education sciences

MDPI

Article

Integration of Project-Based Learning (PjBL) Methodology in the Course "Bioprocesses Applied to the Environment"

María-Amparo Bes-Piá, José-Antonio Mendoza-Roca *, Eva Ferrer-Polonio, Alicia Iborra-Clar, Elena Zuriaga-Agustí and María-José Luján-Facundo

Departamento de Ingeniería Química y Nuclear, Universitat Politècnica de València, 46022 Valencia, Spain; mbespia@iqn.upv.es (M.-A.B.-P.); evferpo@posgrado.upv.es (E.F.-P.); aiborra@iqn.upv.es (A.I.-C.); elzuag@etsii.upv.es (E.Z.-A.); malufa@etsii.upv.es (M.-J.L.-F.)
* Correspondence: jamendoz@iqn.upv.es

Abstract: This paper explains the steps carried out for the design of an educational innovation and the outcomes of its implementation. The innovation consists of integrating the contents of two courses ('biological wastewater treatment' and 'bioprocesses applied to the treatment of wastes') for the same academic year using project-based learning methodology to connect knowledge between subjects and to utilize transversal competences. Students from the second year of a chemical engineering master's degree worked on an open-ended project based on a current environmental problem. This methodology lets the students properly acquire several transversal competences, such as 'Design and project', 'Teamwork and leadership', and 'Effective communication', which were evaluated with rubrics. However, according to the students' perception, other skills, such as 'Comprehension and integration, analysis and problem solving', 'Knowledge of contemporary problems', and 'Planning and time management', were also worked on and improved. Based on the results from the matrix analysis and the Likert questionnaire, the organization and development of the activity were positively assessed, highlighting the importance of the lecturers' feedback. The learning outcome in terms of knowledge integration was accomplished, reaching project marks 8.5–10 on a 0–10 scale.

Keywords: project-based learning; environmental subject; engineering education; transversal competences; rubric assessment; integrated learning

Citation: Bes-Piá, M.-A.; Mendoza-Roca, J.-A.; Ferrer-Polonio, E.; Iborra-Clar, A.; Zuriaga-Agustí, E.; Luján-Facundo, M.-J. Integration of Project-Based Learning (PjBL) Methodology in the Course "Bioprocesses Applied to the Environment". *Educ. Sci.* **2023**, *13*, 570. https://doi.org/10.3390/educsci13060570

Academic Editor: Kyriacos Athanasiou

Received: 31 March 2023
Revised: 18 May 2023
Accepted: 23 May 2023
Published: 2 June 2023

1. Introduction

The entry of Spain into the European Higher Education Area (EHEA) and Bologna Process led to a change in the structure of Spanish University degrees. Thus, the five-year chemical engineering degree was divided into a four-year bachelor's degree and a master's degree, whose duration may range between 72 and 120 ECTS [1]. ECTS is an acronym for European Credit Transfer and Accumulation System, being a tool in Europe to measure the workload of the courses (1 ECTS implies between 25 and 30 h of workload for students).

At Universitat Politècnica de València (UPV), Spain, the chemical engineering master's degree started in the 2014–2015 academic year. The number of ECTS to finish the degree is 120 ECTS (two academic years). In the first academic year, students are registered in the compulsory courses whose student outcomes are those that appear in the Spanish guidelines for a master's degree in chemical engineering. In the second academic year, students can choose different elective courses according to the program curriculum [2].

These elective courses are grouped in such a way that students have to register in all the courses of the selected groups. In Spain, courses within the same group are typically treated independently, with separated lectures and assessments for each course. This separation of courses can lead to students having difficulties connecting knowledge between them and avoiding complex problem solving. Integrated learning of the subjects will improve the ability of the students to face the jobs market since job positions entail more integrated tasks.

To carry out the above-mentioned integration of knowledge, project-based learning (PjBL) is proposed. PjBL is an instructional method, in which students undertake teamwork and develop projects based on real-life situations. The role of the teachers is enhancing knowledge construction through real-world projects [3,4]. Its objectives are the integration of skills and abilities, the enhancement of skills, and promoting learning. The PjBL concept has been promoted since the end of the 1960s at the medical school of McMaster University in Canada [5]. In the last three decades, PjBL has been described by some authors [6], gaining great importance in the last few years, when education shifted from teaching-oriented to student-centered.

Some studies in the field of the application and assessment of collaborative work at all educational levels confirm the positive effect of this methodology on the learning process [7,8].

Focusing on the field of chemical engineering, studies about the application of PjBL also reported an improvement in the learning process [9–11] and the consequent accomplishment of the employer's needs [12]. San Valero et al. [13] used PjBL to improve the written, graphical verbal, and non-verbal communication of chemical engineering students.

Related to courses' integration in chemical engineering, Ballesteros et al. [14] proposed to apply PjBL to *unit operations* and *modeling and simulation* courses using a joint course project. The project consisted of designing, assembling, and characterizing a pump, including modeling and experimental tests. Burkholder et al. [15] proposed PjBL, integrating the learning outcomes of courses for the first academic year in a chemical engineering degree.

As mentioned above, some general skills are acquired by the students through PjBL. Universitat Politècnica de València elaborated a list of transversal competences (TCs) that have to be monitored through its programs (Table 1).

Table 1. Transversal competences from UPV.

TC	Description
TC-01	Comprehension and integration
TC-02	Application and practical thinking
TC-03	Analysis and problem solving
TC-04	Innovation, creativity, and entrepreneurship
TC-05	Design and project
TC-06	Teamwork and leadership
TC-07	Ethical, environmental, and professional responsibility
TC-08	Effective communication
TC-09	Critical thinking
TC-10	Knowledge of contemporary problems
TC-11	Permanent learning
TC-12	Planning and time management
TC-13	Specific instrumental

In general, the crosscutting concepts between courses and the collaboration between the employers and the lecturers are crucial to improve the insertion of students into the world of professional work [16]. In most degrees, courses are taught as isolated matters so that students avoid properly linking the contents. As a result, the understanding and the learning are not complete, making it difficult to face the present situations in industries or companies where a real comprehension of the subjects is entirely necessary. In this way, this paper tries to provide a helpful step forward using the PjBL methodology.

The primary goal of this work is to integrate parts of the content from two courses using the PjBL methodology, as the integration of concepts is essential for acquiring a comprehensive understanding of degree programs. Thus, the first research question (RQ1) is whether PjBL can be applied successfully to the acquisition of TCs with a methodology developed by the authors involving two different courses. Which competences have been acquired and the perception of the students about the applied PjBL (RQ2) are also important issues that are discussed in the next sections. This educational innovation aimed to improve

several skills, such as 'Effective Communication (written and spoken)', Design and Project', and 'Teamwork'. This paper also includes steps for the PjBL design, its implementation, and the outcomes achieved. At the same time, this work is a further step to supply more empirical evidence about the efficiency of PjBL, as suggested by a recent review article [17].

