CHALLENGE-BASED LEARNING APPLIED TO THE DESIGN AND EXPLANATION OF CERTAIN MASS TRANSFER UNIT OPERATIONS AGAINST A PANEL OF EXPERTS

M.L. Castelló Gómez[1], C. Barrera Puigdollers[1], L. Seguí Gil[1], A. Heredia Gutiérrez[1], J. García Hernández[2]

[1]*Food Technology Department. Universitat Politècnica de València (SPAIN)*
[2]*Biotechnology Department. Universitat Politècnica de València (SPAIN)*

Abstract

Technological advances of recent times make soft skills such as critical thinking, problem solving and collaborative work essential for university graduates to progress. Also, due to the ease of access to a large amount of information, alternative teaching-learning methods become necessary to catch the students' attention and motivate them to learn. To this end, challenge-based learning has been incorporated into the areas of science and engineering by involving students in real-world problems and in the development of specific solutions. In the context of the courses Transport Phenomena in the Food Industry I and II (Degree in Agrofood Engineering), 24 fourth-year students were challenged to fully describe and design a food process that includes both solid-liquid extraction and a hot air drying unit operation. To this aim, the students worked in groups of 3-4 people under the supervision of the lecturers. Students were asked to deliver 4 different tasks. Deliverable 1 consisted of a flow chart including the main stages of the process, which was carried out from the information found in different bibliographical sources. Along with it, an estimation of the mass flows of raw materials and finished products, together with the specification of the different variables involved in each one of the stages of the process were also submitted to evaluation (deliverable 2). The approach and resolution in an Excel file of those mass and energy balances that, along with other equations and the handling of specific graphs, are necessary to calculate the yield of the whole process and the flow rate and composition of each one of the intermediate streams were also assessed (deliverable 3). After that, students were asked to record a screencast regarding the decision-making and calculations to face the challenge. These screencasts were displayed against a panel of other expert lecturers who gave them some recommendations and evaluated the oral presentation following a rubric. To favour a much more objective evaluation, another rubric was employed to evaluate deliverables 1 to 3. In the opinion of the students, which was collected through a questionnaire at the end of the challenge-based learning experience, it allowed the students to develop both the specific skills of each one of the two subjects and the soft ones, specifically those related to collaborative work, problem solving, time control and oral communication.

Keywords: Challenge-based learning, mass transfer operation, flow chart, oral presentation, screencast, panel of experts, rubrics.

1 INTRODUCTION

Learning experiences are a challenge for Higher Education professionals and their institutions, since they are responsible for the academic and professional development of students so that they can efficiently address contemporary problems [1]. Thus, despite the efforts made so far, it is necessary to continue planning, working out and sharing teaching experiences that clearly contribute to the development and evaluation of and soft skills professional competences, which are transferable, allowing other lecturers to implement similar actions, adapted to other contexts. In this regard, development and assessment of skills throughout university education, especially soft skills, has become a challenge for lecturers [2]. Making an explicit statement of what it means to be competent at different levels requires being able to specify the learning outcomes associated with that competence at each level (Education and Training 2020 Work program. European Commission) [3].

Challenge-Based Learning (ChBL) is a collaborative learning experience in which teachers and students work together to learn about compelling issues, propose solutions to real problems and take action. The approach asks students to reflect on their learning and the impact of their actions and publish their solutions to a worldwide audience [4]. In this scenario, ChBL is presented as a meaningful learning proposal that implies the mastery of various transversal and professional competences such as critical thinking, teamworking, problem solving and decision-making.

Particularly in engineering courses, the **management of computer tools** in the resolution of simulated cases greatly facilitates progress in the establishment of knowledge and gives it a real practical sense. Also, in the current scenario caused by Covid-19 pandemic, where teleworking has been imposed and the mastery of technology is already required, these skills are compulsory for the future workers. Furthermore, the **search for information** in different online databases gives to the student data to design in a brief period processes quite close to the real ones. Discriminating between reliable and non-reliable sources of information and selecting only the required data for their final goals is also worked by means of this activity. **Working in groups** to develop all the required steps to reach a particular objective is also an opportunity to learn from their equals, having always their lecturer supervision by means of tutorial sessions and simulating the day to day in a real project office. Besides, if students prepare an oral presentation explaining to their colleagues and to a panel of expert the idea, how they have developed it, which are the main results following the mathematical models and finally their main conclusions, they can receive a feedback from them and improve their solution.

