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Development of engineering skills in students of biotechnology: Innovation project "From laboratory to industry"

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ABSTRACT

Professors of Chemical Engineering often find that students are discouraged by the highly technical nature of the subject, have a poor understanding of how the subject relates to their field and lack the basic engineering skills and competences. This purpose of this paper is to report on a teaching innovation experience in the course in Biochemical Engineering, part of the Degree in Biotechnology at the Universidad Francisco de Vitoria (Madrid, Spain). The aim of the innovation project was to motivate students and overcome the difficulties posed by the course. To this end, a series of practical seminars were designed with individual and group learning activities, for the acquisition of engineering competences, developing higher-order thinking skills and transversal competences. The evaluation of the project was based on the learning-teaching experience of professors, the academic performance of students and student surveys at the end of the course. All indicators showed that the new methodology had a positive impact both on the attitudes of students and on learning outcomes. Furthermore, students had a more precise and positive vision of the interrelation between Chemical Engineering and Biotechnology in general, favourably influencing their learning in other courses within the degree program.

1. Introduction

The fields of Biotechnology and Chemical Engineering are closely related; Biotechnology is defined as the use of biological systems, made up of living organisms or their parts, to obtain knowledge, goods and services of interest to society (Nagel et al., 1992; Verma et al., 2011). Given the breadth of this definition, the field encompasses a diverse range of disciplines: from Life Sciences, such as Biochemistry, Genetics or Microbiology, to the Social Sciences, including Economics or Law. Furthermore, the field of Biotechnology also requires the use of tools from various branches of Engineering. Specifically, the study of biological systems for use in industrial applications also demands an understanding of chemical and physical processes within the field of Chemical Engineering.

The wide range of degree programs in Biotechnology offered by universities throughout the European Union all have in common the inclusion of courses in the field of Bioengineering (Foley, 2016). These courses, from an introduction to biotechnological processes to specific courses on the design of reactors and bioprocesses, generally account for at least 30–45 ECTS (ANECA, 2005).

In Spain, directives on official degree programs in Biotechnology incorporate at least 26 ECTS in Bioengineering and Biotechnological Processes, encompassing the areas of Biochemical Engineering, Bioreactor Engineering, Biotechnological Processes, Products and Projects, etc. The aim is to ensure students acquire the skills necessary to apply their theoretical knowledge to industrial production, connecting their knowledge of cells and molecules with biotech industry where they must be able to design processes for the use and exploitation of organisms, cells or biomolecules to produce goods and services (ANECA, 2005). Table 1 summarizes the mandatory courses relating Chemical Engineering field including in Biotechnology Degree programmes taught at several Spanish Universities. Whereas all programmes include basic contents, overall ECTS destined to Chemical Engineering teaching varies from 11 to 36, what brings to light how different biotechnology academic programmes could be.

Thus, it is essential that students, future biotechnologists, are fully knowledgeable about the application of the basic tools of Chemical Engineering to the study of bioprocesses. The goal is that students acquire an in-depth understanding of the nature and application of chemical and physical phenomena which ultimately will determine the viability of any industrial biotechnological process. Thus, the syllabus of the Degree in Biotechnology must combine a solid knowledge of biology

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Table 1
Summary of the mandatory courses relating chemical engineering field including in Biotechnology Degree programmes taught in different Spanish Universities.

University	Mandatory courses relating Chemical Engineering	ECTS
Universidad de Salamanca (USAL, 2023)	Thermodynamics and kineticsFundamentals of Biochemical Engineering IFundamentals of Biochemical Engineering IIBioreactors	24
Universidad Politécnica de Madrid (UPM, 2023)	BioreactorsBiotechnological processes and products	11
Universidad de Oviedo (UniOvi, 2023)	Thermodynamics and kineticsBasis of Biochemical EngineeringBioreactors	18
Universidad del País Vasco (EHU, 2023)	Fundamentals of Chemical Engineering and BiotechnologyFluid dynamicsThermodynamics and kineticsMass transport phenomenaBioreactor designMathematical modellingSeparation processes	35
Universidad de Granada (UGR, 2023)	Thermodynamics and kineticsIndustrial biotechnological processesFundamentals of Biochemical EngineeringBioreactorsSeparation and purification technologies	30
Universidad Rovira I Virgili (URV, 2023)	Thermodynamics and kineticsBiochemical EngineeringSeparation and purification technologiesBioreactor engineering	18
Universidad Pablo de Olavide (UPO, 2023)	Thermodynamics and kineticsFundamentals of Biochemical Engineering Separation processesBioreactorsBiotechnological processes	28.5
Universidad de Santiago de Compostela (USC, 2023)	Thermodynamics and kineticsFundamentals of bioprocess engineeringFluid transport and heat transferMass transport phenomenaBioreactors	28.5
Universidad de Cádiz (UCA, 2023)	Thermodynamics and kineticsBioprocess engineering principlesSeparation processesFluid transport and heat transferBioreactorsBiotechnological processes	36
Universidad de Zaragoza (UniZar, 2023)	Chemical Engineering Bioreactors	15
Universidad de León (UniLeon, 2023)	Thermodynamics and kineticsFluid transport and heat transferBasis of engineeringBioreactorsSeparation processes	24
Universidad de Extremadura (UNEX, 2023)	Thermodynamics and kineticsBiochemical Engineering Principles BioreactorsIndustrial biotechnological processes	24
Universidad de Almería (UAL, 2023)	Applied thermodynamics and kineticsBioreactorsSeparation processesBiotechnological processes	24
Universidad de Castilla-La Mancha (UCLM, 2023)	Thermodynamics and kineticsBiotechnological processes engineering IBiotechnological processes engineering IIBioreactors	24
Universidad de Murcia (UM, 2023)	Applied thermodynamicsFundamentals of bioengineeringBiochemical reaction engineering and bioreactors	21
Universidad Politécnica de Valencia (UPV, 2023)	Thermodynamics and kineticsBiotechnological process engineering IBiotechnological process engineering IIBioreactors	21
Universidad de Valencia (UV, 2023)	Introduction to biochemical engineeringBasic units in biotechnological processesBioreactors	16.5
Universidad de Barcelona (UB, 2023)	Chemical Engineering	6
Universidad Pública de Navarra (UPN, 2023)	Thermodynamics and kineticsBiotechnological process engineeringBioreactors	18
Universidad de Girona (UDG, 2023)	Fundamentals of thermodynamicsBiochemical engineeringBiochemical engineering: laboratoryProcesses, products and proyects in biotechnologyProcesses, products and proyects in biotechnology: laboratoryBioreactor engineeringKinetics	30
Universidad de Vic (UVIC, 2023)	Fundamentals of engineeringBioreactorsProcess and products in biotechnology	18
Universidad de Lleida (UDL, 2023)	Thermodynamics and kineticsBioreactorsProcess and products in biotechnology	18
Universidad Miguel Hernández (UMH, 2023)	Thermodynamics and kineticsBiochemical engineering	12
Universidad Francisco de Vitoria (UFV, 2023)	Biochemical engineeringBioreactors	12

and biochemistry with the ability to apply basic engineering tools to industrial biotechnological processes (Foley et al., 2016).

1.1. Description of the course

This project was carried out for the course in Biochemical Engineering, aiming to facilitate the learning process and improving learning outcomes. The course is part of the "Biotechnological Tools" Module, within the Degree in Biotechnology program (UFV, 2022) at the Universidad Francisco de Vitoria (UFV). Students enrolled in this course are expected to have sufficient prior knowledge, skills and competences in mathematics, physics, cellular biology, general chemistry and biochemistry. Biochemical Engineering is a foundation course for the subsequent courses in Bioreactors and Industrial Microbiology.