2. Materials and Methods

2.1. Contextualization

The following educational innovation involves a group of two courses from the environmental group of courses named 'Bioprocesses applied to the environment', taught in the second academic year of the chemical engineering master's at the Universitat Politècnica of València (Spain). Specifically, it involves the courses 'Bioprocesses applied to the treatment of wastes' and 'Biological wastewater treatment'. Normally, the enrolled students (those who are registered on the course) take both courses at the same time, in the first semester. Only incoming students (exchange students coming from other universities in Spain or abroad) can be enrolled in one of them. For the innovative design, we considered the maximum number of students enrolled in the last 3 academic years (average of 14). In addition, one of the lecturers involved in this project teaches both courses, which favors a necessary link between courses to allow for better development for this educational innovation.

'Bioprocesses applied to the treatment of wastes' is a course related to the management of waste mainly using biological treatments, such as biometanization or accelerated/fast composting processes, but also includes sorting waste treatment plants or landfill facilities. It has 4.5 ECTS, and the only class per week has a duration of 165 min. On the other hand, 'Biological wastewater treatment' is a course related to the management of urban and industrial wastewaters through aerobic and/or anaerobic biological treatments, including Sequencing Batch Reactors or Membrane Bioreactors. It has a load of 6 ECTS and two classes, one of 120 min and the other of 90 min, given each teaching week. In total, the innovation activity involved 1.7 ECTS of the 10.5 ECTS of both courses. These innovation activities are described in Section 2.2.2.

Although the educational innovation was designed for the above-mentioned master's degree, it is expected to be a guide that could be implemented in other degrees, independently of the branch of knowledge. Thus, this procedure could be taken as a reference for the PjBL implementation to different courses, preferably to courses of masters' degrees with less than 20 students. For successful implementation, it is crucial to coordinate the workload of the PjBL with the workload of other courses. In the following section, PjBL design is thoroughly explained through a series of stages.

2.2. PjBL Design

This section describes the different stages carried out for designing this educational innovation.

2.2.1. Preliminary Stage

Before designing the PjBL for a current environmental problem, lecturers from both courses met with three relevant professionals working in waste and wastewater management companies (a manager of a large wastewater treatment plant and two managers of municipal waste treatment plants). The meetings aimed to ask them mainly about the current topics or problems within these fields (waste and wastewater) and to choose the most required skills for workers from the TC list of UPV. The questions, which were answered by these experts in a template, are collected in Table 2. These questions were designed by the authors of this work.

Table 2. Interview questions for professionals working in waste and wastewater management companies.

Number	Question
1.	Which are the main problems in waste or wastewater management nowadays?
2.	What is the main waste or wastewater management knowledge required?
3.	Is there any direct relationship between waste/wastewater sectors in your company?
4.	If yes, are you looking for an individual solution or integrated ones?
5.	Which are the main TCs required? (*)
6.	Could you suggest a present problem in your sector to be worked on by the students?
7.	Would you be willing to collaborate further in giving feedback to the solutions proposed by the students?

(*) Selected from Table 1.

2.2.2. Educational Innovation Design

The educational innovation design includes the following items:

(a) Selection of a current environmental problem to work with PjBL

To carry out this item, the lecturers brainstormed, taking into consideration the meetings and responses to the questions carried out by professionals. A list of possible topics to work on was elaborated and one of them was chosen according to technical and environmental relevance and the available information so that students could develop the PjBL.

(b) Selection of the contents in both subjects

Once the topic was chosen, specific contents to be worked on in each course were selected. It was very important to keep a link between the contents of both courses so that the students could reach an overall vision of the problem and could find a proper solution to it.

(c) Elaboration of a Detailed Statement

Next, the statement of the environmental problem selected was developed. In it, all the required aspects to be worked on were clearly indicated (i.e., extension of the final report). It is worth mentioning that the statement must be open-ended, allowing one to obtain different solutions. Thus, the statement does not select processes, operation conditions, etc.

(d) Student support material

Additionally, lecturers from both courses prepared some sources and support material. The aim of providing this information was to give the students some specific sources as starting points to work on the proposed project.

This material was uploaded to the PoliformaT platform. PoliformaT is an educational platform that is widely used by lecturers and students at UPV. Each course has its own space for managing contents, tasks, tests, and exams. In addition, allows for communication between students and lecturers via chat or Teams meetings. The support material mainly consisted of articles explaining waste and wastewater treatment facilities with technical information about the operation processes.

Figure 1 displays, as an example, a view of the PoliformaT platform for the course 'Bioprocesses applied to the treatment of wastes'. Specifically, it shows a screenshot of the main folder, denominated "Integrated design" created for this activity. It contained the previously mentioned attached files, which are indicated in the figure: Detailed Statement, Student's Guide, Student support material, and assessment Rubrics (explained in e).

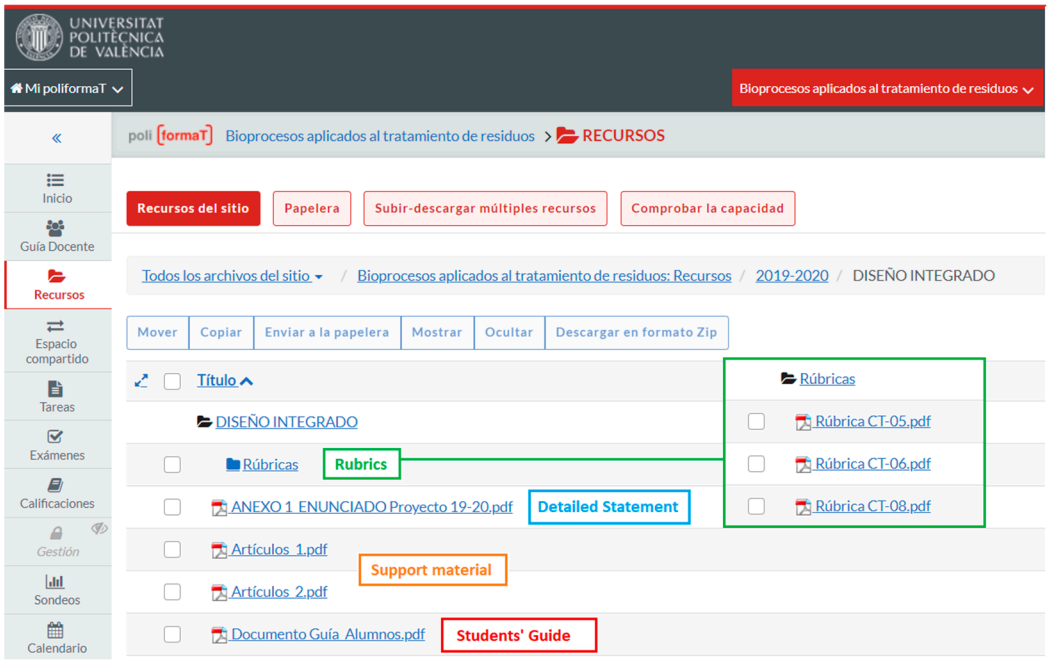

Figure 1. PoliformaT platform screenshot showing the attached files for the activity ('Bioprocesses applied to the treatment of wastes' subject).

(e) Elaboration of the Student's Guide

Lecturers prepared an activity guide for the students to facilitate the understanding and development of this activity. This guide includes: (c.1) the statement of the project to work; (c.2) aims of the work, including the learning outcomes; (c.3) tasks to perform, including also the 'Activities Schedule' and the 'Activity Assessment' plan.

