APPLICATION OF PROBLEM-BASED LEARNING (PBL) IN THE COURSE "INDUSTRIAL CHEMICAL TECHNOLOGY" OF THE MASTER'S DEGREE IN INDUSTRIAL ENGINEERING

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Abstract

This paper describes the application of Problem-Based Learning (PBL) in the subject "Industrial Chemical Technology" of the Master's Degree in Industrial Engineering from the Universitat Politécnica de València (UPV). This course includes contents related to the Basic Operations of Chemical Engineering, not previously studied by most students. This fact, together with the difficulties associated with the management of 300 students have conditioned the type of methodologies that can be applied and, therefore, the level of depth at which the contents can be developed. Therefore, the main methodology applied so far has been the participative masterclass, with problem solving in the classroom. Although the results in terms of percentage of students who pass the course are very satisfactory, the approach to learning is superficial in some aspects and teachers believe that it should be adapted to master's level. To achieve deeper learning of students in the contents of the course, it has been decided to partially modify the methodology, integrating Problem-Based Learning (ABP). This new methodology will consist of grouped resolution of problems integrated into the same real industrial process, which will allow students to also acquire a more global view of the contents covered in the course. The level of the problems will be increased compared to those solved in the classroom and students will be required to search, select and justify additional data and information to solve the problems that will also be multidisciplinary.

All this innovation is part of an Innovation and Educational Improvement Project granted and funded by the "Vicerrectorado de Estudios, Calidad y Acreditación (VECA)" of the UPV. This work describes how the PBL has been defined for implementation in the course and analyses the results achieved to date, identifying the aspects to be improved for the continuation of the methodology in the following academic years.

Keywords: Problem-Based Learning, Chemical Technology, Industrial Engineering, Deep Learning.

1 INTRODUCTION

This work is part of a Project of Innovation and Educational Improvement requested and granted in 2019, to integrate Problem-Based Learning (PBL) into a course of the Master's Degree in Industrial Engineering of the Universitat Politècnica València (UPV). The Project lasts two academic courses: in the first one (2019-20), the methodological change to be made was defined, and the activities and materials were developed; and in the second academic year (2020-21), the implementation of innovation has been carried out during the first semester. This article describes the innovation raised and how it has been implemented in this academic year, and discusses the main aspects to be modified that have been identified during the course.

1.1 Course context

The course object of the Innovation Project is "Chemical Industrial Technology", a core course of the 1st year of the Master's Degree in Industrial Engineering of the Higher Technical School of Industrial Engineering of the UPV that is taught since the 2014-2015 academic year. The course consists of 4.5 ECTS credits, 3.6 of which are classroom theory and practice, and the remaining 0.9 laboratory and computer practices. The course has approximately 300 students who, since 2019-20, are divided into 8 theory groups and 24 practice groups.

With regard to the structure of the contents of the course, these are divided into the teaching units shown in Table 1.

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Table 1. Teaching units of the course

Teaching Units (TU)	Name	Lab sessions
TU 1	Introduction to Chemical Industrial Processes	
TU 2	Chemical Engineering Balances	Non Stationary Mass Balace
TU 3	Kinetic and Reactors	
TU 4	The Chemical Plant	
TU 5	Separation Operations	Simple Batch Distillation of a Binary Mixture

Of the 5 teaching units, the first 3 are evaluated in the first mid-term, exam of the course (after 6 weeks of class) and the next 2 in the second mid-term exam (after another 6 weeks of class). In each block of 6 teaching weeks, students perform, in groups of 3 to 5 members, a laboratory practice and a computer practice about the contents of the same teaching unit, as indicated in Table 1. As a result of these practices, students submit a group-written report, presenting and discussing experimental results.

Regarding the methodology applied in the course, it is based on the participatory master lesson with problem solving in the classroom, in addition to the laboratory and computer practices already discussed. This methodology develops the corresponding specific competences, in addition to the three transversal competences (TC) assigned which are: "Understanding and Integration" (TC1), "Analysis and Problem Solving" (TC3) and "Teamwork and Leadership" (TC6). The first and the last one are developed and evaluated through laboratory and computer practices, while "Analysis and Problem Solving" competence is developed from problem solving in the classroom and evaluated through written exams.

Finally, the course assessment includes the grade of each mid-term exam (45%) and the mark of the practice reports (5% each one). Each exam consists of a multi-choice 12-question test, which accounts for 35% of the score, and one or two problems, representing the remaining 65%.

