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Application of Circular Economy Techniques for Design and Development of Products through Collaborative Project-Based Learning for Industrial Engineer Teaching

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Abstract: Collaborative project-based learning aims to get students to take responsibility for their knowledge processes. The objective of this research is to analyze the viability of applying circular economy techniques for the design and development of products, through learning based on collaborative projects in industrial engineering. A survey was carried out between 2015 and 2019 on final year students of industrial engineering in Spain, from five different academic years. The responses obtained were analyzed statistically. The results indicate that the students who had more previous knowledge about the circular economy, valued its relevance for the design and development of products as well as for the practice of the profession more. In addition, it was demonstrated that the implementation of circular economy strategies in the design and development of products through collaborative projects allows the acquisition of different knowledge: eco-design, product planning and distribution, reuse, recycling, etc. Moreover, most of the students considered that the circular economy should be a complementary discipline and a transversal competence.

Keywords: educational competences; project engineering; project management; higher education; competences; collaborative models; circular economy; SDG; project-based learning

1. Introduction

One of the main challenges for humanity in the 21st century is sustainable development (SD). SD can be defined as current development that does not endanger the progress of future generations [1].

Following the relative success of the Millennium Development Goals [2], the United Nations has proposed a working agenda aimed at reducing inequalities, ensuring peace, and developing prosperity known as the Sustainable Development Goals (SDGs) [3]. With a timeframe of 15 years (2015–2030), the SDGs are made up of 17 goals, 169 targets, and 263 indicators [3].

Despite their motivational nature, the achievement of the SDGs is not going as fast as it was thought it would [4,5]. The participation of all actors—government entities, private companies, civil society, non-governmental organizations, etc.—is required to achieve the SDGs [2,3,5,6]. In this sense, universities can play a dynamic role in order to dynamize the SDGs' attainment [5,7–9] and promote sustainability [10–12].

The teaching of the SDGs at university must be understood within a broader paradigm of education for sustainable human development (ESHD) [5,9]. Education for sustainable human development is a topic of growing interest in scientific literature as well as a challenge for educators and institutions of higher education [13].

The SDGs must be understood in a holistic way [3,5]. It is not possible to isolate each SDG separately. There is a clear interrelationship among them. Thus, there is a relationship between SDG 4 (quality education) with other objectives, such as SDG 3 (health and well-being), SDG 5 (gender equality), SDG 1 (poverty reduction), etc.

In this context, the circular economy can be an interesting tool for achieving the SDGs [14]. This economic model seeks to optimize the use of resources—both energy and materials [15]. Thus, resources are kept for as much time as possible in the production cycle, reducing the amount of waste [15]. This model is opposed to the linear one based on extraction, production, consumption, and disposal, proposing a cyclicality that increases efficiency in the use of resources and eliminates waste [15].

Despite the current interest in the concept of the circular economy between scholars [16,17], its translation into practice is limited [17]. Furthermore, the number of papers dealing with the teaching of this economic model (circular economy education) is still very limited [15].

The main objective of this paper is to analyze the application of circular economy techniques to the development of project-based learning activities for students in the final year of industrial engineering degree courses. The specific objectives of the paper are (1) to describe the project-based learning activities carried out during the last 5 years and (2) to know the students' opinions about the activities developed as well as the usefulness of circular economy techniques in the development of products.

The remainder of this article is organized as follows: in Section 2 theoretical backgrounds are developed; subsequently, methodology is described; and results are presented (Section 4) and discussed (Section 5). Finally, the main conclusions and future research are exposed in Section 6.

2. Literature Review

In this article a project-based learning experience in the field of the circular economy is analyzed. The experience will be analyzed within the paradigm of ESHD and in the context of teaching SDGs at university.