For all this, the aim of this paper is to show the ChBL experiences carried out in the courses Transport Phenomena in the Food Industry I and II of the Agrofood Engineering Degree at UPV, in which students were challenged to fully describe and design a food process that includes both solid-liquid extraction and a hot air drying unit operation.

2 METHODOLOGY

The ChBL process in the context of two core courses in the 4th year of the Degree in Agrofood Engineering (intensification in agri-food industries) is described below. It is worth noting that courses Transport Phenomena in the Food Industry I and II (TP1 and TP2, respectively) are thought consecutively during the first semester and that the students enrolled in both subjects are almost the same. Previous knowledge is assumed in solving mass and energy balances. Also, of the three properties that can be transferred in a food system (mass, heat and momentum), the challenge-based learning aimed to deep in two unit operations involving a mass transport: solid-liquid extraction and hot air drying.

2.1 Challenge description

The challenge posed to the students on the first day of class was, attending to the basic principles of a sustainable industrial process design, to fully describe a new food process or improve an existing one including a solid-liquid extraction operation (for subject TP1) and a hot air drying step (for subject TP2). Simulating the real activity of the Process Engineering Department of an Agri-Food Company, students were asked to work for 7 weeks on groups of 3 to 4 people under the supervision of the lecturers, mainly outside the class time and in the distance due to the health alert situation caused by COVID-19 disease. As for the tasks to be carried out by the students, they gain in complexity as they progressed in the contents of the course.

2.2 Students' tasks

Within the first week of the course, students had to individually answer an initial questionnaire to find out, among other things, their previous experience in this kind of activities and their predisposition towards them.

Within the second week of the course, students had to form the groups and define the food process to be designed. They could choose one of the processes suggested by the lecturers (obtaining vegetable oils from seeds, nuts or olives' orujo, horchata and other vegetable beverages manufacture, tea or soluble coffee making, etc.) or a completely different one.

Within the next two weeks of the course, students had to build the complete flow diagram of the process (deliverable 1) and define both the flow rates and compositions of the main streams, as well as the conditions (type and amount of solvent, counter-current or with fresh solvent in each stage extraction, drying air conditions, continuous or intermittent dryer, etc.) to carry out the process (deliverable 2). To this aim, students should search for information in specialized databases and web pages. Decision-making should promote the rational management of natural resources and minimize waste generation without diminishing the process efficiency.

In weeks 5 and 6 the students were asked to raise and solve mass balances to calculate the flow rate and composition of all the streams involved in the process. They should also apply the graphical methods taught in class in order to estimate the number of stages involved in the solid-liquid extraction process or the composition of the air as it passes through the drying unit. Finally, students will apply certain equations to calculate both the yield and the efficiency of the process. To carry out these tasks the students will have the feedback from lecturers on previous deliveries along with class notes. Obtained results will be orderly collected and delivered in a spreadsheet (deliverable 3).

In the last week of the course the students had to record a 3 to 4 min presentation in which each member of the team explained one of the different tasks done (deliverable 4). The video was screened on the last session of the course in front of an expert panel made up of 3 lecturers/researchers with experience in designing unit operations for the food industry.

Once all tasks were completed, students were asked to assess their individual experience through a final questionnaire.

It is intended through these tasks that students acquire certain soft skills, such as problems analysis and solving, effective communication, critical and creative thinking or time planning and management. Also, specific skills of the Degree on Agrofood Engineering will be worked on, particularly the ability to use the basic principles of food engineering and the capacity to consolidate, expand and integrate the knowledge.

2.3 Assignments rating

Deliverables 3 and 4 were scored according to the criteria collected in the corresponding rubric (Tables 1 and 2). Deliverable 3 was only scored by the lecturer of the course, while deliverable 4 was individually scored by the three members of the expert panel. Final mark was obtained from the average of the marks obtained in each of the two deliverables. With some exceptions, all the team members received exactly the same mark. Rubrics were made available to the students from the beginning of the activity.

Table 1. Rubric used to score deliverable 3.