Related to 'Activities Schedule', Table 3 collects the timing of the activities, which were performed during semester A, which begins in September and finishes in December. As can be observed, the activity was developed during the twelve teaching weeks of the semester. The activities shown in the schedule were carried out in the classroom. This is represented by green and blue squares for classes of 'Bioprocesses applied to the treatment of wastes' and 'Biological wastewater treatment', respectively.

Table 3. Activities schedule for the educational innovation.

	Semester A (Week)												
Activity (Face-to-Face Class)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Deliverable**
PBL presentation		■											
Working session				■									1
Working session							■						2
Working session								■					
Working session										■			3
Oral presentation + discussion (project)												■	Final report
Activity assessment												■	DAFO, Likert

■ Bioprocesses applied to the treatment of wastes'; ■ 'Biological treatment for wastewaters'.

The schedule starts with the project presentation. In this session, the Detailed Statement, the Student' Guide, and the material prepared by the lecturers were explained to the students. Since PjBL requires cooperative work, students were divided into groups of three or four people according to their preferences. Working in groups is key because it improves motivation, promotes deeper learning and critical thinking, or enhances the

ability to find information, among other skills. In addition, it encourages sharing ideas and knowledge [18].

Next, four face-to-face working sessions were scheduled. Students had to develop the solution for the environmental problem by managing the information collected from different sources (classroom notes, technical articles, web pages, technical rules, and legislation, etc.). In these sessions, lecturers helped students with guidance and supervision tasks. In addition, students were encouraged to attend face-to-face or online tutorials when it was necessary. It must be said that, apart from these sessions, the contents of the courses were taught each week according to the class's calendar, i.e., theory and practical classes or laboratory practices. In these face-to-face classes, apart from traditional participative teaching, several learning-by-doing methodologies, such as problems and answering 'open-close' questions, were also used. The use of these methodologies together with the PjBL in both subjects aimed to motivate the students and to promote deep learning.

The last two sessions were carried out in the last week of the semester. One of these sessions was dedicated to delivering the final written reports and presenting them orally. The oral presentation had a duration of 20 min. The students showed the designed solution to the rest of the groups and lecturers. Normally, the presentations are shown as PowerPoint files. After the presentation, lecturers randomly asked students some questions concerning the justification of the designed solution. Even a short debate could be established with the rest of the groups when a comparison between solutions was made.

In the last session, the students and lecturers carried out an 'Activity Assessment'. The 'Activity Assessment' covered two dimensions: on the one hand, the evaluation of the work carried out by the students (1) and, on the other hand, the evaluation of the educational innovation design (2).

Assessment Dimension (1) entails the evaluation of the final report, project defense, and teamwork. Through each piece of evidence, the TCs related to 'Design and project', 'Teamwork and leadership', and 'Effective communication' were assessed. According to the UPV list, these are TC-05, TC-06, and TC-08, respectively. These TCs were selected according to the answers of the professionals to question 5 in Table 2. An interesting work carried out by Passow [19] reported that graduates of all engineering disciplines considered teamwork, communication, data analysis, and problem-solving skills to be highly important in their professional experience, which supports our TC selection to be assessed. For the particular case of 'Teamwork', one concern in PjBL is the rating method since the students in the same group may not have the same motivation or expectations. In this way, Aranzábal et al. [20] proposed the use of monitoring questionnaires for the individual accountability of the students in the same team. It has to be highlighted that all the educational innovations should be developed together with the appropriate tools for the assessment of student outcomes [21].

For evaluating the TCs, rubric was chosen as the assessment method. Rubrics are frequently referenced in the literature about learning assessment and are widely applied, as Panadero et al. [22] reported in a review about the use of rubrics for assessment. According to this work, "rubrics improve student performance such as increasing transparency, reducing anxiety, aiding the feedback process, improving student self-efficacy, or supporting student self-regulation".

Tables A1–A3 (see Appendices A–C) show the evaluation rubrics created by the lecturers. For their creation, lecturers took the models provided by the UPV and other sources as references [23–25]. In all rubrics, the rating scale is divided into three performance levels and includes an evidence section, as recommended by UPV. These rubrics were used to assess the students in groups.

These assessment rubrics were uploaded to the PoliformaT platform from the start of the course. In this way, students knew the skills evaluation criteria from the beginning.

Assessment Dimension (2) entails the evaluation of the educational innovation design. For it, two evaluation methods, one qualitative and one quantitative, were selected (a SWOT analysis matrix and a questionnaire, respectively).

SWOT analysis collected, in a matrix, the analysis assessments of the students, considering internal (strengths and weaknesses) and external (opportunities and threats) factors. The questionnaire was based on a Likert scale, and students were asked to assess each question on an agreement scale that ranges from (1), which means 'completely disagree', to (5), 'completely agree'. A mean value from the collected data of each question was calculated to perform the Likert analysis, and these data (mean values and standard deviation values) were represented in bar graphs. Table A4 (see Appendix D) collects the elaborated questionnaire for the educational innovation assessment. It consists of 22 questions, referred to as Q1–Q22, that are grouped into five aspects related to activity organization and development, learning process, TCs acquired, and evaluation assessment.

2.2.3. Implementation

The implementation of this educational innovation was developed according to the Activity Schedule. During this period, the lecturers acted as supervisors. They never gave solutions or data. The assessment results achieved are commented on in the next section.

The weights of this innovation activity in the global mark of the courses were 30% and 25% for 'Bioprocesses applied to the treatment of wastes' and 'Biological wastewater treatment', respectively. It is expected that this percentage will encourage students to achieve the aimed outcomes, which will be measured through the obtained grade. The evaluation of the activity was carried out as follows: final report (45%), oral presentation and discussion (45%), and teamwork (10%). These parts were assessed with the rubrics TC-05, TC-6, and TC-08. Other assessment methods, such as a final exam and laboratory practices reports, were also considered in the final mark of both courses.

3. Results and Discussion

The implementation results of this innovation are presented in the following subsections.

3.1. Assessment Dimension 1: Evaluation of the Work Carried out by the Students

Tables 4–6 collect the results achieved by the groups in the assessment rubrics.

Table 4. Evaluation results for 'Design and project' (TC-05) rubric.

Criteria	C. under Development	B. Good	A. Excellent
Develop a project based on real data and with references well documented	0%	9%	91%
Consider technical aspects	0%	0%	100%
Consider environmental aspects	0%	0%	100%
Consider economic aspects	0%	27%	73%

Table 5. Evaluation results for 'Teamwork and leadership' (TC-06) rubric.

Criteria	C. under Development	B. Good	A. Excellent
ICTs [1] use in co-working: Dropbox, WhatsApp, Teams, Skype, Doodle . . .	0%	0%	100%
Active collaboration: group organization, sharing info, interchange ideas, content selection . . .	0%	9%	91%
Delivery according to schedule	0%	100%	0%
Learning group atmosphere and group cohesion	0%	9%	91%
Conflict resolution (if case)	0%	0%	100%
Group roles	0%	0%	100%

[1] Information and communication technologies (ICTs).

Table 6. Evaluation results for 'Effective communication' (TC-08) rubric.