Biochemical Engineering is imparted in the 2nd year of the Degree and accounts for 6 ECTS, corresponding to a total of 60 h, divided into theoretical-practical classes (50 h) and seminars (10 h). During the 2021/2022 academic year, when this teaching innovation project was implemented, the theoretical-practical classes were imparted using a hybrid methodology in which all students received a weekly 4-hour class; that is, an 2-hour online class in which both groups (A and B) attended and a weekly presential class of 2 h given to each group separately. The seminars were presential attended and were imparted to only half the students of each group at a time for more effective learning and oversight.

In the 2021/2022 academic year, student evaluation was as follows (UFV, 2021):

- Seminars, with a weight of 20% of the final mark of the course. This mark corresponds to the average mark for the various assignments of the seminar, weighted according to the time necessary and estimated difficulty of the task. Attendance is mandatory and students must achieve a mark of at least 5 out of 10 to pass the course.
- Partial exams, with a weight of 20% of the final mark of the course. This mark corresponds to the average of the two highest marks in the 3 partial exams during the semester. These exams are conducted remotely during the online sessions using the *Lockdown Browser®* test environment. The contents evaluated in these exams were also included in the final exam of the course.
- Final exam, with a weight of 60% of the final mark of the course. To pass the course students must achieve a mark of at least 5 out of 10.

The learning outcomes expected of this course (as per the Teaching Guide) were the following (UFV, 2021):

- To acquire essential engineering skills and knowledge for the design and scaling of the instruments necessary for the development of a biotechnological process.
- To acquire the ability for analytical, synthetic, reflexive, critical, theoretical and practical thinking.
- To acquire an understanding of the fundamental principles and laws of physics, mathematics, chemistry and biology as the foundations of biotechnology.

- To acquire the skills and competences necessary for experimental work: design, execution, collection of results and drawing conclusions.
- To acquire the knowledge of biochemistry and molecular biology necessary for the development of biotechnological processes and products.
- To acquire the ability to calculate and interpret the relevant parameters of transport phenomena, material balances and energy in bio-industrial processes.
- To acquire the technological and engineering knowledge necessary for the design of processes.

1.2. Background of the study

Teaching courses in Chemical Engineering in non-specialised university degree programs presents a significant challenge to students and teachers alike. For teachers, it is important to identify student needs and the context and integration or position of the course within the degree program (biotechnology, food sciences, environmental sciences, etc.). These aspects will determine the depth of the theoretical content included in the course, depending on the previous courses of the curriculum (mathematics, chemistry, thermodynamics, programming etc.). For this reason, lectures requires an extra pedagogical effort to adapt many concepts and are frequently taught less rigorously in order to achieve that students understand intuitively some ideas (González-Garcinuño et al., 2020; Mauricio, 2022). Furthermore, focussing the course appropriately, using practical case studies, situations and exercises that engage students will have a direct impact on their motivation, which will directly improve their probability of success in learning and acquiring desired skills (Atkinson, 1957). Particular, this involves the development of certain social skills necessary for teamwork (Mendo-Lázaro et al., 2018; Rosenzweig et al., 2019).

From the student's point of view, the highly technical content of courses in Chemical Engineering can be particularly challenging for students without an engineering background. Additionally, many students regard Chemical Engineering as unrelated or tangential to their area of study making these courses especially difficult (Ramírez et al., 2020). Typically, biotechnology students are attracted to the biology knowledge rather than the mathematic and engineering (Foley, 2016).

The principal difficulties experienced by UFV students in the Degree in Biotechnology programme are associated with the acquisition of the basic tools of engineering, such as calculation skills, decision-making and drawing conclusions from experimental results (Ripoll et al., 2021).

An important aspect of these difficulties is the perceived difficulty of the subject on the part of students, as reported in end-of-semester evaluations and elsewhere. Habitually, over 80% of students consider these subjects as difficult or very difficult (Table 2). Furthermore, the majority of students report that their initial interest in the subject was medium-low (Table 3).

In previous years, the Biochemical Engineering course included 15 h of practical laboratory work for the study of enzyme kinetics. The study plan of the Degree in Biotechnology at the UFV is eminently practical, with over 500 h of experimental laboratory work. In order to address some of the difficulties experienced by students, it was decided to substitute laboratory work relating to enzyme kinetic parameters estimation, associated only to a part of the course syllabus and focused on developing essentially practical competences, with a series of seminars dealing with the resolution of practical case studies and with a particular emphasis on engineering competences. This decision was carefully made after analysing that similar biological systems and analytical techniques were also employed in laboratory training of other sujects, such as biochemistry, integrated laboratory II, and biocatalysis.

Table 2
Student perception of the difficulty of the course according to the teacher evaluation surveys by the Quality Department of the university.

Academic year	20/21		21/22	
Group	A (n = 21)	B (n = 29)	A (n = 33)	B (n = 29)
Very difficult	9.5	17.2	42.4	31.0
Difficult	85.7	65.5	45.5	55.2
Normal	4.8	10.3	9.1	13.8
Easy	0.0	6.9	0.0	0.0
Very easy	0.0	0.0	3.0	0.0

Table 3
Initial student interest in the course according to the teacher evaluation surveys by the Quality Department of the university.

Academic year	20/21		21/22	
Group	A (n = 21)	B (n = 29)	A (n = 33)	B (n = 29)
Very low	0.00	6.9	6.1	3.5
Low	14.3	10.3	24.2	17.2
Medium	47.6	65.5	45.5	44.8
High	28.6	17.2	21.2	31.0
Very high	9.5	0.0	3.0	3.5

This was the origin of the teaching innovation project "*From laboratory to industry*" consisting of four interconnected theoretical-practical seminars. The aim of these seminars is to study the basic stages of bioprocesses (kinetic analysis of the transformation, isolation and purification of the product, material balances and transport systems). What is innovative in this approach to teaching Biochemical Engineering is the design of a comprehensive program that systematically explores all the stages of an industrial biotech process.

1.3. Objectives of the project

The objectives of the project "*From laboratory to industry*" are the following:

1) To reinforce the calculation skills of students of the Degree in Biotechnology, essential for the acquisition of a number of general competences which graduates must have.
2) To develop students' abilities in decision-making and drawing conclusions based on experimental results.
3) To enhance students' perception of the importance of the course in Biochemical Engineering.
4) To raise students' awareness of the importance of Chemical Engineering in the development of biotechnological processes.

2. Methodology

2.1. Participants

The participants in the project were students of the Degree in Biotechnology enrolled in the course on Biochemical Engineering in the 2021/2022 academic year. The students were separated into two groups (A and B) of 69 and 50 students respectively. Of these only students in their first enrolment in the course participated in this program (48 students in group A and 41 students in group B) given that repeating students have an alternative evaluation system and were exempted from this part of the program.

2.2. Pedagogical design

To achieve the objectives of the project, 4 theoretical-practical seminars of 2.5 h each were organised, giving students the opportunity to work in an in-depth and coordinated manner on the course content. This content lays the foundations for the study of the basic stages of bioprocesses (kinetic analysis of the transformation, isolation and purification of the product, material balances and transport systems). To ensure the overall cohesion of the course content, over the course of the session students will learn the different stages of bioprocesses which are a key aspect of biotechnology: the production and use of the β-galactosidase enzyme (Expasy, 2022).

The timing of the seminars was coordinated with the content of the theoretical-practical classes of the course to ensure the fullest possible understanding of the subject (UFV, 2021).

The following is a detailed outline of the methodology followed in each of the seminars:

- **Seminar 1: Study of the activity of the β-galactosidase enzyme.** This session is divided into the following activities:

  i) Firstly, students are asked to make an individual calculation of the kinetic constants (v_{max} and K_m) in Michaleis-Menten kinetics (Michaelis & Menten, 1913; Johnson & Goody, 2011) based on a series of given experimental concentrations and velocities. For this student follow two different procedures: the linearization of the kinetic equation and subsequent linear regression and non-linear regression. For the linear regression calculation the student must also calculate the error associated with the estimation of each parameter using an Excel spread sheet (Fig. 1. B). In previous courses, professors have seen that student competence in handling this tool varies widely. To enhance the rhythm of the seminar, and to offer particular attention to struggling students, a series of videos is shown explaining the activity and the calculation procedure (Fig. 1. A). Students perform the activity while watching the videos and thus are able to advance at their own pace while the professor can take the time to address any questions or doubts the students may have (Felder and Brent, 2005). These videos were created by the course professors themselves. Students are evaluated on the Excel file they upload onto the virtual classroom platform, which weight in the final mark of seminar 1 is 50%. In this activity, the following items were assessed:(Fig. 2)
  - Calculations employing experimental data to use in linear regression.
  - Estimation of kinetic parameters by means of linear regression.