ITEM	RATE	Excellent 10-9	Good 8-7	Acceptable 6-5	Not reached 4-0
Search for information and selection of process conditions according to sustainability and energy efficiency criteria	**20%**	A good search has been carried out (on manufacturers' websites, product labels, scientific databases ...) and the process conditions have been selected according to sustainability criteria. Furthermore, the sources consulted have been correctly referenced.	In general, there has been an effort to search for information in different sources (on manufacturers' websites, product labels, scientific databases ...) and the process conditions have been selected according to sustainability criteria, but the sources have not been cited.	Not enough sources have been consulted to establish the most appropriate process conditions based on sustainable development criteria.	No sources of information have been consulted to define the conditions of the process.
Flowchart making (main unit operations and streams)	**20%**	All the unit operations involved in the process are identified, as well as the inflow and outflow streams in each of them. The graphic representation is clear and facilitates the understanding of the process, detailing the most relevant components for each stream.	All the unit operations involved in the process are identified, as well as the input and output streams in each one of them, but the graphic representation is confusing and makes it difficult to interpret the process.	Some unit operations are missing or not all the components of interest are defined for each of the streams involved in the process.	The flowchart is not provided
Calculation of different streams' flow rate and composition based on the specific process design methodology	**30%**	All the equations and other mathematical tools have been properly selected and applied and the results obtained are correct.	All the equations and other mathematical tools have been properly selected and applied but some of the results obtained are incorrect.	Equations and other mathematical tools have not been in all cases properly selected or applied and, consequently, some of the results are incorrect.	Not all the equations and/or mathematical tools required to obtain the final result have been applied.
Organization of the information in an Excel file	**10%**	Each value is correctly defined. The equations used are indicated and the meaning of each term is explained. In text squares or in another similar way the calculation route carried out is detailed.	Each value is correctly defined. The equations used are indicated but the meaning of each term is not explained. Furthermore, the calculation route carried out is not sufficiently detailed.	The results are shown but the equations used are not indicated or the calculation route carried out is not sufficiently detailed.	The results are shown but neither the equations used nor the calculation route carried out are indicated.
Proper use of the units and the terminology	**10%**	Proper use of the nomenclature and the units in all magnitudes involved in the process.	Proper use of the nomenclature and the units in most of the magnitudes involved in the process.	Incorrect use of the nomenclature or the units in most of the magnitudes involved in the process.	Incorrect use of the nomenclature and the units in most of the magnitudes involved in the process.
Teamworking	**5%**	All members contribute in carrying out the work in the same proportion.	Almost all members contribute in carrying out the work in the same proportion.	There is a significant disproportion in the contribution of each member of the group to the work, but all members contribute to the completion of the work.	There is a significant disproportion in the contribution of each member of the group to the work, and some of them have not contributed at all to the completion of the work.
Punctuality in the deliveries	**5%**	All deliverables on time	All but one deliverable on time	Only two deliverables on time	Less than two deliverables on time

Table 2. Rubric used to score deliverable 4.

ITEM	RATE	Excellent 10-9	Good 8-7	Acceptable 6-5	Not reached 4-0
Content selection	**20%**	The content has been well selected, so that the most relevant information is included in each of the sections of the work: information search, flowchart, calculations and results.	Content from each of the sections of the work is included (information search, flowchart, calculations and results), but some relevant information is missing.	The content has not been well selected, so that relevant information is missing from some of the sections of the work (information search, flowchart, calculations and results).	The content has not been well selected, so that relevant information is missing from most of the sections of the work (information search, flowchart, calculations and results).
Explanation	**10%**	Appropriate use in all cases of the terminology and the technical language in the explanation of the tools and the calculation route.	Appropriate use in most cases of the terminology and the technical language in the explanation of the tools and the calculation route.	Appropriate use in a few cases of the terminology and the technical language in the explanation of the tools and the calculation route.	Inappropriate use of the terminology and the technical language in the explanation of the tools and the calculation route.
Graphical elements	**10%**	The explanation is supported by a slide presentation that has an appropriate font size and amount of text, and that includes images and other graphic elements that facilitate the understanding of the speech.	The explanation is supported by a slide presentation that, although it has not an appropriate font size or amount of text, it includes images and other graphic elements that facilitate the understanding of the speech.	The explanation is supported by a slide presentation that has not an appropriate font size or amount of text, in addition to incluing images or other graphic elements that do not facilitate the understanding of the speech.	The explanation is supported by a slide presentation that has not an appropriate font size or amount of text, in addition to not incluing images or other graphic elements that facilitate the understanding of the speech.
Interaction with the panel of experts	**10%**	Students answer in a clear and concise way to all the questions, thus evidencing the domain of the subject.	Students answer well to all the questions, but there are certain shortcomings in the domain of the subject.	Students are generally able to answer the questions, but in some cases deviate from the purpose of the question.	Students do not answer or answer something that does not correspond to what was asked.
Oral language	**20%**	Appropriate use of formal language, with a non-monotonous tone of voice and arousing the interest of the audience.	Adequate use of formal language, but with some deficiencies in verbal fluency.	Appropriate use of formal language, but the tone of voice is monotonous and does not arouse the interest of the audience	Students abuse of colloquial language, bore, do not arouse interest and/or denote deficiencies in their oral expression.
Teamworking	**10%**	Each member of the team contributes equally in the time of the presentation and in the amount of content presented.	Most of the member of the team contributes equally in the time of the presentation and in the amount of content presented.	Most members of the team do not contribute equally in the exposure time or in the amount of content presented.	Some members of the group do not intervene in the presentation of the results.
Duration	**20%**	The presentation time does not exceed the established time.	The presentation time does not exceed that established by more than 50%.	The presentation time exceeds the established one between 50 and 100%	The presentation time exceeds the established one by more than 100%.