2.1. Education for Sustainable Human Development at University

In 1987 the World Commission on Environment and Development (WCED) defined sustainable development (SD) as development which "meets the need of the present without compromising the ability of future generations to meet their own needs" [1]. In 2011, the United Nations Development Program (UNDP) defined sustainable human development (SHD) as "the expansion of the substantive freedoms of people today while making reasonable efforts to avoid seriously compromising those of future generations" [18]. Education for sustainable human development (ESHD) seeks to generate formal and informal processes that promote sustainable human development in all areas of society [5].

There are different ways of integrating ESHD throughout the curriculum [9,19,20]: introducing environmental issues into an existing subject, creating a subject specifically related to sustainable development, introducing sustainability aspects transversally, and creating a specialization itinerary around these issues.

On the other hand, there is a lack of awareness of the SDGs in society in general [5,21] and in the university population in particular [5]. Universities can play a fundamental role in the development and achievement of the SDGs [5,7,9]. Universities can contribute from all their areas of work, teaching, research, the transfer of research results, etc. [7]. Recently, a conceptual framework for teaching the SDGs at university level has been proposed [9]. In this conceptual framework five dimensions should be considered. The authors proposed a tetrahedron to represent the conceptual framework. In the center of tetrahedron should be the students—they should be the main important thing in university teaching. Others aspect that should be considered are professors, alliances, students' competences, and teaching methodology.

Above the conventional teaching methodology based on the transmission of knowledge, a transformative methodology emerges that seeks to develop students' skills [5,22–26]. In previous works we have defended the need for a balanced promotion of competences both of a specific nature (directly related to professional practice) and of a transversal nature (related to the creation of active and committed citizenship) [9,22,27]. Both competences are crucial for the development of global and cosmopolitan citizenship [5,6].

Transformative education must be understood in the context of constructivism, and student-centered, in which active methodologies are often used [28].

2.2. Circular Economy Education (CEE)

The circular economy is a multifaceted concept. In fact, a review paper published by Kirchherr et al. (2017) worked with 114 definitions published in the scientific literature [16]. The circular economy is clearly linked to the field of sustainability by promoting economic, social, and environmental development while ensuring the progress of future generations [15]. On the other hand, it is clearly related with the promotion of the SDGs (SDGs 7, 9, and 12).

Regardless of the importance of education, especially in the field of higher education, in promoting sustainability, the number of papers addressing teaching in the field of the circular economy is limited [15,29].

Whalen et al. (2018) analyzed an experience of the use of a serious game in the field of the circular economy [29]. Kirchherr and Piscicelli (2019) developed a teaching experience in the field of the circular economy in an honors program within the bachelor's programs (Utrecht University) [15]. The experience, structured in eight modules, included the conceptual development of the circular economy, notions of eco-design, an introduction to the concept of eco-industrial parks, the analysis of the macroeconomic impacts of the circular economy, excursions, a party organized under the criteria of the circular economy, and an integrating module as a conclusion. The initiative was developed using the methodology of problem-based learning, under a constructivist perspective and taking special care of non-dogmatism, interaction between students and between students and teachers, and learning by doing. The results of the experience were excellent from the point of view of both pupils and teaching staff.

The skills required for design in the field of the circular economy have recently been analyzed using 18 semi-structured interviews with people in the industry [30].

2.3. Project-Based Learning

Project-based learning (PBL) is an active methodology in which students learn through the development of a project, preferably in a group [22,31,32]. The students collaborate on an assignment that has a certain relation with their future professional context, and they do it working on both specific and professional competences [22,33,34].

Interest in PBL, as well as other active teaching methodologies such as gamification and flipped classroom, is growing at various educational stages [27,35]. These methodologies are based on social constructivism whereby students should be in the center of the teaching–learning process, building their own knowledge by themselves and with others: mates, teachers, and outsiders [9,27,36–38]. This collaborative learning constitutes the social nature of this type of learning [9,27]. Its use has a double objective—on the one hand it improves the development of competencies on the student's side, and on the other hand it seeks a better motivation and commitment to the course of the students [22,33,35,39].