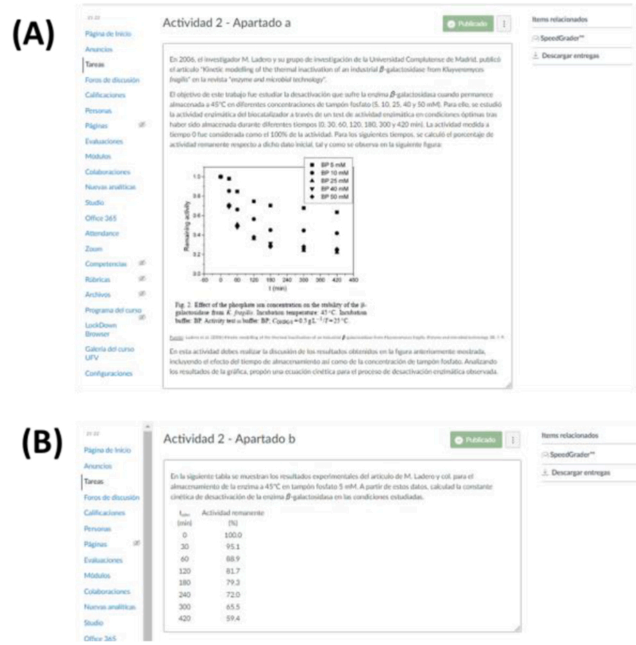

Fig. 2. (A) Image of the task created on the Canvas® platform for activity *ii*) in Seminar 2; (B) Image of the task created on the Canvas® platform for activity *iii*) in Seminar 2.

  - Calculations relating error propagation in determination of kinetic parameters value.
  - Estimation of kinetic parameters by means of non-linear regression.
  - Correct use of units.

  ii) The students are then divided into groups of 4, each having completed the previous activity with different experimental results, obtained with different concentrations of biocatalyst. Students first compared the results of the previous activity, verifying

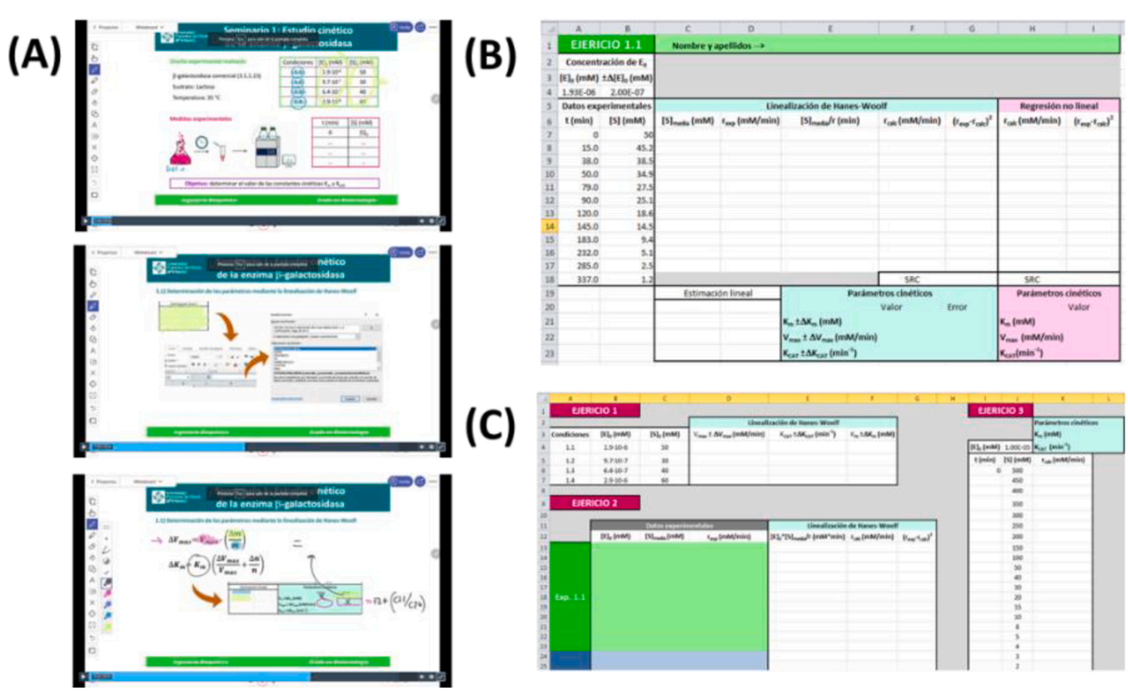

Fig. 1. (A) Screenshot of the explanatory videos of the activities in Seminar 1; (B) Image of the Excel® spread sheet for activity *i*) in Seminar 1; (C) Image of the Excel® spread sheet for the execution of activity *i*) in Seminar 1.

that the Michaelis-Menten constant remains stable while the maximum velocity is different for the different members of the workgroup. This will allow students to identify any calculation errors in the previous individual exercise by comparing their results (Mennin, 2007). Then, using these results the students make a calculation of the other kinetic parameter of interest, the turn-over number, when analysing experimental results from experiments with different concentrations of biocatalyst.

Once the kinetic behaviour has been characterised, each group of students integrated the Michaelis-Menten differential equation. In this way students learn how, through mathematical calculation, they can relate and predict the substrate concentration over time. Students then estimated the concentration and velocity for a given enzyme concentration and the influence of the substrate concentration on the reaction velocity. In this activity, students are evaluated on the Excel file that each group uploaded to the virtual classroom platform (Fig. 1. C), which weight in the final mark of seminar 1 is 25%. In this activity, the following items were assessed:

- Summary of previous results.
- Calculations employing experimental data given to use them in a sole linear regression.
- Estimation of kinetic parameters by means of linear regression.
- Calculations relating error propagation in determination of kinetic parameters value.
- Calculations of substrate concentration profile and rate evolution employing different experimental conditions (initial substrate concentration and initial enzyme concentration).
- Correct use of units.

iii) After the seminar, each group of students must submit within one week a general analysis of the trends observed in the graphs produced for the previous exercise. The aim is that students interpret, not only the general trend and meaning of the trend in each, but also to interrelate the trends observed in each of the three graphs. This activity weights 25% in the final mark of seminar 1. In the rubric, the following items were assessed:

- Scientific format in figures (axis title, units, legend, etc.)
- Quality of discussion relating the observed tendencies in each figure separately.
- Quality of discussion relating the interconnection of the different figures.

Once completed, the professors will provide students with a video showing corrections and comments, to ensure that all students fully understand the meaning of these trends.

- **Seminar 2: Study of inhibition phenomena by product and enzyme inactivation of β-galactosidase.** This session is divided into the following activities:

i) The first activity consisted in analysing the phenomenon of enzyme inactivation of the β-galactosidase enzyme. In pairs, the students are introduced to the problem through a short video. Students are asked to find the general expression of the Michaelis-Menten constant according to the substrate concentration, rather than according to the concentration of the inhibitor, a subject dealt with previously in theoretical classroom work. From this expression, students were able to predict the new concentration and reaction velocity over time using the same conditions as in activity *iii*) of the previous seminar. Thus, by representing these new results on the graph from seminar 1, students can study the effect of substrate inhibition with these new variables.