3 RESULTS

Next, some examples of the practical cases treated in courses TP1 and TP2 are shown.

3.1 Examples of the study cases

First of all, it is important to bear in mind all the study cases in these courses, which are presented in Table 3. As it can be seen, most of the students choose a single process to address the challenges posed in each of the two courses. In a few cases (groups 4 and 6) the processes to be designed were completely different. It should be noted that the students organized themselves in such a way that all the design options addressed in theoretical sessions were analysed through the different challenges. Then, some flow charts and the mathematical tools will be exposed for the particular case of horchata manufacture.

Table 3. Practical cases addressed in two courses of the Agrofood Engineering Degree at UPV.

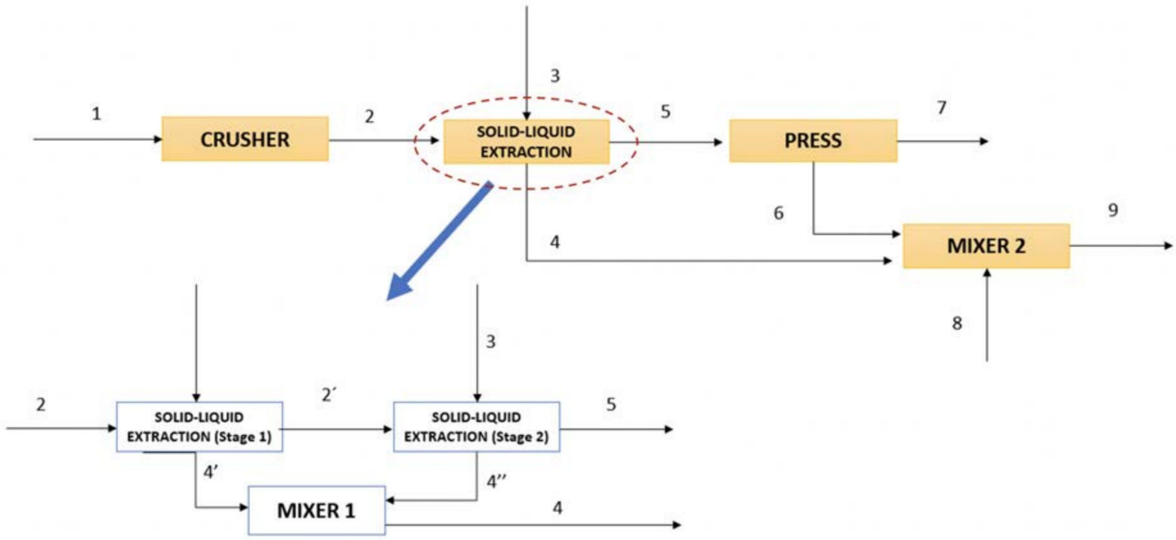
Group	*Manufactured Product*	*Solid-liquid extraction*	*Hot air-drying operation*
1	Horchata	Soluble solids extraction with water from dried and crushed tigernuts	Convective drying of whole tigernuts to produce tigernut flour
2	Sunflower oil	Fat fraction extraction with hexane from dried and crushed sunflower seeds	Convective drying of sunflower seeds as a pre-extraction treatment
3	Almond oil	Fat fraction extraction with hexane from dried and crushed almonds	Convective drying of whole almonds as a pre-extraction treatment
4 (TP1)	Olive pomace oil	Fat fraction extraction with hexane from olive orujo	
4 (TP2)	Dehydrated onion for seasoning		Convective drying of sliced onions
5	Green tea	Soluble fraction extraction with water from dried tea leaves	(*)
6 (TP1)	Cod liver oil	Fat fraction extraction with ether from cod liver	
6 (TP2)	Dried apple slices		Convective drying of apple slices
7	Soluble chicory	Soluble solids extraction with water from dried and crushed chicory	Convective drying of chopped chicory

(*) This group of students was only enrolled in TP1 course.

