high-quality work in problem-solving and also connecting Biochemical Engineering to the world of Biotechnology. In particular, quizzes about relevant concepts in Chemical Engineering produced very good results although the limited time allowed to complete this task, and questions on calculations and units, were the main difficulties students encountered.

The following learning outcomes were achieved through the use of new learning activities:

- Abstracting to extract relevant information from a practical case using the proper mathematical methods.

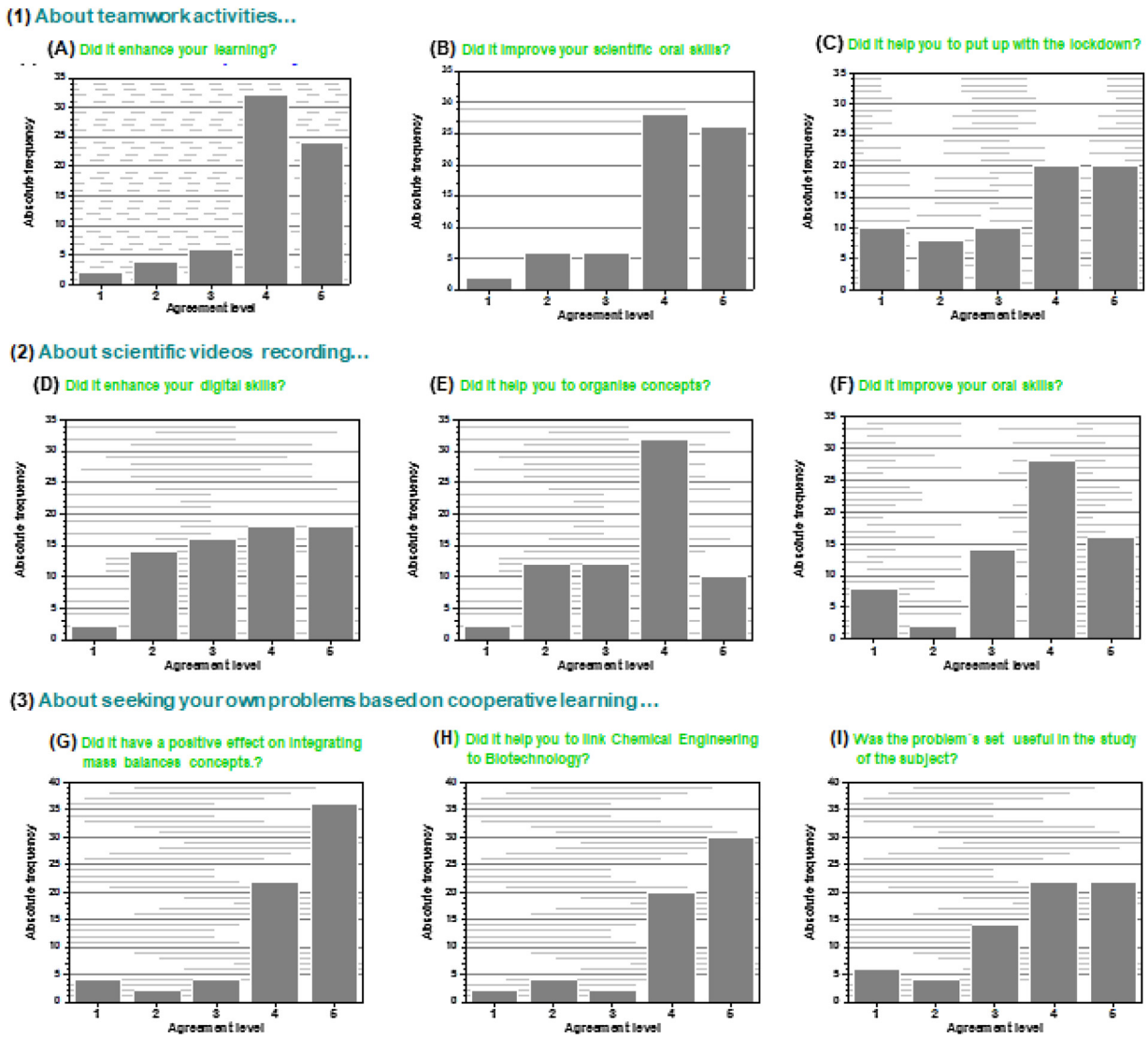

Fig. 9. Results of the online survey of students after completing the new methodology (Sample size: 68) **Key:** 1 strongly disagree; 2 disagree; 3 neutral; 4 agree; 5 strongly agree.

- Being able to obtain information from a practical case for the application of the principles of Biochemical Engineering.
- Discussion among classmates about the results and repercussions of a practical case. Finding a correct solution to a practical case.

Considering these learning outcomes, no significant differences can be observed between the studied groups. Thus, it appears that the learning sequence was correctly designed to meet the needs of different learning styles, regardless of student background and their area of study.

Students reported a generally positive perception of the learning experience. Cooperative learning was found useful for developing skills during the course while teamworking was rated very positively among participants.

Globally speaking, in comparison with previous years, before this new methodology was introduced, there was a significant improvement in student performance in the Biochemical Engineering course. This was particularly the case in student motivation, greater student accompaniment, monitoring and feedback, and developing student autonomy. Furthermore, the new methodology is fully transferable to in-class learning. Each activity enhances student learning from different perspectives and styles. Transversal competences that are often difficult to teach and assess even in face-to-face lessons have been achieved by means of the proposed activities. Therefore, applying this methodology in traditional courses may also have a positive impact on the acquisition of these competences. In the future, the technique of peer-review of created problems and recorded solutions will also be proposed to enhance the acquisition of higher-level skills and competences.

Declaration of Competing Interest

The authors reported no declarations of interest.

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