In this activity, students are evaluated based on the following items:

- Deduction of product inhibition formula (5% weight final score)
- Calculation to determine the evolution of apparent Michaelis-Menten constant, substrate concentration and rate. Estimation of inhibition constant by means of non-linear regression (35% weight final score).
- Quality of discussion comparing results obtained in seminar 1 and 2 (15% weight final score).

i) In the second activity, students were presented with a graph from a scientific paper (Ladero et al., 2006) showing the effect of storage time and conditions on the loss of β-galactosidase enzyme activity. Each pair of students presents an analysis of the results shown on the graph in an activity submitted on the virtual classroom. In view of the results, students are asked to determine the optimum storage conditions, and to produce an analysis of the type of enzyme inactivation kinetics. This activity weights 15% in the final mark of seminar 2. In the rubric, the following items were assessed:
   i. Understanding of experimentś information showed in the figure.
   ii. Quality of the observed tendencies discussion.
   iii. Quality of the conclusions regarding best conditions for enzyme storage and proposed deactivation kinetics.

Once the assignment has been submitted, at a certain stage of seminar 2 professors will discuss the problem to ensure students fully understand the topic.

i) Based on the conclusions drawn from the previous activity, and using the calculated residual activity over the course of the storage time from the previous experiment, each group made the appropriate calculations to determine the enzyme inactivation constant. This activity weights 35% in the final mark of seminar 2. In the rubric, the following items were assessed:
   - Interpretation of given experimental data.
   - Linearization of experimental data.
   - Estimation of deactivation kinetic parameter value.
   - Correct use of units.

- **Seminar 3: Design of the production process, isolation and use of the β-galactosidase enzyme**. In this seminar the students worked in groups of 4. These were new groups, that is, at least 2 members of the group were students with whom the others had not worked in the previous seminar. This was to ensure the proper integration and interaction of all students in the group. Initially, the general stages of industrial bioprocesses were explained: (*1*) production of the biocatalyst, (*2*) isolation and purification, and (*3*) use of the biocatalyst in the process. Each group was assigned one of these stages, tasked with designing a material balances type problem. This exercise was designed based on the success of a previous teaching experience during the 2020 lockdown period (Ripoll et al., 2021).

For the correct execution of the activity, each group must, firstly, search for information in order to focus the explanation of the problem on a real process with scientific rigor. Additionally, each group received instructions on the type of operation (discontinuous, continuous, fed-batch) and the minimum number of unitary operations involved in the process. Students were also required to incorporate in some way the information learned about the β-galactosidase enzyme in previous seminars. All explanations should include information about the kinetics of the unitary operations and include, at least, two characteristics form a list provided to orient the difficulty of the proposed problems (different stream densities, effectiveness of the separation operation, include a stream divisor or a recirculation in the process, calculate the volume, etc.).

For the evaluation of this exercise, students were required to submit their work within two weeks, including the description or explanation of the material balances problem and the resolution of the problem recorded on video. This video should last no more than 10 min and all members of the group must actively participate in the explanation. The evaluation rubric (Table 4) considers the degree to which the students fulfilled the requirements for the development of the problem, the originality of the problem, the scientific rigor with which they addressed the problem and other formal aspects such as the capacity for synthesis to meet the time restrictions, the capacity to transmit scientific information effectively, oral communication, the digital format of the presentation, etc.

- **Seminar 4: Controlled operations in material transport in biotechnological processes.** In this seminar, students work in groups of 3. To connect the content of Seminar 4 with those of previous sessions the activity consisted of a unitary absorption operation for the elimination of a contaminant in the gaseous current in an industrial process involving the β galactosidase enzyme. In this activity, students must identify the phase with the most resistant to transport and, based on this, estimate the concentration of the transferred composite between the two phases. Subsequently, based on the flow, composition and conditions of the of the currents into the absorption column, students are required to calculate the composition of the outflow determining the material balances for each of the phases of the operation. Finally, two alternatives are presented for the operation: (*a*) co-current flows and (*b*) counter-current flows (Fig. 3). For each of these students must present on a *yi* vs *xi* graphs the inflow and outflow points for each alternative, and the straight line of the operation. Based on the results, students will consider the differences observed and their implications for the required size of the equipment and the form of operation for this specific example.

  In this activity, students are evaluated based on the following items:

- Calculation of main resistance to mass transport (10% weight final score).
- Draft of concentration profile along the involved phases according to the calculated main resistance (10% weight final score).
- Application of mass balances (total mass and each component) in each involved phase (15% weight final score).
- Resolution of mass balances to determine mass flow rate and composition of outlet streams (15% weight final score).
- Calculation of inflow and outflow points for co-current and counter-current flows (15% weight final score).
- Plotting of straight line of the operation for each operational mode (10% weight final score).

Table 4
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 exaḿs 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
4 About the format	
4.1 Is the format of presentation correct?	– / 3
4.2 How good is oral communication?	– / 3
4.3 Does video accomplish time limitation?	– / 3
Total	– /45

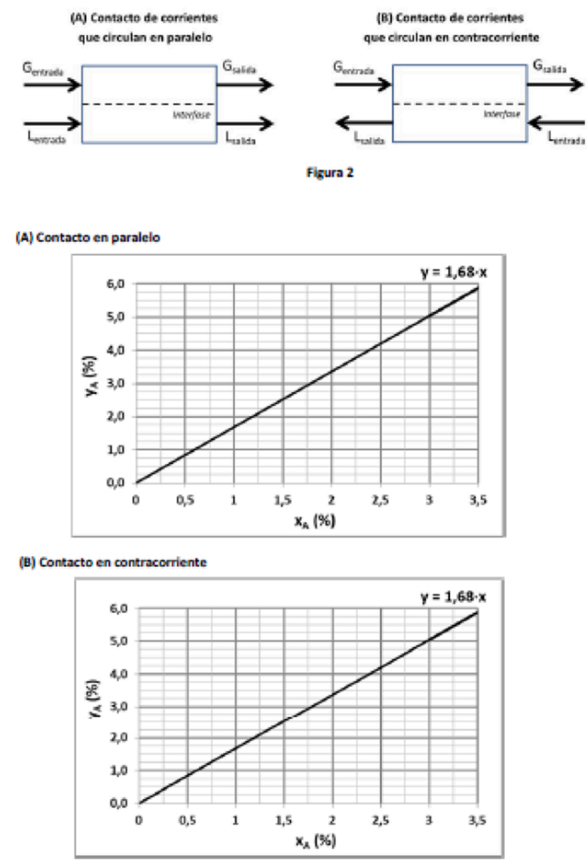

Fig. 3. Image of the graphs included in the activity of Seminar 3.

- Quality of figureś discussion and conclusions relating advantages of each operational mode (15% weight final score).

Once completed, the professors will provide students with a video showing corrections and comments, to ensure that all students fully understand the differences between both operational modes (co-current and counter-current flows).

2.3. *Teaching methodology*

The project has two principal objectives. The first is for students to develop their calculation skills, decision-making and ability to draw conclusions from experimental results; the second is to enhance student perception of the course in Biochemical Engineering, a key part of their degree program allowing them to interrelate different content and contextualise them within the field of Biotechnology (Ripoll et al., 2021). Furthermore, students were encouraged to recognise the relevance of Chemical Engineering in the development of biotechnological processes in general.

To achieve these objectives, the teaching innovation project focuses on effective student learning (Theobald et al., 2020) using a pedagogical methodology that is both collaborative, searching for higher efficient learning (Gillies, 2003; Stump et al., 2011; Torras, 2015; Rajabzadeh et al., 2022), and hands-on, learning by doing, fostering the autonomy of students as well as improving their engagement (Torras, 2015; Stephenson & Sangrà, 2013; Guest & Riegler, 2017; Bachhawat et al., 2020). Using a social and connectivist approach (Siemens, 2004), the project builds connections between students through group work through which, based on practical case work (Rajabzadeh et al., 2021; Crespí et al., 2022), they establish a network of learning and repositories of information to generate new knowledge (Guerrero and Flores, 2009). Groups for collaborative activities were formed by the teachers, in order to promote classmate support and encourage the socialization of each student. Each of the four sessions is structured with a sequence of guided learning, supported by a variety of resources available through the Canvas® platform, including audio-visual materials, scientific publications and tasks requiring the interpretation and manipulation of results. Such teaching and learning sequences were designed and implemented considering both competences and learning skills pursued along this course on Biochemical Engineering (Guisasola et al., 2017).