3.1.1 Example of solid-liquid extraction

Following the instructions given by the lectures in class and also by means of some learning objects [5-8] students prepared the statement of their practical cases and also the flow chart. This is one example:

The process of making horchata is composed by the following main basic operations: Hydration of the tigernut and its crushing, the extraction with water of the solids present in the tigernut, the subsequent pressing of the residue and finally the mixing of the liquid phase with sugar (Fig. 1). The step of solid-liquid extraction can be carried out in subsequent stages to increase the yield of the process. In this particular case, two stages, using new solvent (60 L of water) in each one, have been considered in order to extract the solid phase of 20 kg of tigernuts. To find out how much liquid phase is obtained in the solid liquid operation, mass balances along with the management of the triangular-rectangular diagram will be used. The contribution to the sustainability in these cases is related to the increase in the number of stages to improve the yield of soluble solids extraction using different ratios of solvent:solid. Besides, the increase in the amount of soluble solids recovered from the press stage was also taking into account.

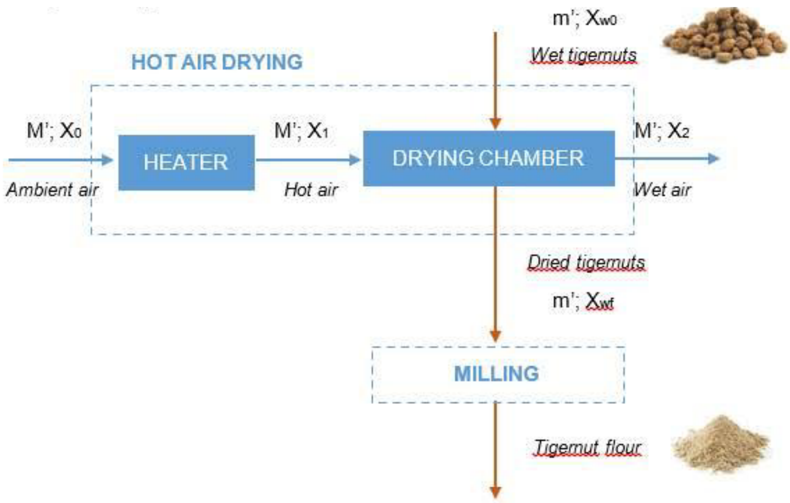


Notation of the streams: 1: Selected soaked tigernuts, 2: Ground tigernuts, 2': Refined tigernuts obtained from the first stage of extraction, 3: Water, 4': horchata obtained from the first stage of extraction, 4'': Horchata obtained from the second stage of extraction, 4: Extract (Horchata), 5: Final refined tigernuts obtained from the second stage of extraction, 6: Horchata from pressing, 7: Solid residue obtained from pressing, 8: Sucrose, 9: Final horchata

Figure 1. Soluble solids extraction from tigernuts considering two stages and the use of new solvent at each stage.

3.1.2 Example of hot air-drying operation

The students identified two main unit operations in the flour manufacture from tigernuts that do not meet the quality standards required to produce horchata: the convective drying of the whole tuber with air at 70 ºC to a final moisture of 7.5% and the subsequent milling until obtaining a fine powder (Fig.2). The challenge in this case was designing the tray dryer required to dry 100 kg of wet solid per hour. For this purpose, the thermodynamic properties of the air as it passed through the drying unit were first calculated with the help of mass balances in steady state without generation and the Molliere's diagram by assuming an 85% thermodynamic yield. Then, the drying time was obtained from the water effective diffusivity value found in the literature [9] and the solution to the second Fick's Law for a spherical geometry and short processing times.



Notation: M' and is the dried air flow in kg d.a/h; X_i is the absolute moisture of the air at point i in kg w/kg d.a; m' is the dried solid flow in kg d.s/h; X_{w0} and X_{wf} are respectively the initial and final moisture of tigernuts in dry basis (kg w/kg d.s).

Figure 2. Flow chart of tigernut flour manufacture.

3.1.3 Deliverable 3 evaluation

Deliverable 3 grades were obtained by using the rubric previously entered in the methodology section. Fig. 3 shows, for the team designing the manufacture of different products from tigernuts, the ratio between the final grade obtained at the corresponding evaluation test and that obtained in deliverable 3. Average values of the 3 members of the team together with the standard deviation are plotted. As it can be seen, the values obtained were closed to 1, specially in TP1 course, thus indicating that the activity contributed effectively to the expected learning and acquisition of certain professional skills. Slightly lower values observed in TP2 course could be explained in terms of the students' fatigue coupled to the usual less time availability by the end of the term. Relatively high standard deviation values are probably due to the different capacities of the students and/or the differences in their involvement in completing the challenge.