Criteria	C. under Development	B. Good	A. Excellent
Oral communication			
Non-verbal communication: gestures, posture, eye contact, facial expressions, etc.	0%	18%	82%
Verbal communication: proper vocabulary, rhythm, tone, clarity and conciseness	0%	9%	91%
About presentation content: well-structured, support material, subject mastery, keep the attention on the audience, etc.	0%	9%	91%
Discussion about the final report	0%	27%	73%
Written communication			
Structure and format of the project: index, titles, subtitles, references, etc.	0%	0%	100%
About project content: data, calculations, justifications, clarity, conciseness, proper vocabulary, written expressions, orthography	0%	27%	73%

3.1.1. 'Design and Project' Assessment

Firstly, it must be expressed that most of the students showed excellent design and project skills. According to the specific criteria for TC-05, students accomplished what was expected very well. In fact, remarkable scores (between 73 and 100%) for all criteria were achieved, as shown in Table 4 Based on the results described on the assessment dimension 2 (Section 3.2) and on the observation, there were several factors that led to these results: rubrics containing the concrete descriptors for each level of performance, the activity Students' Guide, lecturers' feedback and supervision, and the motivation that students showed during the activity. Only the economic aspects criterion was not taken into account by approximately one-quarter of the groups (27%).

3.1.2. 'Teamwork and Leadership' Assessment

Students developed excellent teamwork and leadership skills. In fact, nearly 100% of the groups achieved high scores concerning ICT use, group collaboration, group roles, cohesion, and lack of conflicts (Table 5). The fact that teams were formed by the students may explain that no conflicts were detected. Bani-Hani et al. [26] also reported that teams can perform better if the students are not randomly grouped by lecturers.

The criterion of work deliveries according to schedule was not performed well. Only the final report could be handed in by the due date by 100% of the groups. The problem of heavy workload and the timing have been mentioned in articles [27–30], which made it necessary to check this issue. In this way, Herrero-de Lucas et al. [31] proposed a procedure for determining the student's PjBL workload by comparing the number of hours declared by the students and the ones proposed by the syllabus. In our work, students were asked to write down the number of hours devoted to the project during non-face-to-face classes (see Q5, Table A4). As a result of this, a range of 10–15 h was reported by the groups, being considered appropriate by the lecturers. Consequently, the reason for not completely accomplishing the schedule could not be attributed to the workload caused by the PjBL but to the other projects that students perform in the frame of other courses of the same academic year.

3.1.3. 'Effective Communication' Assessment

Related to effective communication competence, in general, students also showed outstanding written and oral communication skills (Table 6). Around 73% and 100% of

the students achieved excellent results for the different criteria. However, although the non-verbal communication score was also very high, about 20% of the students should improve some items, such as eye contact or posture.

It is worth mentioning that all groups achieved the maximum mark in the criteria concerning the structure and format of the project: index, titles, subtitles, references, etc. The reason supporting these results is that students, from the first year of the bachelor of chemical engineering, write reports, mainly on laboratory practices. This result highlights the importance of developing TCs via active learning methodologies for different activities through all academic years [32,33].

3.1.4. Numbered Marks

In order to transform A, B, and C performance levels into numbered marks, the following mark ranges were established between 0 and 10 points: A (10–8.5), B (8.5–6), and C (<6). For each group, the final project mark (involving final report, oral presentation, discussion, and team group) was calculated considering a mark for each indicator in the three rubrics, as shown in Equation (1). Note that the mark for rubric TC-08 was divided into two (oral presentation + discussion) because the weight of the indicator related to the discussion of the project was 20%.

$$\begin{aligned} \textit{Project mark} \; = & 0.45 \times \left(\frac{\sum_{i=1}^{4} \textit{indicator mark}}{i} \right)_{TC-05} \\ & + 0.10 \times \left(\frac{\sum_{j=1}^{6} \textit{indicator mark}}{j} \right)_{TC-06} \\ & + \left(0.25 \times \left(\frac{\sum_{j=1}^{5} \textit{indicator mark}}{k} \right)_{TC-08} \right. \\ & \left. + 0.20 \times \left(\textit{indicator mark}_{discussion} \right)_{TC-08} \right) \end{aligned} \quad (1)$$

Finally, Table 7 shows the average final project mark for all groups and the standard deviation. As can be seen, the average mark obtained by the students was very high, which confirms that the PjBL methodology is an appropriate tool for achieving integrated learning.

Table 7. Average score for the activity and standard deviation.

Min–Max Score	Average Score + SD for All Groups
8.5–10	9.25 ± 0.58

3.2. Assessment Dimension 2: Evaluation of the Educational Innovation Design

This section collects the results from the evaluation of the educational innovation design from the Likert questionnaire and a SWOT analysis matrix. In both cases, students were asked anonymously.

3.2.1. Likert Analysis

Figure 2 collects the main points of the three first items from the survey (Table A4), corresponding to questions Q1–Q11.

Concerning activity organization (Q1–Q3), students widely agreed that, in general terms, it was well organized, as the main point for the 4.3/5 Likert scale for Q1 reflects. In addition, students considered that the material supplied by the lecturers was quite useful, despite some students' discrepancies. The standard deviation (see Figure 2) showed that some students would prefer having this support material, probably as a starting point.

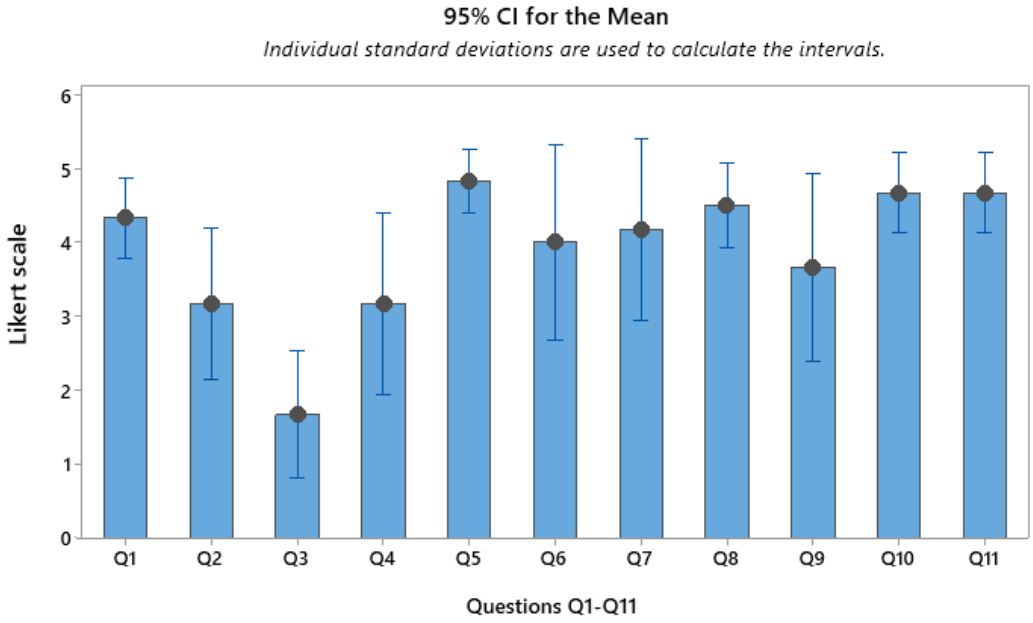

Figure 2. Results of questions Q1–Q11 of the questionnaire concerning activity organization and activity development.