The various learning sequences and their activities are designed to offer students a variety of different experiences (resolution of practical cases, invention of problems, description and explanation of new proposals, etc.) associated with the development of bioprocesses (Reynolds & Hancock, 2010). The use of these sequences of activities seeks to foster students' ability to construct new knowledge from their experiences and skills learned over the course of the degree program (Wats & Wats, 2009; Kolb, 2015). The learning-teaching process should take into account the individual characteristics of each student, their degree of motivation, attitudes and forms of learning in order to encourage the acquisition of new skills and competences in an effective way (Atkinson, 1957; Felder & Brent, 2005; Wats & Wats, 2009).

By shunning a merely transmissive pedagogical model, where the weight of the learning experience rests with the teacher, this project aims to give students a more active role. Students are the protagonists, responsible for their own learning and the acquisition of higher-order thinking skills, according to Bloom's taxonomy (abstraction, analysis, evaluation, creation, etc.) applying the course content to real contexts with a hands-on, learning by doing. This way, not only theoretical knowledge is developed in students, but their skills on practical applications and their abilities for research and design as well (Nikolić & Dabić, 2016; Bachhawat et al., 2020; Hu & Li, 2020).

2.3.1. Modality of the project

The teaching innovation project in Biochemical Engineering uses a presential modality while making use of the latest ICT (information and communications technologies) in order to impart the program asynchronously and provide students with materials and resources for both independent and classroom learning. The aim of this b-learning modality is to enhance the classroom learning experience through seminars with learning sequences that emphasise the acquisition of competences associated with the course taking into account current knowledge on learning processes and styles (Kolb, 2015; Hu and Li, 2020). Furthermore, new ICT resources are used to foster student interaction and the generation of networks of knowledge among students.

2.3.2. Learning-teaching roles

In line with the above, professors in this project act not merely as communicators of content of knowledge but rather facilitate learning through a hands-on approach using practical cases drawn from current scientific advances and literature. Thus, students are guided through a specific learning process or experience in each of the sessions with the aim of improving their performance and engagement (Kolb, 2015; Bachhawat et al., 2020; Rajabzadeh et al., 2021).

The student must be the agent of their own learning, taking decisions, deploying critical thinking and developing their higher-order cognitive skills, from abstraction to the generation of new scenarios and cases, achieving this way important competences defined in the EEES paradigm required for nowadays university and work skills (Felder and Brent, 2004a and b; Mendo-Lázaro et al., 2018; Seifan et al., 2020).

2.4. Competences

In line with the above, the learning sequences of the four sessions of the project are taken into account in the evaluation system of the course in Biochemical Engineering. A number of different activities, such as creating spread sheets on which the student performs the appropriate mathematical transformations for each stage of a project, the resolution of suppositions and interpretation of the results of each session, written assignments and projects designed by the students and their resolution in video-tutorials created by the students. The aim of this methodology is for students to acquire and consolidate a number of skills and competences according EEES space and improving learning process (Guisasola et al., 2017; Mendo-Lázaro et al., 2018), such as (UFV, 2021):

- The capacity for analytical, synthetic, reflexive, critical, theoretical and practical thinking.
- The ability to calculate and interpret the relevant parameters of transport phenomena, material balances and energy in bio-industrial processes.
- The technical and engineering skills necessary for the design of industrial processes.

Thus, the focus is on the development of transversal competences (Sa & Serpa, 2018) and higher-order thinking, according to Bloom's taxonomy (Nikolić & Dabić, 2016): abstraction, analysis, evaluation, creation and design of new ideas and scenarios, etc. (Table 5) associated with each session of the project.

2.5. Evaluation of the learning experience

At the end of the semester, student enrolled in the course were asked to give their opinion on some aspects of the seminars imparted during the 2021/2022 academic year. All students were duly informed that the survey was entirely voluntary and that responses were entirely anonymous. The survey was conducted in the classroom on the final day of the course using a questionnaire designed with Google Forms®.

The survey designed to evaluate the perception of students about aspects considered most important by professors is provided in Table 6. Question 1 aimed to identify which activities within the seminars had the greatest impact on improving students' calculation skills and the ability to draw conclusions from experimental results (Objectives 1 and 2 of the project). Question 2 aimed to know the general level of student satisfaction with the learning sequencing and its organisation. Finally, Question 3 evaluated the perceived success in achieving Objectives 3 and 4 of the project; that is, student perceptions of the importance of Chemical Engineering tools in industrial biotechnological processes.

3. Results and discussion

3.1. Perspective of professors

Professors had a generally positive opinion of the teaching innovation project. The imparting of seminars with smaller groups than in the

Table 5
Transversal competences and higher-order thinking skills developed in learning activities.

TRANSVERSAL COMPETENCES	Seminar 1	Seminar 2	Seminar 3	Seminar 4
Oral communication skills	X	X	X	X
Teamwork	X	X	X	X
Digital skills			X	
Creative and innovative thinking		X	X	X
Critical thinking	X	X		X
Knowledge transfer			X	
Time management	X	X	X	X
HIGHER-ORDER THINKING SKILLS	Seminar 1	Seminar 2	Seminar 3	Seminar 4
Create an original work			X	
Evaluate and make judges				X
Analyse and make connections	X	X		X
Apply information in new situations	X	X	X	X

Table 6
Survey structure to evaluate student's opinion.

QUESTION 1	Not at all useful	Not very useful	Somewhat useful	Very useful	Extremely useful
Indicate the degree to which the practical seminars were useful in the course.					
Indicate the degree to which the practical seminars were useful in developing the following competences:					
More rapid and accurate performance of mathematical calculations					
Understanding of the physical significance of derivatives					
Understanding of the physical significance of integrals					
Analysis of the parameters and variables in equations					
Discussion of experimental results					
Drawing conclusions from graphs					
Capacity for teamwork					
QUESTION 2	Very poor	Poor	Regular	Good	Excellent
Indicate your degree of satisfaction with the interrelation of practical work in the seminars and the theoretical classroom content.					
Indicate your degree of satisfaction with the coordination of the seminars with the theoretical classwork.					
QUESTION 3	Totally disagree	Somewhat disagree	Neither agree not disagree	Somewhat agree	Completely agree
Indicate your degree of agreement with the following affirmations:					
For the development of industrial processes it is essential to understand the kinetics of transformation					
Material balances provides valuable information on industrial biotech processes					
Studying transport phenomena in separation operations is essential to understand time and size of equipment required					
In general, Biochemical Engineering is a useful area of study within Industrial Biotechnology					
The seminars helped me to better integrate the concepts of the course.					
The seminars helped me to understand the interrelation between the various subjects in the course.					

classroom allowed professors to offer closer support to the students, identifying and resolving difficulties in situ during the process, both individually and as a group fostering learning through them cohesion (Bachhawat et al., 2020; Zamecnik et al., 2022). In qualitative terms, the attitude of students during the seminars was positive, proving to be proactive and cooperative in group work, succeeding in the acquisition of soft skills, consistently with literature (Gillies, 2003; Stump et al., 2011; Rajabzadeh et al., 2022). Quantitatively, the academic performance seen in the seminars was satisfactory, to be further discussed in 3.2, below. Fig. 4 shows screenshots of the work submitted by students resolving problems on material balances. The variety and originality of the formats demonstrate the degree of effort and engagement of students in this assignment (Rosenzweig et al., 2019).

The restructuring of the course and the substitution of laboratory work for interrelated, project-based seminars also required changes to the content of the course. Some of the activities for the seminars allowed for a more in-depth study of certain subjects compared to courses in previous years looking for a relevant improvement in both engagement and performance of students (Bachhawat et al., 2020; Steinhardt, 2022).