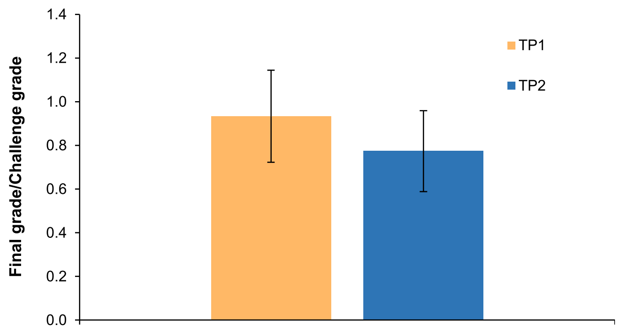


Figure 3. Comparison between the evaluation test grade and that of deliverable 3.

3.2 Oral presentations and exposition to the panel of experts

Fig. 4 shows some screenshots of the horchata challenge explained by the students in a short video of about 5 min. All the components of the group spoke in the video and gave evidence of having learnt the methodology to work with the specific mathematical and graphical tools used in solving solid-liquid extraction. Also, students' answers to the questions made by the experts' panel were quite clear and precise, and evidenced an almost absolute domain of the subject. When explaining the design of the tigernut flour manufacture process, very similar results were obtained.

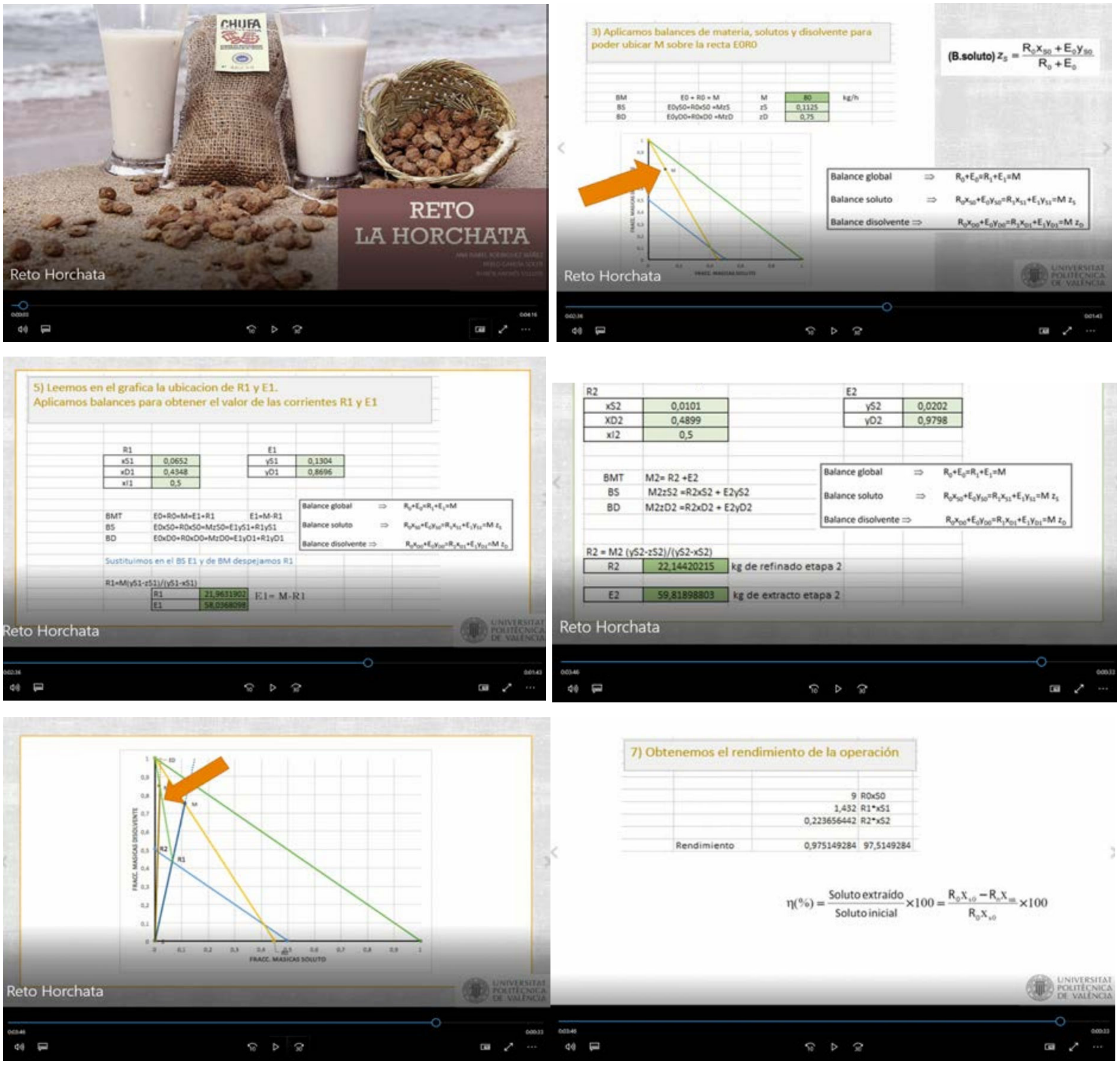
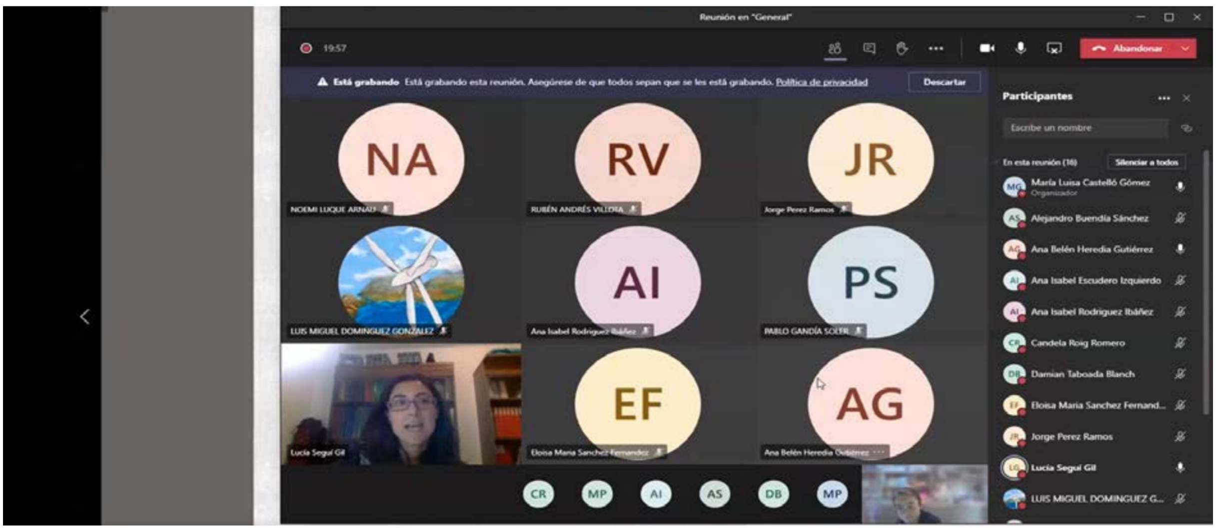