In addition, students prefer guided projects rather than projects without tutorial feedback, which means that students supported the role carried out by lectures. It consisted of guiding the project following some of the issues recommended by Chan [32]. Lecturers strove to promote discussion and students' independence, minimizing their intervention during the project.

Related to activity development results (Q4–Q9), about 50% of students were also in favor of increasing the number of working sessions since they prefer working as part of the class timetable together with the other members of the group and lecturers. In addition, students clearly pointed out that part of the work had been developed out of class (lecturers had considered a maximum of 20 h outside class activities). As previously mentioned, the number of working hours out of the class ranged between 10 and 15, which was considered appropriate by lecturers. Further, students assessed working in groups as positive (4/5 Likert scale), and no dropout was registered. Students also agreed with showing and defending the work carried out, although the standard deviation values indicated that some students would prefer avoiding it (see Figure 2). It worth mentioning that main points achieved for Q7 (4.2/5) and Q8 (4.5/5) reinforcing tutorial and guide action carried out by the lecturers.

With reference to the learning process achieved (Q10–Q11), the score selected by the students was very satisfactory. More than 90% of the students completely agreed that working on a current environmental problem with the PjBL methodology let them learn and properly integrate both subjects. This issue is paramount since there are several factors affecting the effectiveness of PjBL implementation and one of these is to find actual problems that engage students [29]. This is the reason why, in this work, a step consisting of interviewing several relevant professionals suggesting topics for the PjBL was crucial.

Figure 3 shows the main points for the two last aspects from the survey (Table A4), corresponding to Q12–Q22.

Regarding TC acquisition (Q12–Q15), students clearly recognized that the activity let them work and improve several TCs. In addition to design and project (TC-05), teamwork and leadership (TC-06), and effective communication (TC-08), other TCs were improved at the same time, as can be seen in Figure 4. According to the students' perception, half of the students considered that the skill comprehension and integration (TC-01) was also acquired. Analysis and problem solving (TC-03), knowledge of contemporary problems

(TC-10), and planning and time management (TC-12) were selected by 33% of the students, and application and practical thinking (TC-02), ethical, environmental, and professional responsibility (TC-07), and critical thinking (TC-09) by 17% of students. As a result, it can be stated that the PjBL methodology is a powerful methodological tool since it allows for working on and improving a great number of TCs.

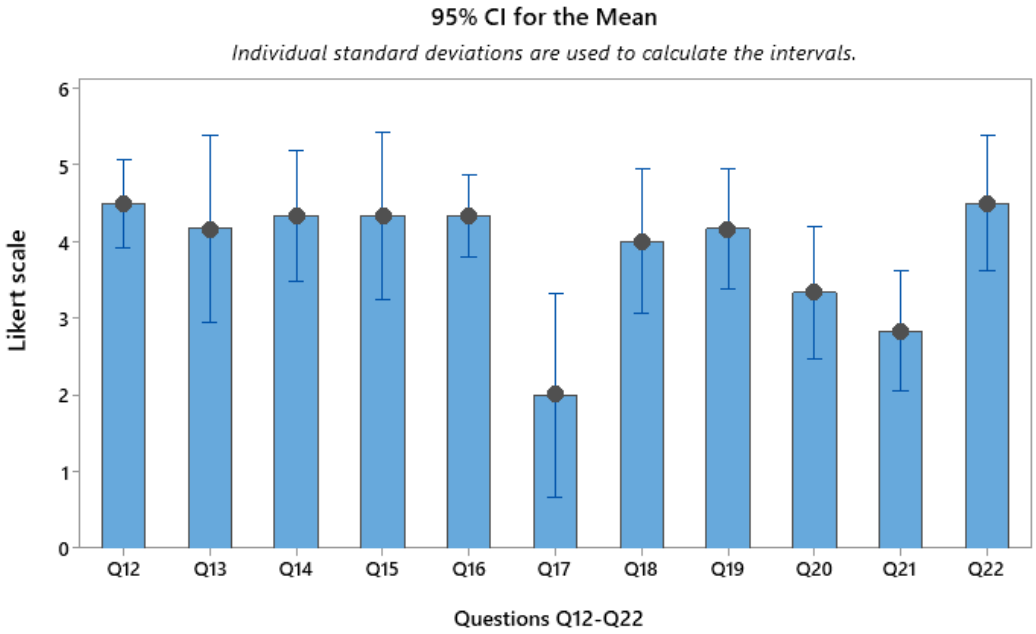

Figure 3. Results of the questions Q12–Q22 of the questionnaire concerning TC acquisition and activity assessment.

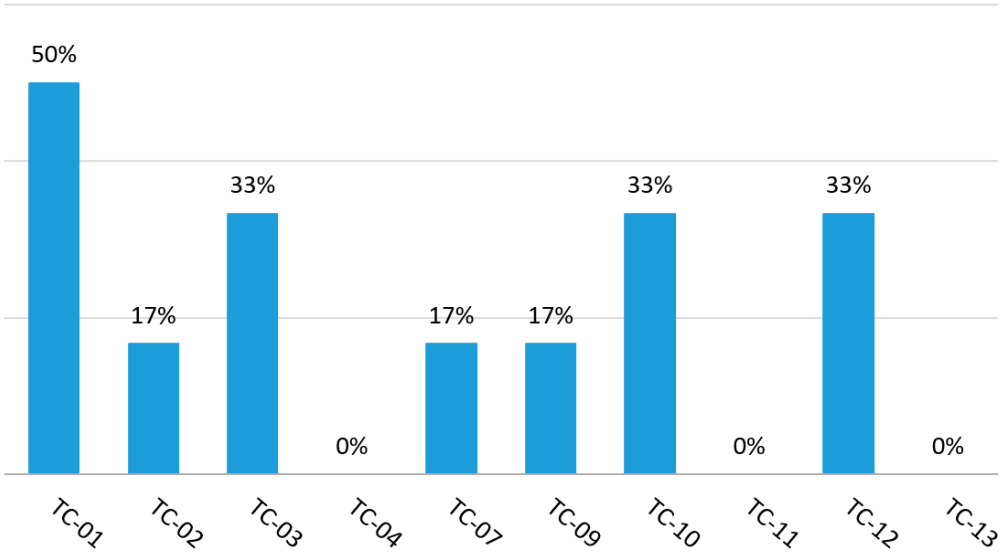

Figure 4. Number of students (%) considering the acquisition of other TCs.

Concerning the 'activity assessment' aspect of the questionnaire (Q16–Q22), it can be stated that students highly approved (4.3/5 Likert scale) of the weight of the activity in the global mark in both courses (Q16), but some students considered that it should be higher (Q17). This was the reason why the standard deviation value in Q17 was higher than in the rest of the questions (see Figure 2). In the same way, students highly approved of having the assessment rubrics from the beginning of the project (Q19), since rubrics collect and detail what is expected for the project. These results reinforce the importance of using assessment tools in PjBL, as

suggested by some authors [29,30]. In addition, the results showed that the PjBL methodology is gaining ground since some students positively agree to extend this methodology to other topics from both courses (Q21). However, referring to this, lecturers agree with other authors that it is better to mix several active learning methodologies, since this makes students more alert, motivated, and highly participative [34]. On the contrary, it could overload students considering the number of additional hours required during the activity.