The use of the Canvas® platform facilitated student evaluation using

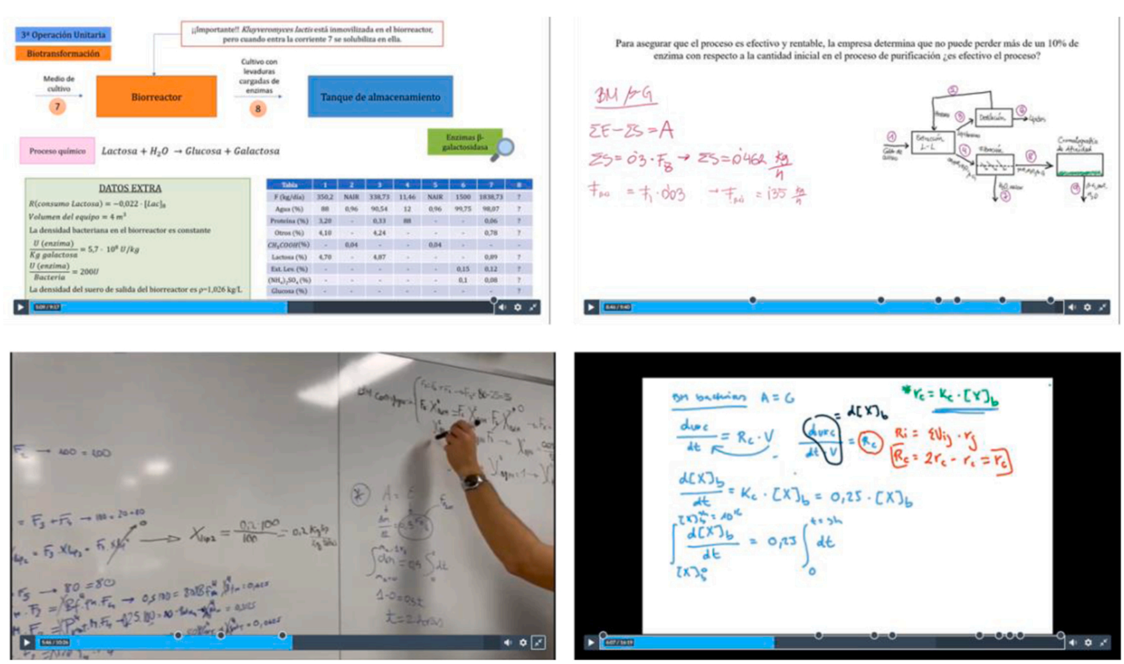

Fig. 4. Screenshot of the videos submitted with the resolution of the material balances problem in Seminar 3.

rubrics designed for each of the activities. As assignments were submitted by the work groups using the virtual classroom platform, all team members were able to access corrections and feedback on their work at the same time. In the case of corrections in the video presentations, students submitted their videos using the Studio® tool, an application embedded in the Canvas® platform. This tool allowed professors to added comments to the videos where appropriate, as shown in Fig. 4, where the circles in the video timeline indicate where the professor has added a comment. Thus, students receive clear and concise feedback and are able to identify and correct errors easily. On the other hand, both quality and efficiency of learning are improved (Aldosari et al., 2022).

3.2. Academic performance

The seminars were evaluated as described in Section 2.2 *Pedagogical design*, above. Considering the difficulty of the activities, and the time required by students to complete them, the weighting of each of the seminars in the final mark for the course was as follows: Seminars 1, 2 and 3, accounted for 6% each of the final mark; Seminar 4 accounted for 2% of the final mark. Regarding the scoring of the seminars, only individual activity in seminar 1 was evaluated individually. Apart from this task, the score of the collaborative activities is common to all members of the group. The average results of students in group A were broadly similar to those of Group B. Thus, the results for the seminar activities are analysed and discussed as a whole, that is, as a single group. The sample consisted of 89 participants, all of whom scored above 5 out of 10, successfully passing this part of the course. A total of 70 students (78%) scored 'very good' while 13% (12 students) received an 'excellent' and only 8% received a 'pass'. (Fig. 5).

The marks obtained by the 89 students in each seminar are presented in Fig. 6. For seminars 1, 2 and, 3 over 96% of students passed (Fig. 6), with 85 students receiving a mark of 5 or above. More specifically, 76% of students received a mark over 7 ('very good'). Seminar 4, however, was the most difficult, related to unit operations controlled by transport phenomena. Some 43% of students did not pass this seminar, with 38 out of 89 students scoring below 5; 40% of students passed the seminar while only 13% and 3% received a 'very good' or 'excellent' mark, respectively. The most successful seminar-practice was seminar 2 (Inhibition and enzyme inactivation), in which the highest number of students received 'excellent' grade (64 students, 72%). Seminars 1 (enzyme kinetics and errors) and 3 (proposed material balances) showed similar results in the number of students receiving a 'very good' grade, some 50% of students (ElZomor et al., 2018).

The distribution of the marks in the different seminars is coherent with both the difficulty of the theoretical content and the type of competences developed in each seminar activity. Generally speaking, the students are much more familiar with the content on enzyme kinetics

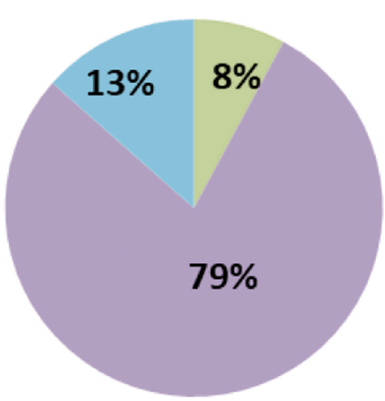

Fig. 5. Relative distribution of final average mark of the seminars (n = 89). *Legend:* blue: 'pass' (marks from 5 to 7); purple: 'very good' (marks from 7 to 9); green: 'excellent' (marks equal to or above 9).

(Seminars 1 and 2), which were taught using a different approach in previous courses, such as Fundamentals of Biochemistry and Metabolic Biochemistry. The subject on material balances (Seminar 3) was entirely new to students, requiring mathematical competences, such as the algebraic resolution of systems of equations, resolution of differential equations and dimensional analysis. Some 30–35% of the theoretical-practical sessions were dedicated to the resolution of material balances in different biotech processes. Students generally acquired a solid, in-depth understanding of this subject while their involvement within their own learning process was fostered (Natsis et al., 2018). Transport phenomena (Seminar 4) were addressed at the end of the semester. This part of the syllabus requires a greater level of abstraction and command of thermodynamic concepts as well as calculation skills which entailed more difficulties for students. Students in Biotechnology degree in other universities also have showed difficulties to understand mass transfer phenomena (González-Garcinuño et al., 2020). This fact was reflected not only in the average marks for this seminar but also in the average marks in the partial exams during the semester, as it is shown in Table 7 6. However, the comparison between the average marks in partial exams in academic years 20/21 and 21/22, showed a slight improvement in part 1 and 3.

The incorporation of activities designed to develop higher-order thinking posed a greater challenge for students, particularly activities in Seminars 3 and 4 involving decision-making and justification and the creation of new content (see Table 4). These are more complex cognitive processes that require greater command of the subject matter taken into account along the design of this course (Guisasola et al., 2017). Furthermore, these seminars deal with most intrinsically difficult areas of the course and the results (Fig. 6) reflect this. These results alerted professors to the need for new learning strategies to deal with this part of the course and which is fundamental for the third year course "Bioreactors", dealing with the limitations of aerobic cultures due to oxygen transfer (García-Ochoa et al., 2010).