1.2 Justification of the innovation

Generally, the course has excellent academic results, with a percentage of students passing greater than 90%. However, despite the good academic results obtained by students, the lecturers agree that the approach of learning of the students is superficial mainly because the problems that are solved are shown as independent units, not getting an overview of industrial chemical processes, as it would be desirable. On the other hand, the assessment of some of the transversal competences (TC1 and TC3) is too focused on examination problems, which is not the most appropriate way to assess their degree of acquisition. In addition, the accreditation processes of the Master (both ABET and EURACE), have shown that the course is one of the 1st tear that carries out the least evaluable activities outside of exams and practices.

Therefore, an Innovation and Educational Improvement Project was requested in order to modify part of the methodology of the course to improve the learning of students and give it a deeper approach according to a Master's level.

1.2.1 Learning approaches

Learning approaches refer to how students deal with an academic task. These approaches derive both from the student's perceptions of the task and from his personal characteristics [1], and two approaches can basically be distinguished: superficial and deep. Superficial learning is characterized by passive memorization of knowledge, focused on accomplishing the task. In this approach, learning is seen as an imposition that results in a disconnection between new information and knowledge already acquired. On the other hand, the deep approach of learning is characterized by the interaction of new ideas and concepts acquired with prior knowledge, as well as by the critical analysis of the results. In this approach, the student is aware of his own learning process and his motivation lies precisely in this [2].

It is proven that there is a connection between the teaching method and the depth and complexity of learning. In fact, students learn in a certain way according to the way they are taught and evaluated, being able to modify their learning approach through methodological approaches based on learning

[3]. Thus, compared to traditional teaching methods, active methodologies involve greater student involvement in their own learning process, resulting in a higher level of understanding, increasing their deep approach to learning and reducing the superficial one [4, 5].

One of the methodologies focused on active learning is Problem-Based Learning [6]. It is a student-centered method, based on the use of problems as the starting point for acquiring new knowledge. Since the course in which the methodology is intended to be modified is mainly based on problem solving, it has been decided that this will be the new methodology to implement to achieve deeper learning of our students.

This methodology has undergone some changes when adopted by different institutions, being that of Maastricht University, for example, one of the most widespread, especially in Europe. One of the main variables of the PBL has to do with the degree of structuring of the problem, finding from rigidly structured problems with a high degree of detail, to open problems that do not present data and in which students must investigate and define the problem ([7].

In any of its variants, several studies have shown that Problem-Based Learning has an improvement effect on students' learning approach. Thus, it has been proven that this strategy has a positive effect on students' procedural learning, as well as on decreasing mental burden during the learning process [8]. In addition, it has been shown that this methodology plays an important role in the permanence of knowledge [9].

Problem-Based Learning has been shown to allow the acquisition not only of cognitive knowledge, but also a number of skills and transversal competences [10, 11]. Thus, it provides students with the opportunity to work as a group and gain experience in teamwork, as it is required for professional development. In addition, this methodology allows to develop the self-learning of the student, since efficient search and selection of information is required for its application in the resolution of the problems [12].

However, it should be noted that when students first face this strategy they show some resistance and frustration in the early stages, due to the ignorance of how they have to develop the tasks and manage their own learning. In this situation, the student's motivation for the activity is essential to successfully develop the learning objectives. Among the motivational strategies that enable the success of the PBL are, on the one hand, the contextualization of problems, trying to make them as realistic as possible, bringing the student closer to his professional future [13]; and, on the other hand, it is very important the tutorial action of guide and accompaniment by the teacher [14].

The following sections describe the innovation proposed, based on PBL, as well as its implementation throughout the first semester of this 2020-21 academic year.

2 INNOVATION DESCRIPTION

The PBL methodology is applied in the course by solving contextualized problems within the same industrial process, which allows students to acquire an overview of it. Problems have been raised with a multidisciplinary approach, including not only technical but also economic and sustainability aspects. In this way, in addition to students gaining a global view of the complexity of a chemical industrial process, they are intended to understand the important role of the chemical industry in society [15]. On the other hand, the problems raised require students to search for some kind of information: legislation, regulations, physical-chemical properties, etc. In this way, the competencies related to the search and critical selection of information will be developed.

For the development of the activity, the students of each theory group (with 38 students on average) will be divided into teams of maximum 5 students, and solve a problem in each part of the semester: in the first one, the problem will be related to teaching unit 2 (mass and energy balances); and, in the second one, the problem may be related to any of the separation operations studied in teaching unit 5.

The activity is considered mandatory for all students, and will be carried out in a distance way, to make it possible for all students to carry out it and acquire better learning.

As a result of the activity, each team shall develop the following 3 deliverables:

- Deliverable 1 (D1). Description of the context of the assigned industrial process, including a diagram of blocks of the same.
- Deliverable 2 (D2). Resolution of the teaching unit 2 problem.

- Deliverable 3 (D3). Resolution of the teaching unit 5 problem.