Figure 4. Screenshots taken from the student's short video explaining the design of the horchata manufacture process.

In addition, Fig. 5 collects screenshots of the Teams sessions in which the participation of both the students and the experts' panel in the ChBL experiences presentation is evidenced.



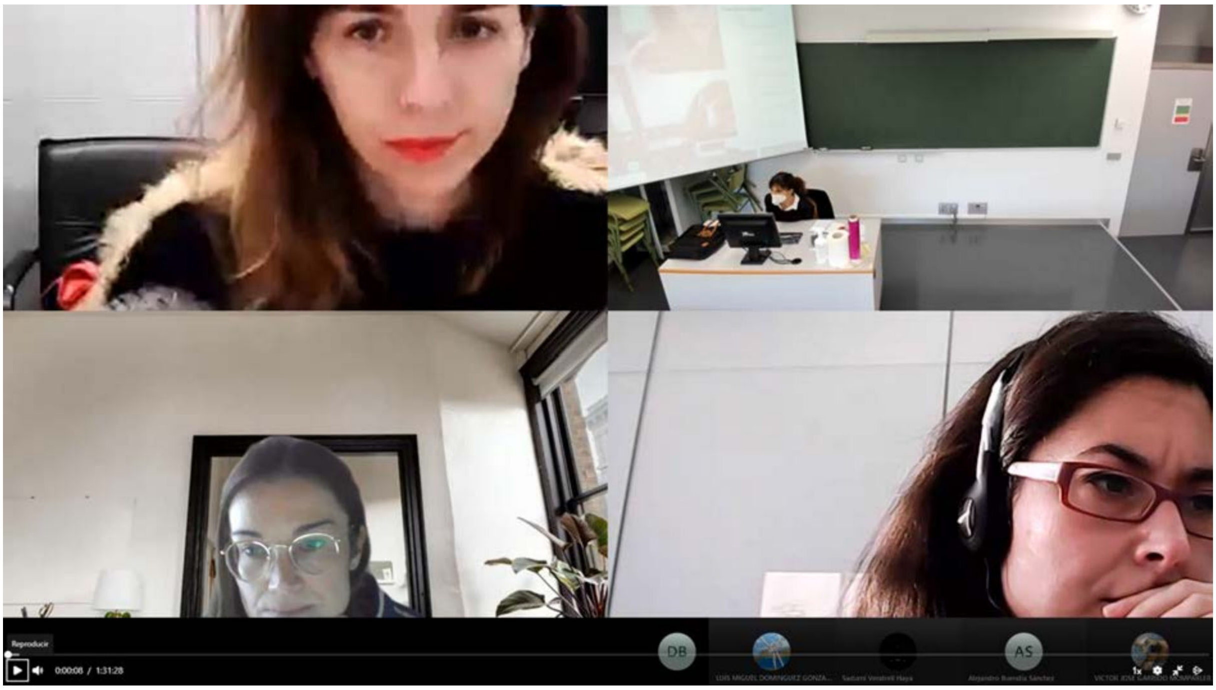


Figure 5. Screenshots of the challenge exposure sessions in front of the panel of experts held on November 3, 2020 (challenges around the solid-liquid extraction) and December 18, 2020 (challenges around the hot air drying process).

3.3 Students' opinion

In this section, students' answers to the questionnaires formulated at the beginning and at the end of the ChBL experience are analysed. Among the different questions, only those related to the contribution of the learning proposal to the acquisition of certain soft skills and professional competences were selected for discussion. Results obtained (Fig. 6) showed that students' expectations before taking the challenge were that it will mostly contribute to improve their ability to use basic computer tools, followed by the ability to apply engineering principles to the food industry and then by the ability to search and use information. After performing the challenge, the ability to search and use information was in the first place, the ability to apply engineering principles to the food industry remained in the second place, and the third place was shared by three abilities: use the principles of engineering facilities, use basic computer tools and assess social and environmental impact.

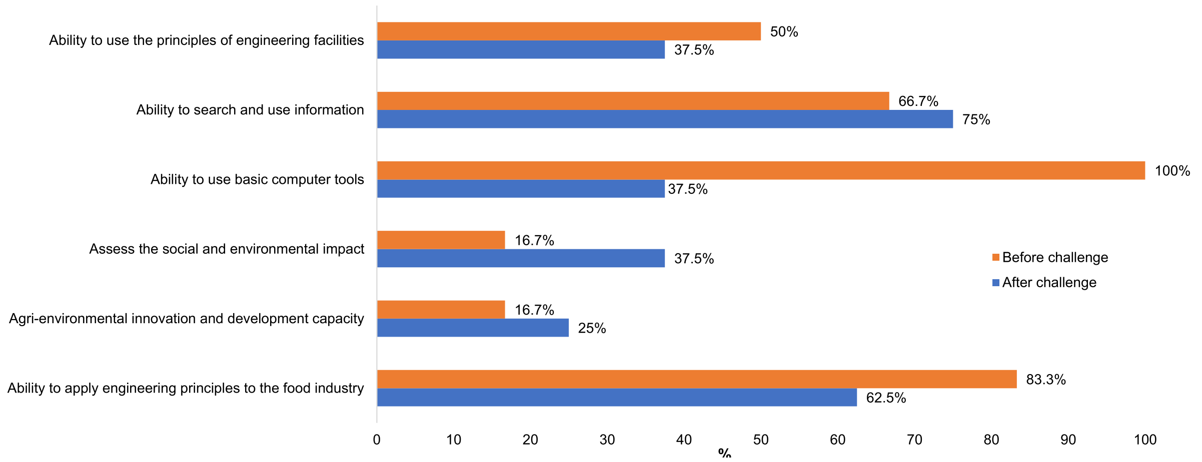


Figure 6. Students' answers to the questionnaire before and after performing the challenge-based learning activities

4 CONCLUSIONS

A challenge-based learning experience consisting on fully describing a new food process or improving an existing one including a solid-liquid extraction operation and a hot air drying step in the context of two core courses of the Degree in Agrofood Engineering was proved to allow the students to develop both the specific skills of each one of the two courses and the soft ones, specifically those related to collaborative work, problem solving, time control and oral communication.

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