Many works analyze experiences of the use of PBL at universities [34]. Nevertheless, just a few investigations addressed circular economy skills through this methodology. A search of documents published in the previous 5 years using the SCOPUS database [40], using the terms "problem based learning" and "circular economy", was realized in April 2020. Only five documents were obtained. Of these documents, four corresponded to conference papers [33,41–43], and just one is an article [10]. Thus, the analysis and description of project-based learning initiatives in the field of the circular economy is a challenge for the scientific community.

3. Methodology

3.1. Syllabus Design

This study was developed in the optional program "Integral Management of Innovation Projects" as part of the University's master's degree in Industrial Engineering. This is one of the 6 programs offered by the degree and it is made up of the following subjects: Management Planning and Project Control [44]; Management of Innovation in Industrial Design [45]; and Formulation, Management, and Evaluation of R&D Projects [46].

The itinerary is taught at the School of Industrial Engineering of the University of Extremadura (Spain) and consists of 18 European Credit Transfer System credits (450 students working hours). The program addresses numerous project management issues. The contents offered are related to project management standards according to the Project Management Institute [47]. Parametric design tools for product design and development and the circular economy are introduced transversally.

In order to apply the skills taught during the theoretical sessions, students were asked to develop a collaborative project that involved the three subjects. This project focused on the design and development of an innovative product, different for each academic year, which solves a previously identified design problem. Works developed during the 5 courses were a covering system for solar collectors, a deployable work shed, surgical light, a diffuser for the air-conditioning of operating rooms, and a cleanliness system for photovoltaic solar panels. Autodesk Inventor Professional 3D design and parametric modeling software was used for the product design phase [48].

Different planning tools were explained and used during theoretical sessions for the management of the project. In order to design and develop the product, different techniques of the circular economy were exposed, which were to be applied. The topics discussed included eco-design, the carbon footprint, life cycle analysis, the optimization of resource consumption for manufacturing, the environmental impact of transport for packaging and distribution [49], the reutilization of materials, etc.

Projects were developed in teams of 2–4 engineers. They had two clearly differentiated parts: (1) preparing an R&D project and (2) writing a technical product project. The first part contained the construction of the state-of-the-art product and the determination of the objectives of the product to be developed as well as the methodology, programming, and planning of the execution. The second part followed the classic morphology of a technical project (the report, plans, specifications, and budget) and was dedicated to the design of the product. The objective of this structure was to follow the complete process of design and development of products, from the application for funding to the implementation of an innovative idea to the realization of a prototype. The project was clearly differentiated into two parts: innovation management and product design.

In the innovation management part, an analysis was made of all the current commercial products and patents that could be used for the future design. Then a plan of the whole project was proposed, taking into account all the phases and tasks involved in the entire development of the project. In addition, the budget was detailed, and the exploitation plan of the results was drafted. The product design part described the methodology that was to be used in the design and development of the product. This design satisfied a number of specific criteria. After the product was modeled, the necessary analyses were performed to verify the product's functionality. In this last part, students were required to apply different strategies of the circular economy, such as the selection of materials, eco-design of the product, planning of transport, and others.

At the end of the semester, the final project documentation was delivered by the students. It included both the memory of the two parts of the project and the files of the software used. The evaluation of the assignment was divided into two parts: submission of the project and public defense before a tribunal made up of teachers of the subjects. Although the overall assessment included examinations, the highest percentage (80%) was awarded for the project.

3.2. Survey Design

The survey developed for this study is provided in Appendix A. Thirty questions were asked, which were classified into three groups: prior knowledge, the difficulty of acquiring concepts in circular economy, and the usefulness of these techniques. The groups had 5, 10, and 15 questions, respectively. The possible answers were as follows: not at all agree; somewhat agree; indifferent; agree; and totally agree, according to a Likert scale.

The survey design process began with an in-depth study of the circular economy fundamentals to identify its strategies and key points. A brainstorming session was held to specify the objective of the questions. An initial proposal was then drawn up with 70 questions. The survey was reviewed by experts at a meeting, and 40 out of the 70 questions were eliminated. Among the reasons for these removals were mainly ambiguous questions, similar questions, and questions that did not meet the objective of the survey. In addition, a change was realized in the structure of the survey, obtaining the three groups mentioned above.