To evaluate the impact of the teaching innovation project, the academic performance of year 2021/2022 when the project was implemented and the previous academic year 2020/2021. The 2019/2020 academic year was not included for comparison given the disruptions caused by confinement measures imposed due to the COVID-19 crisis. The comparative results are shown in Fig. 7. The number of students that obtained a mark between 5 and 7 points increased by 5% in the 21/22 academic year in which the new teaching methodology was implemented. In addition, students who failed the subject decreased around 13%. However, the students who did not attended the final exam increased around 6%. It is noteworthy that the number of students who obtained a 'very good' grade also increased significantly. However, the 'excellent' ratings decreased slightly. In short, it should be noted that the percentage of students who have satisfactorily passed the subject in the 21/22 academic year was 76.5%, supposing an increased success rate of 10% than the previous year.

These results reveal the impact of the new strategies and activities implemented in the course Biochemical Engineering, which clearly proved effective in notably raising success rates in the ordinary period in the year 2021/2022 compared to 2020/2021, in direct relationship with the acquisition of autonomy and learning autonomy (Guest & Riegler, 2017) as commented previously.

3.3. Student perceptions of the teaching methodology

A survey was conducted on the final day of class to evaluate student perceptions of the learning methodology using practical seminars. The survey was completely voluntary and a total of 40 students participated. As shown in Fig. 8, students evaluated the methodology positively, with over 82.5% responding that the practical seminars helped in their understanding and study of the course material. Specifically, 10 students reported the methodology was 'very useful' or 'extremely useful'.

Additionally, the survey aimed to evaluate student perceptions of the

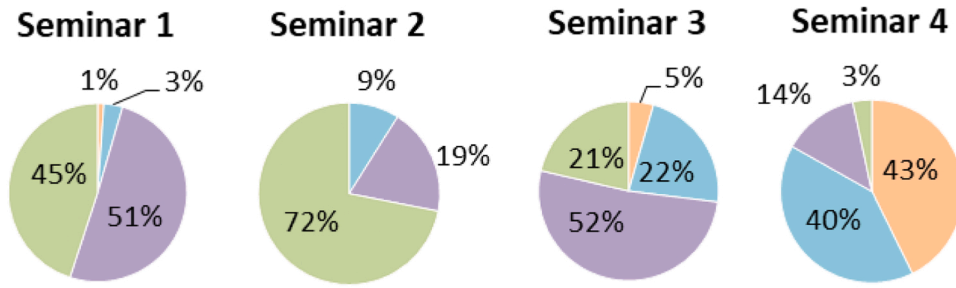

Fig. 6. Student results of students in different seminars (n = 89). *Legend:* orange: 'fail' (marks under 5); blue: 'pass' (marks from 5 to 7); purple: 'very good' (marks from 7 to 9); green: 'excellent' (marks equal to or above 9).

Table 7
Average marks obtained in partial exams in academic years 20/21 and 21/22.

Academic year 20/21		Academic year 21/22	
Partial exam	Average mark	Partial exam	Average mark
1a: Enzyme kinetics	5.8 ± 3.0	1: Enzyme kinetics + Inhibition kinetics	6.0 ± 2.6
1b: Inhibition kinetics	5.7 ± 2.4		
2: Mass balances	5.3 ± 2.5	2: Mass balances	5.1 ± 2.8
3: transport phenomena	4.4 ± 2.8	3: transport phenomena	4.6 ± 2.4

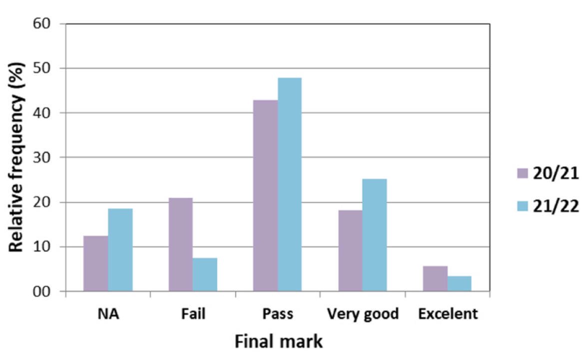

Fig. 7. Student performance in the course during the years 2020/2021 and 2021/2022. *Legend:* 'NA' not attended; 'fail' (marks under 5); 'pass' (marks from 5 to 7); 'very good' (marks from 7 to 9); 'excellent' (marks equal to or above 9).

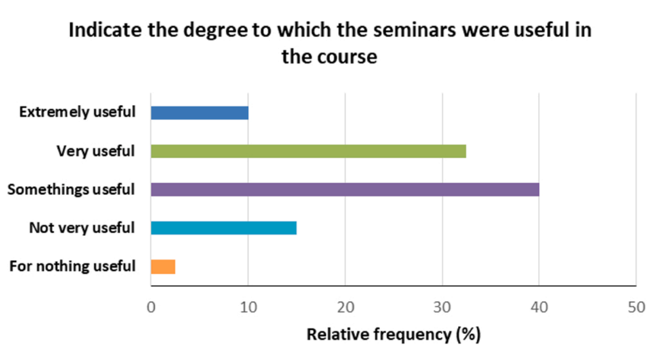

Fig. 8. Student perceptions of the utility of the seminars in the course ($n = 40$).

impact of the seminar activities in developing key scientific competences, such as the interpretation of graphs and calculation skills (Fig. 9). According to students, the most useful skills they developed were to improve their mathematical skills, analysis of parameters and equations, discussion and analysis of experimental results, drawing conclusions from graphs and the amiability to work effectively in teams, which particularly asks for the development of very precious social skills for current work life (Mendo-Lázaro et al., 2018). Over 90% of students found the seminars 'somewhat useful', 'very useful' or 'extremely useful' in developing these competences. However, regarding those competences related to mathematical concepts, specifically the physical significance of derivatives and integrals, some 30% of students reported the seminars were not useful in this aspect. The understanding of these mathematical tools is fundamental for graduates in biotechnology, particularly if they seek to pursue a career in industrial biotech. It should be noted that the survey dealt exclusively with the value of the activities carried out within the seminars and not in the entire course, where these concepts are worked on in a number of ways. But in light of the results, the professors have proposed the design of new learning activities to help students to overcome these barriers.

Students were very satisfied with the interrelation of the practical work in the seminars with the theoretical content of the course, with some 80% of participants expressing a good or excellent opinion. Additionally, half of the participants, 20 students, rated the coordination between seminars and theoretical classwork as good or excellent (see Table 8). Finally, students were asked to indicate the degree to which they agreed with a series of affirmations about the seminars on industrial biotechnological processes. The majority of students, some 85%, agreed or strongly agreed with statements signalling the importance of Chemical Engineering within the field of Biotechnology, and thus achieving the specific objective to "To raise students' awareness of the importance of Chemical Engineering in the development of biotechnological processes" (Natsis et al., 2018).

However, this opinion did not extend to the affirmations "the seminars helped me to better integrate the concepts of the course" and "the seminars helped me to understand the interrelation between the various subjects of the course", related to the first objective "To reinforce the calculation skills of students of the Degree in Biotechnology, essential for the acquisition of a number of general competences which graduates must have"; 22.5% of students neither agreed nor disagreed with this statement while 65% somewhat agreed or agreed, and only 12.5% somewhat disagreed or entirely disagreed (see Table 8).

These results clearly show the significant impact of the seminars on student learning, particularly in terms of student accompaniment over the course of the project as well as the greater correlation and interrelation between the concepts and content of Biotechnology course and Biochemical Engineering.