On the other hand, students consider that self-assessment (Q18) (4.0/5 Likert scale) and peer review (Q20) (3.3/5 Likert scale) could be important assessment tools to implement in PjBL methodologies. Therefore, these kinds of evaluation should be taken into consideration in Assessment Dimension 1. However, some authors doubt the effectiveness of these tools and state that students with a lack of motivation could negatively interfere in the assessment process [35,36]. In this way, the authors share the statement pointed out by Yuan et al. [37] regarding the idea that the impact of the self-assessment mainly depends on the effectiveness of the self-assessment feedback. Finally, students highly supported (4.5/5) that lecturers ask them their opinions about the activity (Q22), since students perform a crucial role in the learning process and their opinions are required.

3.2.2. SWOT Analysis

Table 8 shows the SWOT analysis matrix and includes a summary of the responses written by the students in the four factors: internal strengths, internal weaknesses, external opportunities, and external threats.

Table 8. Summary of students' answers for SWOT.

Strengths	Weaknesses
"We have integrated concepts from both courses, and we have achieved real learning." *"Good work in groups and organization."* *"We improved some transversal competences and acquired others."* *"Good information searching skills."*	*"Lack of knowledge in some concepts of theory, required for developing the project."* *"Lack of time management."* *"Sometimes there was a lack of communication between the members of the group."* *"Finding some specific data was difficult at the beginning. We spent quite a lot of time surfing on databases."*
Opportunities	**Threats**
"This activity was motivating because we faced with a present environmental problem." *"There is a common teacher in both courses who let us ask questions during the same working session."* *"Tutorial was key because we received instant feedback."* *"Working sessions let work properly in-group."*	*"Although we had in the Activity Schedule, the recommended dates for handing deliverables, it was very difficult to follow it, since we had loads and loads of duties, including studying and other works to do during the semester, especially at the end of it."* *"Some topics of the subjects should be taught previously in order to move along the final report."*

From the answers collected in the SWOT matrix (Table 8), the lecturers considered taking some actions for the next academic course. The changes would include the modification of the teaching timing for the topics involved in order to cope with "*Lack of knowledge in some concepts of theory, required for developing the project*." In this way, students would previously know the required concepts for developing the project. Further, the Activity Schedule should be revised to avoid an excessive working load due to the high number of projects in the frame of other course subjects at the end of the semester. It was considered of great importance to be taken into account for future iterations since it was a threat reported by the students (Table 8).

On the other hand, some comments, mainly the ones related to the strengths, such as '*we have integrated concepts from both courses, and we have achieved real learning*', encouraged the lecturers because they cover the achievement of the goals for this innovation activity. In addition, the comments included in the opportunities item agreed with the factors selected

by the lecturers to carry out this activity, i.e., selection of a current environmental problem, the number of working sessions, having a common teacher in both courses, and the tutorial guidance with feedback carried out during this educational innovation.

4. Conclusions

This paper details the steps carried out for the design and implementation of an educational innovation consisting of integrating the contents of two courses using the PjBL methodology. In addition, this educational innovation aimed to work on and improve several skills, such as 'Effective Communication (written and spoken)', Design and Project', and 'Teamwork'. These skills were selected by professionals who were interviewed in a preliminary stage of the developed PjBL methodology. The fact that professionals indicated which competences are required for the future graduates and the current problems to be solved in the wastewater and municipal waste fields enhanced the students' interest in the project. The results of the assessment of the transversal competences and the perception of the students about the PjBL have been reported and discussed.

The PjBL methodology lets students acquire several TCs, such as 'Design and project' (obtaining excellent scores between 73 and 100% of the students), 'Teamwork and leadership' (between 91% and 100% of the students achieved excellent levels in five of six criteria), and 'Effective communication' (between 73% and 100% of the students achieved excellent levels at the different criteria). These evaluations were carried out using rubrics (i.e., final report, oral presentation and discussion, and teamwork) and the aforementioned results lead to conclude that most of the students showed excellent TCs concerning communication, project, and teamwork, which were TCs required by the employers.

The SWOT analysis matrix and the Likert questionnaire were suitable tools for activity assessment and promoted students' self-reflection, which was expressed through their comments. In this way, the students proposed that teaching timing for some topics should be modified, and the Activity Schedule should be revised to avoid excessive work loads. The excessive workload could be a possible limitation for the application of the PjBL. Thus, coordination meetings with lecturers of the other subjects for the same academic year are essential for the success of the proposed PjBL. Concerning the Activity Schedule, minor variations should be performed so that students have all the theory needed for the PjBL activities.

Regarding TC acquisition, students clearly recognized that the activity let them work on and improve several TCs. However, the TCs "Innovation, creating and entrepreneurship" (TC-04) and "permanent learning" (TC-11) were not chosen by the students as acquired TCs. Concerning TC-04, students might consider that it is a skill for which they are not prepared and that requires a deeper knowledge of the involved topics. Concerning TC-11, the response of the students seems strange, since the chosen topics, suggested by the professionals, indicate that students have to be aware of permanent learning to be able to solve future challenges. It is possible that students do not fully understand the meaning of this TC since they might consider "permanent learning" after finishing a master's degree.

The results from the questionnaire showed that students highly agreed with the organization and development of the activity and with the learning process and skills achieved. Students regretted less-guided projects and agreed with tutorial feedback. In general, students strove to find a proper solution for the proposed environmental problem and showed strong motivation, as proved by the outstanding final project marks accomplished by the groups.

The PjBL methodology presented in this work could be applied in other chemical engineering courses, even in core courses, such as mass transfer, separation processes, or reaction engineering, though the higher number of students has to be taken into account. Application to other disciplines is also possible.

Finally, it has to be highlighted that the achieved outcomes show empirical evidence of the effectiveness of the PjBL methodology in terms of integration of concepts, deep learning, motivation, and TC acquisition in the field of chemical engineering.

Author Contributions: Conceptualization: J.-A.M.-R., E.F.-P. and M.-A.B.-P.; PBL design: all authors; results and analysis of Assessment Dimension 1: E.F.-P., A.I.-C. and M.-A.B.-P.; results and analysis of Assessment Dimension 2: J.-A.M.-R., E.Z.-A. and M.-A.B.-P.; writing and review: all authors. All authors have read and agreed to the published version of the manuscript.

Funding: This research was granted by Vice-Rectorate for Studies, Quality and Accreditation of the Universitat Politècnica de València through the program INNOVATION AND EDUCATIONAL IMPROVEMENT PROJECTS (Reference of the projects: PIME/18–19/Ref. 91 and PIME/19–20/Ref. 150/Ref. 151/Ref. 152).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Evaluation rubric for 'Design and project' (TC-05).

Criteria	C. under Development	B. Good	A. Excellent	Evidence
Develop a project based on real data and with references well documented	The project hardly contains real data nor references well-documented	The project contains proper real data but references are not well-documented	The project contains proper real data and references are well-documented	Deliverables Final report Oral exposition Project defence
Consider technical aspects	Only consider few technical aspects	Consider main technical aspects	Consider all or most of technical aspects	
Consider environmental aspects	Only consider few environmental aspects	Consider main environmental aspects	Consider most of environmental aspects	
Consider economic aspects	Only consider few economic aspects	Consider main economic aspects	Consider most of economic aspects	

Appendix B

Table A2. Evaluation rubric for 'Teamwork and leadership' (TC-06).