3.3. Data Collection

The survey was provided in two formats—on paper for current students and in digital format for ex-students. Twenty-eight students from 5 different academic years (from 2015-16 to 2019-20) gave their answers. They constituted all of participants in the specialty of Integrated Management of Innovation Projects from the master's degree in Industrial Engineering at the University of Extremadura. The number of surveys was low due to poor enrollment, although it corresponded to 100% of students.

3.4. Data Analysis

The statistical analysis software Statistical Package for Social Science (SPSS) was used to analyze the data [50]. Initially, a descriptive analysis of the sample was carried out. Then, the randomness of the responses was tested using a randomness test [51]. This test defines a run as a sequence of consecutive values greater than or equal to the cut-off point (mean, median, mode, or specified value), preceded or followed by others below this cutting point. A minimum value of runs (an extreme case is 2) or an excessive number of them indicates that the observations are not random. For this study, the randomness test was performed based on the median, as this cutting point was appropriate for this type of survey response.

A reliability analysis of the instrument was carried out using Cronbach's alpha test [52] to measure the validity of the survey and determine if the questions were correct [53]. The test takes values between 0 and 1. The higher the alpha value, the more reliable the scale. As a general rule, values higher than 0.70 are accepted [5,54,55]. It is the right test for questionnaires with more than two answer options, such as a Likert scale.

Finally, answer patterns were analyzed to establish relationships between the different dimensions. In this analysis, we obtained the mean responses and standard deviations for each of the questions. A distinction was realized between the different courses to determine their main differences. In addition, the response percentage for each of the questions was calculated in order to observe the trends in positive and negative responses.

4. Results

4.1. Randomness Test

The significance level for each question is shown in Table 1. From now on, the questions use the abbreviation Q followed by the corresponding number to represent a survey question. Analyzing the results, it can be concluded that the randomness of the questions was not verified for Q_1, Q_2, Q_4, Q_{28}, and Q_{29}.

Table 1. Significance based on the median.

Q_1	Q_2	Q_3	Q_4	Q_5	Q_6	Q_7	Q_8	Q_9	Q_{10}	Q_{11}	Q_{12}	Q_{13}	Q_{14}	Q_{15}
10^{-5}	10^{-4}	0.597	0.003	0.204	1.000	0.338	0.950	0.361	0.094	0.102	0.710	1.000	0.866	0.386
Q_{16}	Q_{17}	Q_{18}	Q_{19}	Q_{20}	Q_{21}	Q_{22}	Q_{23}	Q_{24}	Q_{25}	Q_{26}	Q_{27}	Q_{28}	Q_{29}	Q_{30}
0.338	0.577	0.075	0.226	0.386	0.277	0.319	1.000	0.550	0.747	0.075	0.130	0.006	0.031	0.950

There was no randomness in questions Q_1 and Q_2, as most students did not have previous knowledge of the circular economy and had not used its techniques before. This is a fairly consistent pattern, which gives an idea of the non-randomness. Most pupils agreed in their answers to questions Q_{28} and Q_{29}, which will be debated in the discussion section.

4.2. Internal Consistency Analysis

The alpha value for the complete survey (30 elements) was 0.890. Corrected total correlation values of elements were obtained that were lower than 0.4 (which would invite the withdrawal of the said item from the questionnaire because it implies a low correlation of the item with respect to the rest). However, the "alpha if removed" column did not provide a higher value of alpha than the current one. Therefore, the consistency of the designed test was validated.

The value for each group of questions was 0.826, 0.773, and 0.832, respectively. If Q_3 was eliminated it would obtain 0.886 for the block of questions 1. In the second block of questions, α was only improved by removing Q_7 providing a value of $\alpha = 0.805$. For the third block, the exclusion of Q26 and Q28 would allow an improvement of up to 0.841. It was decided not to delete any of the cited questions because the current alpha value was already adequate.