3.4. Limitations of the study

This paper describes the experience of a teaching innovation project for the course Biochemical Engineering based on the use of practical seminars as a new learning/teaching methodology to address the principal difficulties identified by professors in the acquisition of the course competences (Bachhawat et al., 2020). The perceptions of students and the results of the innovation project were evaluated. However, the design of an effective questionnaire that accurately measures the

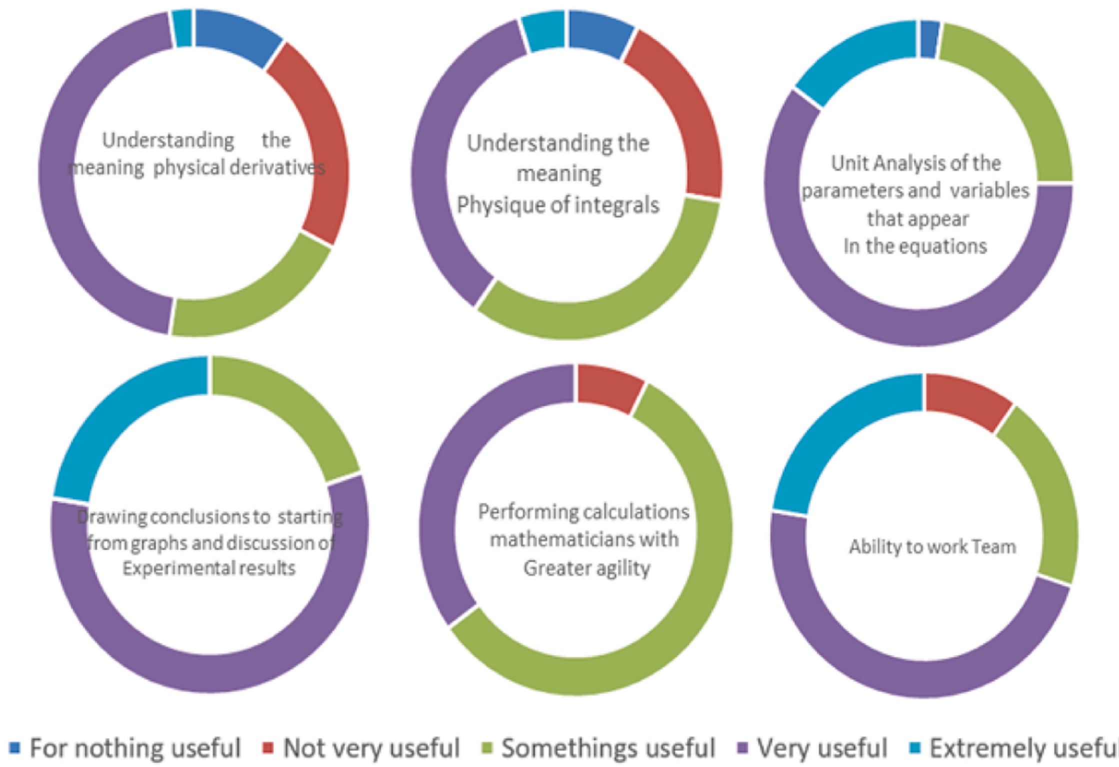

Fig. 9. Student perception of the utility of the seminars in developing mathematical competences ($n = 40$).

Table 8
Student evaluation of the impact of the teaching innovation project based on practical seminars. Questionnaire conducted at the end of the course ($n = 40$).

QUESTION 2	Very poor	Poor	Regular	Good	Excellent
Indicate your degree of satisfaction with the interrelation of practical work in the seminars and the theoretical classroom content.	0.0	2.5	17.5	62.5	17.5
Indicate your degree of satisfaction with the coordination of the seminars with the theoretical classwork.	0.0	10.0	30.0	45.0	15.0
QUESTION 3	Totally disagree	Somewhat disagree	Neither agree not disagree	Somewhat agree	Completely agree
Indicate your degree of agreement with the following affirmations:	-	-	-	-	-
For the development of industrial processes it is essential to understand the kinetics of transformation	2.5	5.0	5.0	42.5	45.0
Material balances provides valuable information on industrial biotech processes	2.5	7.5	5.0	40.0	45.0
Studying transport phenomena in separation operations is essential to understand time and size of equipment required	2.5	2.5	10.0	40.0	45.0
In general, Biochemical Engineering is a useful area of study within Industrial Biotechnology	2.5	5.0	10.0	37.5	45.0
The seminars helped me to better integrate the concepts of the course.	7.5	2.5	25.0	45.0	20.0
The seminars helped me to understand the interrelation between the various subjects in the course.	7.5	5.0	22.5	47.5	17.5

opinions, experiences and behaviour of students is a complex process. The inexperience of the authors in this area may have led to the inclusion of ambiguous or biased questions. In future, the surveys on student perceptions should be carefully reviewed to avoid any possible bias in the questions. The authors highlight the importance of appropriate open and closed questions, the wording of the questions, their order, etc. Future projects should incorporate experts in learning evaluation to design a reliable survey with quantifiable results, creating a multidisciplinary research team to evaluate learning outcomes. As an area for improvement in further studies, an initial survey addressing the student's motivation level, initial expectations, and previous knowledge might be included at the beginning of the course, what could help the authors to evaluate the impact of the teaching methodology on the main goals of the project.

It is important to note that the proposed learning methodology was applied and evaluated only with students of Biotechnology in a single university during a single academic year. Thus, the results may vary greatly depending on the institutional environment and academic background of the participants. It should also be noted that the results may vary according to the year of the degree program. It would be instructive to test this methodology in different years of the same degree program as well in Masters' degree programs or other courses related to Chemical Engineering, such as Bioreactors, imparted in the third year of the Degree in Biotechnology at the Universidad Francisco de Vitoria.

Finally, the data obtained regarding the impact of the methodology and students' academic results were managed anonymously and separately from any personal data. Consequently, only global conclusions can be drawn from the results, without considering individual outcomes where motivations and the personal circumstances of the student may have an effect (Rosenzweig et al., 2019). This paper offers a comparative analysis of the results of the last two years of the course; of course, a study over a longer period would provide more solid or revealing results.

4. Conclusions and future work

This paper has presented the teaching innovation project "*From laboratory to industry*" articulated in 4 interrelated laboratory sessions imparting the content of the course Biochemical Engineering in a hands-on, in-depth and comprehensive manner. The activities of the seminars were designed with a particular emphasis on the active role of the student, using a collaborative learning methodology supported by the latest ICT, looking for the best development of efficient learning skills in students as well as their engagement within their own learning process (Stump et al., 2011; Rajabzadeh et al., 2022). This methodology furthers the acquisition of engineering-related competences required by students of the Degree in Biotechnology. The academic performance of students in the 2021/2022 academic year suggests that the program is effective. Activities and assignments performed using the Canvas® platform has made it possible to have a precise view of learning outcomes thanks to the use of rubrics and other correction tools designed to provide effective feedback. In this way, the virtual classroom environment has served to intensify and complement the oversight of student performance and their continuous evaluation. This has led to better academic outcomes for students and higher success rates for the course.

The project successfully raised students' awareness of the importance of Chemical Engineering in the development of industrial bioprocesses as reported by the students themselves in the opinion survey. Additionally, the project helped improve the level of student accompaniment, facilitating the detection and resolution of any limitations, difficulties or impediments to student learning. Among these difficulties were the levels of student competence in algebra, calculus and dimensional analysis, which will be the object of future projects to overcome these difficulties. The impact of the project will also be evaluated by comparing the initial interest of students in the Bioreactors course imparted in the following years 22/23 to that of students in previous years. It is predicted that the improved perception of Chemical Engineering (Natsis et al., 2018), and specifically greater student motivation in the Biochemical Engineering course, will lead to greater initial interest in this subject and a proper yield in terms of learning (Atkinson, 1957; Rosenzweig et al., 2019).

The academic results of students in the 2021/22 course were better than those of previous years before this methodology was implemented. Specifically, academic performance increased around 10% in comparison to the previous academic year.

Regarding future actions, one project is the creation of a repository of material balances type problems from the projects and solutions of the students themselves in Seminar 3. These will be selected from the projects deemed excellent and with sufficient scientific rigor. Furthermore, different strategies are proposed to reinforce the part of the content related to transport phenomena, which generally present greater difficulty for students. Among other actions there is a plan to implement a joint activity combining Physiology and Biochemical Engineering, both taught in the same semester (Reynolds and Hancock, 2010; Kolb, 2015; Rosenzweig et al., 2019). This activity will offer a dual vision to the phenomena of material transfer in the human body, combining an engineering and biological approach to the process.

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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