The activity will weigh 10% in the final grade. Because it is a mandatory activity, the student who does not perform it will have a score of 0 in that activity and it cannot be recovered.

3 INNOVATION IMPLEMENTATION

This section describes how PBL has been implemented in the course, during the first semester of this academic year 2020-21.

3.1 Implementation schedule

Table 2 shows the schedule of the PBL methodology, which shows the preparation and deadline times of each deliverable, as well as other highlights of the activity.

Table 2. Schedule of PBL in the course

Teaching week	1	2	3	4	5	6	Mid-term exam 1
Aprox. date	21th Sept	28th Sept	5th Oct	12th Oct	19th Oct	26th Oct	9th Nov
Teaching unit	TU 1	TU 2	TU 2	TU 3	TU 3	TU 3	
PBL activity	PBL explanation	Team forming Start Task D1		Deadline D1 Start Task D2	Deadline feedback sheet D2	Deadline D2	
Teaching week	7	8	9	10	11	12	Mid-term exam 2
Aprox. date	16th Nov	23th Nov	30th Nov	7th Dec	14th Dec	11th Jan	20th Jan
Teaching unit	TU 4	TU 4	TU 5	TU 5	TU 5	TU 5	
PBL activity			Start Task D3		Deadline feedback sheet D3	Deadline D3	

The activity begins in teaching week 1, in which the first class of the subject is taught. In the presentation of the course the PBL activity is described: what it consists of, how it will be organized and evaluated, and the relevant dates.

The formation of the work teams is then activated, which is carried out freely through the intranet tool of the subject during teaching week 2. Guidelines for group formation are: grouped into teams of 3 to 5 people, choose ateam leader, who will be the interlocutor with the teacher to exchange documents, consult doubts and arrange tutoring.

Once the teams are constituted, the task corresponding to Deliverable 1 (end of week 2) is activated, also through the intranet of the subject. In this deliverable students must make a block diagram of the main stages of the assigned process, with their corresponding description. The main objective is that students learn stages of the process they have to work with to solve the problems of the activity. The deadline for the delivery of this report is about 12 calendar days (teaching week 4).

Subsequently, the Task of Deliverable 2 begins at the end of teaching week 4, with a deadline set two weeks later. In order to guide students on the approach to solving the proposed problem, an intermediate delivery (teaching week 5) has been established. It has been called feed-back sheet, and consists of completing a summary table with the following information of the problem: available data, information or data to be searched (including the sources considered) and sequence of steps to solve the problem (procedure and equations needed). This tab allows for a quick review by teachers to guide students on the adequacy of their resolution proposal.

The problem with the contents of the 2nd mid-term exam corresponds to Deliverable 3, whose task begins in teaching week 9, when the separation operations of the teaching unit 5 have already begun to be studied. The delivery time in this case ends in week 12, counting the students with an approximate time of a month and a half to develop this Deliverable, since the classes end after the winter holidays. Similar to Deliverable 2, an intermediate delivery consisting in a new feed-back sheet is established at week 11 (before the winter break), which will serve to guide students on the approach to solving the D3 problem prior to delivery.

It should be noted that the times originally set out in the schedule have been respected throughout the quarter, with the sole exception of the delivery of the D3 feedback sheet, which had to be delayed due to a mismatch in the contents taught in the theoretical classes.

3.2 Activity arrangement

Table 3 shows the seven industrial processes selected for the development of PBL in the course:

Table 3. Selected industrial processes for the PBL

Nº	Industrial process
P1	Soda production by the Solvay process
P2	Orange juice production
P3	Biodiesel production from used oils
P4	Painting of car bodies by cataphoresis
P5	Pomace oil production
P6	Anaerobic digestion of sludge
P7	Biogas processing for subsequent application

The number of problems required has been developed from each process so that, in each theory group, all work teams have a different problem in each part. In addition, each theory group has been assigned 2 different industrial processes so that there is more variety of approaches. Table 4 shows the distribution of processes and problems, carried out according to the number of students enrolled in each group.

Table 4. Distribution of problems assigned in each group

Group	Assigned processes (see Table 3)	Nº enrolled students	Nº of problems
G1	P2 & P5	36	9
G2	P2 & P5	37	9
G3	P1 & P4	37	9
G4	P2 & P3	33	8
G5	P6 & P7	32	8
G6	P3 & P5	40	10
G7	P1 & P4	39	10
G8	P6 & P7	48	11

The biggest difficulty encountered in organizing the activity has been to define as many different problems as number of groups formed in total. To do this, the base structure of the problems has been maintained, modifying in the different versions the starting data, the information to be searched and / or the expected results.