Performing the same test by course, the following values were obtained, starting from the oldest course: 0.902, 0.915, 0.910, 0.752, and 0.770. Given these levels of reliability, the possibility of removing questions to improve internal consistency was not raised. Table 2 shows the response rate for the first block of questions for all courses.

Table 2. Results of the first block of questions.

First Block of Questions							
	Response (%)					Mean	Standard deviation
Questions	1	2	3	4	5		
Q_1	31.0	24.1	20.7	24.1	-	2.4	1.2
Q_2	51.7	17.2	20.7	10.3	-	1.9	1.1
Q_3	3.4	13.8	44.8	17.2	20.7	3.4	1.1
Q_4	48.3	34.5	10.3	6.9	-	1.8	0.9
Q_5	37.9	34.5	20.7	6.9	-	2.0	0.9

The second block of questions in the survey related to the difficulty of learning about the circular economy in product development and design. Students agreed on the appropriateness of using collaborative projects to acquire knowledge in the circular economy. This was reflected in the trend of scored responses ≤ 3. There was evidence of a lack of knowledge in the development and design of products related to adequate water management. The innovative product design criteria should require the use of water management techniques in future courses to improve water management education. Table 3 shows the response rate for the second block of questions for all courses.

Table 3. Results of the second block of questions.

Second Block of Questions							
	Response (%)					Mean	Standard deviation
Questions	1	2	3	4	5		
Q_6	-	10.3	20.7	44.8	24.1	3.8	0.9
Q_7	10.3	41.4	37.9	10.3	-	2.5	0.8
Q_8	-	27.6	31.0	31.0	10.3	3.2	1.0
Q_9	-	31.0	41.4	20.7	6.9	3.0	0.9
Q_{10}	3.4	10.3	24.1	34.5	27.6	3.7	1.1
Q_{11}	3.4	3.4	17.2	55.2	20.7	3.9	0.9
Q_{12}	0.0	20.7	27.6	31.0	20.7	3.5	1.1
Q_{13}	31.0	31.0	31.0	6.9	-	2.1	1.0
Q_{14}	0.0	17.2	24.1	24.1	34.5	3.8	1.1
Q_{15}	3.4	13.8	20.7	37.9	24.1	3.7	1.1

Concerning the third block of questions, the usefulness of the circular economy in the development and design of products was represented. The answers obtained by the students of the 2017/2018 academic year stand out. Table 4 presents the response rate for the third block of questions for all courses.

Table 4. Results of the third block of questions.

Third Block of Questions							
	Response (%)					Mean	Standard deviation
Question	1	2	3	4	5		
Q_{16}	-	-	10.3	41.4	48.3	4.4	0.7
Q_{17}	3.4	10.3	27.6	31.0	27.6	3.7	1.1
Q_{18}	-	-	41.4	37.9	20.7	3.8	0.8
Q_{19}	3.4	13.8	48.3	17.2	17.2	3.3	1.0
Q_{20}	3.4	10.3	24.1	55.2	6.9	3.5	0.9
Q_{21}	3.4	-	20.7	20.7	55.2	4.2	1.0
Q_{22}	-	-	13.8	13.8	72.4	4.6	0.7
Q_{23}	-	20.7	24.1	27.6	27.6	3.6	1.1
Q_{24}	-	6.9	13.8	44.8	34.5	4.1	0.9
Q_{25}	-	13.8	31.0	41.4	13.8	3.6	0.9
Q_{26}	-	6.9	34.5	17.2	41.4	3.9	1.0
Q_{27}	-	10.3	24.1	44.8	20.7	3.8	0.9
Q_{28}	6.9	27.6	31.0	17.2	17.2	3.1	1.2
Q_{29}	-	-	24.1	37.9	37.9	4.1	0.8
Q_{30}	-	3.4	20.7	44.8	31.0	4.0	0.8

These students did not consider the circular economy to be as necessary as a transversal competence (Q_{28}) and indispensable for their professional future (Q_{29}). Furthermore, the students did not see the importance of product design and development to increase the capacity of implementation and analysis of circular economy strategies (Q_{30}). Table 5 shows the average response of each of the courses to questions 28, 29, and 30.