Criteria	C. under Development	B. Good	A. Excellent	Evidence
ICTs [1] use in co-working: Dropbox, WhatsApp, Teams, Skype, Doodle . . .	One ICT is occasionally used	Two ICTs are frequently used	Several ICTs are usually used	Questions Observation assessment
Active collaboration: group organization, share info, interchange ideas, content selection . . .	Rarely collaboration between members of the group	Often collaboration between members of the group	Total collaboration between members of the group	
Delivery according to schedule	Not achieved, neither the final report nor the deliverables	Partially achieved with deliverables or final report	Achieved with deliverables and final report	
Learning group atmosphere and group cohesion	The members of the group divide the tasks of the project and freelance. But members share info	Some parts of the project are divided and worked in pairs. Besides, members share info	All members of the group work together each part of the project	
Conflict resolution (if case)	The members of the group willing deal with conflicts but don't overcome entirely	Some members of the group deal with conflicts and solve them	All members of the group deal with conflicts and solve them	
Group roles (coordinator, speaker, environment)	The roles of the group members are not assigned	The roles of the group members are assigned but partially assumed	The roles of the group members are assigned and assumed	

[1] Information and communication technologies (ICTs).

Appendix C

Table A3. Evaluation rubrics for 'Effective communication' (TC-08).

Criteria	C. under Development	B. Good	A. Excellent	Evidence
Oral communication				
Non-verbal communication: gestures, posture, eye contact, facial expressions, etc.	Scarcely use of no-verbal communication items (one or two)	Good use of no-verbal communication items (three or four)	Excellent use of no-verbal communication items	Observation assessment Oral Presentation and discussion
Verbal communication: proper vocabulary, rhythm, tone, clarity, and conciseness	Poor use of verbal communication items (one or two)	Good use of verbal communication items (three or four)	Excellent use of verbal communication items	
About the presentation: content structure, support material, subject mastery, keeping the attention on the audience, etc.	Presentation is hard to follow mainly due to the content structure, lack of support material and subject mastery	Presentation is easy to follow mainly due to the content structure and support material, but sometimes lack of subject mastery is observed	The presentation is well-structured and keeps the attention on the audience due to the support material, subject mastery, etc.	
Discussion of the final report	Students show poor understanding of the project and some of the questions are not well-answered	Students show a good understanding of the project and the most questions are properly well-answered	Students show an excellent understanding of the project, and the questions are perfectly well-answered	
Written communication				
Structure and format of the project: index, titles, subtitles, references, etc.	Project is poorly structured with lack of some required items	Good structure and format of the project containing most of the required items	Excellent structure and format of the project containing all the required items	Final report
About project content: data, calculations, justifications, clarity, conciseness, proper vocabulary, written expressions, orthography	Project lacks some required items (data, calculations, justifications) and mistakes are frequently. In addition, there are some written mistakes (vocabulary, orthography, etc.)	Project contains most of the required items with some mistakes (data, calculations, justifications) but it is quite clearly written (vocabulary, orthography, etc.)	Project contains the required items without mistakes (data, calculations, justifications) and it is clearly written (vocabulary, orthography, etc.)	

Appendix D

Table A4. Likert questionnaire for the educational innovation assessment.

	Questions	1	2	3	4	5
	Activity organization					
Q1	The activity is well-organized					
Q2	The supporting material by lecturers is key					
Q3	I prefer less guided projects					

Table A4. *Cont.*

	Questions	1	2	3	4	5
	Activity development					
Q4	The number of working sessions in class is proper					
Q5	Extra time out of class was required to develop the project (please write down approximately the number of hours)					
Q6	Team working favors project development					
Q7	The Activities Schedule is useful					
Q8	Tutoring is necessary					
Q9	I like to expose and defend my work					
	Learning process					
Q10	The activity let me improve my knowledge in both subjects					
Q11	The activity let me integrate the knowledge in both subjects					
	Transversal competences					
Q12	The activity let me work and acquire the TC-05 'Design and project'					
Q13	The activity let me work and acquire the TC-06 'Teamwork and leadership'					
Q14	The activity let me work and acquire the TC-08 'Effective communication'					
Q15	The activity let me work and acquire other TC (chose from UPV list *)					
	Evaluation assessment					
Q16	The activity weight % in the global mark is proper					
Q17	The activity weight % in the global mark should be higher					
Q18	The self-assessment should be included					
Q19	Assessment rubrics help me during the project elaboration					
Q20	Peer review should be included					
Q21	I would like to work more contents of the subjects with PjBL					
Q22	I like the teachers to ask me about the PjBL activity opinion					

* Shown in Table 1.

References

1. Feijoo, G.; Ibañez, R.; Herguido, J.; Partal, P.; Tobajas, M.; Sempere, J.; Lopez-Perez, M.F.; Rivero, M.J. Education of chemical engineering in Spain: A global picture. *Educ. Chem. Eng.* **2018**, *24*, 27–31. [CrossRef]
2. UPV (Universitat Politècnica de València). Available online: https://www.upv.es/titulaciones/MUIQ/indexi.html (accessed on 4 March 2022).
3. Brundiers, K.; Wiek, A. Do we teach what we preach? An international comparison of problem- and project-based learning courses in sustainability. *Sustainability* **2013**, *5*, 1725–1746. [CrossRef]
4. Krajcik, J.S.; Shin, N. Project-based learning. In *The Cambridge Handbook of the Learning Sciences*, 2nd ed.; Sawyer, R.K., Ed.; Cambridge University Press: Cambridge, UK, 2014; pp. 275–297. [CrossRef]
5. De Graaff, E.; Kolmos, A. History of problem-based and project-based learning. In *Management of Change Implementation of Problem-Based and Project-Based Learning in Engineering*, 1st ed.; De Graaff, E., Kolmos, A., Eds.; Sense Publishers: Rotterdam, The Netherlands, 2007; pp. 1–8.
6. Blumenfeld, P.C.; Soloway, E.; Marx, R.W.; Krajcik, J.S.; Guzdial, M.; Palincsar, A. Motivating project-based learning: Sustaining the doing, supporting the learning. *Educ. Psychol.* **1991**, *26*, 369–398. [CrossRef]
7. Ralph, R.A. Post secondary project-based learning in science, technology, engineering and mathematics. *J. Technol. Sci. Educ.* **2015**, *6*, 26–35. [CrossRef]
8. Reis, A.C.B.; Barbalho, S.C.M.; Zanette, A.C.D. A bibliometric and classification study of Project-based Learning in Engineering Education. *Production* **2017**, *27*, e20162258. [CrossRef]