3.3 Innovation monitoring

The monitoring of innovation has included two different ways: the monitoring of the work carried out by each team of students, and the monitoring of the development of innovation from the methodological and organization points of view.

With regard to the monitoring of the work of each group of students, it has been established through the following actions:

- Review of Deliverable 1 to identify whether the industrial process context is correctly defined. Otherwise, the group is notified to correct errors and/or supplement the information, before resolving the Deliverable 2 issue.
- Review feed-back sheet of Deliverable 2 & Deliverable 3. The information completed in the tab is reviewed and feedback is provided to the group of students on the adequacy of the same, so that they can correct the errors or omissions in the approach of resolving the problem.

After a first review of the contents of Deliverable 2, a large disparity in the quality of the contents was observed: extension, format, depth, etc. It was therefore decided to give a set of general guidelines, to standardize and improve the quality of Deliverable 3. These guidelines were communicated at the same time as feedback following the revision of the Deliverable 3 feedback sheet.

4 RESULTS

This section describes the main results that are counted at the time of publication of this work. On the one hand, the development of the activity up to Deliverable 2 is analyzed. On the other hand, some aspects are discussed to be improved in view of the application of the methodology in following years.

4.1 Results of activity monitoring

Table 5 shows the results obtained to date in the activity, which correspond to the qualifications of deliverables 1 and 2, and the percentage of feedback sheets of the E2 in which the resolution approach proposed by the students was correct and does not require any relevant modification.

Table 5. Results of deliverables E1 and E2

Group	*E1 average mark*	*E2 feedback sheet OK (%)*	*E2 average mark*
G1	7.2	77.8	7.3
G2	6.9	88.9	7.0
G3	7.9	77.8	6.7
G4	8.1	75	8.1
G5	7.8	100	8.7
G6	6.7	30	8.8
G7	9.2	90	7.6
G8	7.9	33.4	7.5
Total	**7.7**	**71.6**	**7.7**

As shown in the table, the average notes of deliverables 1 in the different groups have ranged from 6.7 to 9.2, with a total average score of 7.7. The same value is observed for the average mark of deliverables 2, although in this case there is less variation in the rating range, with a minimum of 6.7 and a maximum of 8.8. In any case, it can be said that students have obtained good grades in the first two deliverables.

With regard to the feedback sheet for Deliverable 2, there is a large disparity in the percentage of sheets successfully completed, i.e. they did not need any reorientation for the correct resolution of the problem. This may be due to the different complexity in the proposed problems and/or the monitoring and attendance of the theoretical classes by students. However, the feedback sheet has been found to be a useful tool within the methodology applied, as it allows to identify errors of approach and / or the information to be searched before students solve and deliver the problem, which has contributed to the good qualifications of Deliverable 2. In addition, the format defined for the feedback sheet has allowed teachers quick and efficient monitoring of the information written on it.

4.2 Learned lessons

From the development of the PBL methodology in the course, some difficulties and aspects have been identified to be improved that are summarized in the following points:

- Students expressed many doubts to fill in the information required in the feedback sheet. In many cases, it has been shown that they solve the problem before receiving the feedback. To solve this difficulty, it was thought that an example of the feedback table could be made in class, filling it for one of the problems that are resolved in the classroom.
- A large disparity in the quality of deliverables has been identified, which is mainly due to the lack of guidelines provided. It is therefore necessary to develop rubrics with the correction criteria for each of the Deliverables, which must also be provided to students at the beginning of the activity, so that they are aware of the criteria with which they will be evaluated.
- In some cases it has been perceived that there has been no teamwork, but that the students have done an individual distribution of tasks without any collaborative work. Mechanisms for monitoring and evaluating group work, such as co-evaluation or peer evaluation, should therefore be incorporated.
- Improvements on PBL schedule should be done in order to better adjust teaching unit times and PBL activities.

5 CONCLUSIONS

This work has described the application of the PBL methodology in the subject "Industrial Chemical Technology" of the Master's Degree in Industrial Engineering of the UPV. From the results achieved until the publication of this work, the following conclusions can be drawn:

- The average grades of the first two deliverables have been 7.7, so it can be stated that students have successfully developed this part of the activity.
- The feedback sheet has been a very useful tool to properly guide students in solving the problem, and it has also been easily apply by teachers.
- The main difficulties encountered during the development of innovation have been the problems that students have had to fill out the feedback sheets, the disparity in the quality of the Deliverables, and the lack of teamwork in some cases.
- To improve the challenges discussed, the following changes are proposed for the next year: explain how to fill out the feedback tab during theory classes using some of the problems that are solved as an example; develop evaluation rubrics for each deliverable and provide them to students at the start of the activity; and incorporate mechanisms that encourage collaborative work.

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