Table 5. Results for questions 28, 29, and 30.

	Questions 28, 29, and 30		
	Average response		
Course	Q_{28}	Q_{29}	Q_{30}
2019/2020	4.4	4.6	4.1
2018/2019	3.5	4.5	4.5
2017/2018	2.0	3.4	3.6
2016/2017	2.5	3.9	3.8
2015/2016	3.1	4.4	4.4
Total	3.1	4.1	4.0
Standard deviation	1.2	0.8	0.8

It can be appreciated that questions 16 and 22 had a value ≥3 for 100% of the respondents, which showed the importance of the implementation of the circular economy in the development and design of products. Table 6 presents the results of questions 16 and 22.

Table 6. Results for questions 16 and 22.

	Questions 16 and 22						
	Response (%)					Mean	Standard deviation
Question	1	2	3	4	5		
Q_{16}	-	-	10.3	41.4	48.3	4.4	0.7
Q_{22}	-	-	13.8	13.8	72.4	4.6	0.7

Students of the 2019/2020 academic year responded with a higher score for previous knowledge acquired before the teaching of the subjects of the optional program. It should be noted that these students presented the highest average score to questions 23, 24, 28, and 29. These questions explained the relevance of the circular economy in the development and design of products and in the future practice of the profession. Moreover, the circular economy was considered as a complementary discipline and a transversal competence. Table 7 shows the results of questions 23 and 24.

Table 7. Results of questions 23 and 24.

Questions 23 and 24		
Average response		
Course	Q_{23}	Q_{24}
2029/2020	4.6	4.9
2018/2019	3.5	2.5
2017/2018	3.8	4.2
2016/2017	2.6	3.4
2015/2016	3.7	4.0
Total	3.6	4.1
Standard deviation	1.1	0.9

5. Discussion

5.1. Analysis of the PBL Experience

The results obtained in this research illustrate the benefits of the PBL methodology for working transversally with the circular economy and product engineering (Q_{17}–Q_{20}). The students considered that the activity of PBL allowed them to increase their interest in the circular economy, that it consolidated their knowledge about the circular economy, and that it caused an increase in the development of knowledge of the circular economy and in their interest in developing it in other subjects. The average of all these questions is equal to more than 3 out of 5 points. Results are consistent with others previously published in the literature. These studies state that the development of PBL activities is useful for the promotion of competencies in the field of project management and leadership [22,34]. The success of collaborative strategies is based on the proper organization of classroom activities, along with the organization of working groups and the distribution of roles among their members [56].

The research revealed how students consider that the circular economy and the quality of collaborative projects help each other (Q_{18} and Q_{22}). The concepts of the circular economy are easy to understand because they can be implemented in basic training. This allows the knowledge to be obtained before the subjects of the itinerary are taken. It also facilitates the assimilation of knowledge concerning material selection, eco-design, transport planning [57], energy efficiency, recycling, etc.

Students claim to have obtained knowledge about the circular economy (Q_{10}–Q_{15} and Q_{18}) and that it has been relatively easy to learn (Q_6–Q_9). On the one hand, students give a high value to the reuse, recycling, and recovery of waste (Q_{14}); the correct planning and distribution of products (Q_{11}); energy consumption (Q_{12}); and the eco-design of products (Q_{10}). On the other hand, students place a lower value on the acquisition of knowledge about water consumption efficiency (Q_{13}).

It was found that previous knowledge about the circular economy (Q_1–Q_5) was quite scarce among the students who came from different specialties. Students who had previous knowledge had it because they had developed their bachelor thesis specializing in product engineering. This is consistent with previous works published in the literature that claim a deficit in the teaching of the circular economy and indicate the importance of teaching it in the above subjects [15].