9. Fung, K.Y.; Ng, K.M. Teaching chemical product design using design projects. *Educ. Chem. Eng.* **2018**, *24*, 13–26. [CrossRef]
10. Azizana, M.T.; Mellon, N.; Ramli, R.M.; Yusup, S. Improving teamwork skills and enhancing deep learning via development of board game using cooperative learning method in Reaction Engineering course. *Educ. Chem. Eng.* **2018**, *22*, 1–13. [CrossRef]
11. Yang, Y.; Zhang, Y.; Xiong, X.; Zhang, W.; Chen, W.; Shipping, G. From Lab Scale to Mass Production: A Project-Based Learning on the Preparation of (S)-Epichlorohydrin for Enhancing College Student Engineering Practical Abilities. *J. Chem. Res.* **2021**, *98*, 3804–3812. [CrossRef]
12. Fletcher, A.J.; Harrington, R.W. Upskilling student engineers: The role of design in meeting employers' needs. *Educ. Chem. Eng.* **2018**, *24*, 32–42. [CrossRef]
13. San-Valero, P.; Robles, A.; Ruano, M.V.; Martí, N.; Cháfer, A.; Badia, J.D. Workshops of innovation in chemical engineering to train communication skills in science and technology. *Educ. Chem. Eng.* **2019**, *26*, 114–121. [CrossRef]
14. Ballesteros, M.A.; Daza, M.A.; Valdés, J.P.; Ratkovich, N.; Reyes, L.H. Applying PBL methodologies to the chemical engineering courses: Unit operations and modelling and simulation, using a joint course project. *Educ. Chem. Eng.* **2019**, *27*, 35–42. [CrossRef]
15. Ruslan, M.S.H.; Bilad, M.R.; Noh, M.H.; Sufian, S. Integrated project-based learning (IPBL) implementation for first year chemical engineering student: DIY hydraulic jack project. *Educ. Chem. Eng.* **2021**, *35*, 54–62. [CrossRef]
16. Alshehr, A.; Gutub, S.A.; Ebrahim, M.A.B.; Shafeek, H.; Soliman, M.F.; Adel-Aziz, M.H. Integration between industry and university: Case study, Faculty of Engineering at Rabigh, Saudi Arabia. *Educ. Chem. Eng.* **2016**, *14*, 24–34. [CrossRef]
17. Chen, J.; Kolmos, A.; Du, X. Forms of implementation and challenges of PBL in engineering education: A review of literature. *Eur. J. Eng. Educ.* **2021**, *46*, 90–115. [CrossRef]
18. Reza Rajabzadeh, A.; Long, J.; Saini, G.; Zeadin, M. Engineering Student Experiences of Group Work. *Ed. Sci.* **2022**, *12*, 288. [CrossRef]
19. Passow, H.J. Which ABET Competencies Do Engineering Graduates Find Most Important in their Work? *J. Eng. Educ.* **2012**, *101*, 95–118. [CrossRef]
20. Aranzabal, A.; Epelde, E.; Artetxe, M. Monitoring questionnaires to ensure positive interdependence and individual accountability in a chemical process synthesis following collaborative PBL approach. *Educ. Chem. Eng.* **2019**, *26*, 58–66. [CrossRef]
21. Miguel, C.V.; Moreira, C.; Alves, M.A.; Campos, J.B.L.M.; Glassey, J.; Schaer, E.; Kockmann, N.; PorjazoskaKujundziski, A.; Polakovic, M.; Madeira, L.M. Developing a framework for assessing teaching effectiveness in higher education. *Educ. Chem. Eng.* **2019**, *29*, 21–28. [CrossRef]
22. Panadero, E.; Jonsson, A. The use of scoring rubrics for formative assessment purposes revisited: A review. *Educ. Res. Rev.* **2013**, *9*, 129–144. [CrossRef]
23. París-Mañas, G.; Mas Torelló, O.; Torrelles Nadal, C. La evaluación de la competencia "trabajo en equipo" de los estudiantes universitarios. *Rev. D'innovació Docent Univ.* **2016**, *8*, 86–97. [CrossRef]
24. Halfhill, T.R.; Nielsen, T.M. Quantifying the "Softer Side" of Management Education: An Example Using Teamwork Competencies. *J. Manag. Educ.* **2017**, *31*, 64–80. [CrossRef]
25. Villa, A.; Poblete, M. *Aprendizaje Basado en Competencias. Una Propuesta para la Evaluación de las Competencias Genéricas*; Universidad de Deusto: Bilbao, Spain, 2007; ISBN 978-84-271-2833-0. Depósito Legal: BI-388-07. Available online: https://www.itson.mx/oferta/lcef/Documents/LIBRO_AprendizajeBasadoCompetencias.pdf (accessed on 1 March 2021).
26. Bani-Hani, E.; Al Shalabi, A.; Alkhatib, F.; Eilaghi, A.; Sedaghat, A. Factors Affecting the Team Formation and Work in Project-Based Learning (PBL) for Multidisciplinary Engineering Subjects. *J. Probl. Based Learn. Higher Edu.* **2019**, *6*, 136–143. [CrossRef]
27. Lutsenko, G. Case study of a problem-based learning course of project management for senior engineering students. *Eur. J. Eng. Educ.* **2018**, *43*, 895–910. [CrossRef]
28. Ruiz-Gallardo, J.R.; González-Geraldo, J.L.; Castaño, S. What are our students doing? Workload, time allocation and time management in PBL instruction. A case study in Science Education. *Teach. Teach. Educ.* **2016**, *53*, 51–62. [CrossRef]
29. Chan, C.K.Y. Facilitators' perspectives of the factors that affect the effectiveness of problem-based learning process. *Innov. Educ. Teach. Int.* **2016**, *53*, 25–34. [CrossRef]
30. Hu, J.; Ortiz, A.M.; Sriraman, V. Course Implementing PBL in a Concrete Construction Course. In Proceedings of the 2014 ASEE Annual Conference & Exposition, Indianapolis, IN, USA, 15–18 June 2014. Available online: https://peer.asee.org/implementing-pbl-in-a-concrete-construction-course (accessed on 1 March 2021).
31. Herrero-de-Lucas, L.C.; Martinez-Rodrigo, F.; Depablo, S.; Ramírez, D. Procedure for the Determination of the Student Workload and the Learning Environment Created in the Power Electronics Course Taught Through Project-Based Learning. *IEEE Trans. Educ.* **2021**, *99*, 428–439. [CrossRef]
32. Chan, C.K.Y.; Luk, L.I.I. Academics' beliefs towards holistic competency development and assessment: A case study in engineering education. *Stud. Educ. Eval.* **2022**, *72*, 101102. [CrossRef]
33. Etaio, I.; Churruca, I.; Rada, D.; Miranda, J.; Saracibar, A.; Sarrionandia, F.; Lasa, A.; Simón, E.; Labayen, I.; Martinez, O. Cross-curricular skills development in final-year dissertation by active and collaborative methodologies. *Interact. Learn. Environ.* **2017**, *26*, 175–188. [CrossRef]
34. Rodríguez, M.; Díaz, J.; González, E.J.; Gonzáles-Miquel, M. Motivational active learning: An integrated approach to teaching and learning process control. *Educ. Chem. Eng.* **2018**, *24*, 7–12. [CrossRef]
35. Du, X.; Su, L.; Liu, J. Developing sustainability curricula using the PBL method in a Chinese context. *J. Clean. Prod.* **2013**, *61*, 80–88. [CrossRef]

36. Nuñez, J.L.M.; Caro, E.T.; Gonzalez, J.R.H. From Higher Education to Open Education: Challenges in the Transformation of an Online Traditional Course. *IEEE Trans. Educ.* **2016**, *60*, 134–142. [CrossRef]
37. Yuan, J.; Savadatti, S.; Zheng, G. Self-assessing a test with a possible bonus enhances low performers' academic performance. *Comput. Educ.* **2021**, *160*, 104036. [CrossRef]