5.2. Circular Economy Education in the Framework of SDG Education

There is a growing interest in developing education for sustainable human development experiences at a university level [13]. In this regard, teaching the Sustainable Development Goals is a major challenge for higher education institutions [5,9]. SDG 12 is related to responsible production and consumption, so the circular economy could make a very interesting contribution to the achievement of SDG 12. Thus, circular economy education is clearly related to SDG education and ESHD education (Figure 1).

The students participating in the initiative showed a greater knowledge of the concepts related to the circular economy, and in this way this initiative contributes to the diffusion of SDG 12. In a tangential way, other SDGs are also being diffused, such as SDG 7 (Free and Accessible Energy) and SDG 9 (Industry, Innovation, and Infrastructure). In this way, the learning of techniques of the circular economy, through the design and development of products, allows the students of the University's master's degree in Industrial Engineering to increase their knowledge of the SDGs. Therefore, there was a lack of awareness observed in university students about SD.

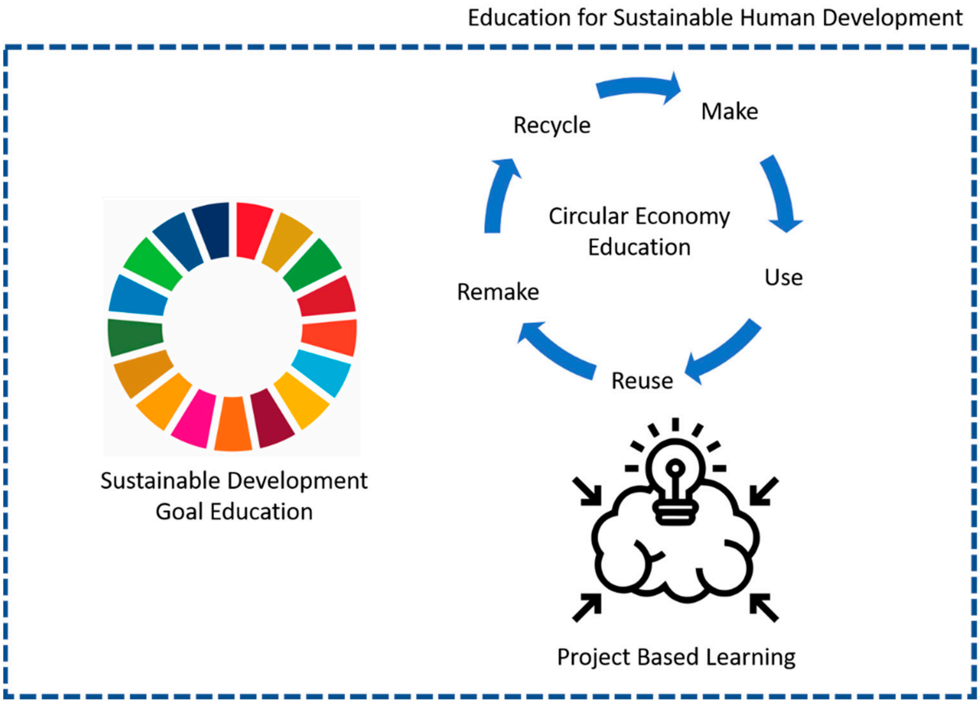

Figure 1. Relationship between Sustainable Development Goal (SDG) Education, circular economy education (CEE), project-based learning (PBL), and education for sustainable human development (ESHD). Icon credits: United Nations [58] and OnlineWebFonts [59].

There are different strategies for carrying out the development of the SDGs within a university curriculum [9,60]: (a) to plan a subject or itinerary about the SDGs, and (b) to develop SDGs in a transversal way in the different subjects or in the coordinated work of several subjects. This last option is the one chosen in this paper for the development of the teaching of the circular economy. The project-based learning activity was developed in a coordinated way in three subjects that were an optional itinerary of the Industrial Engineering master's course.

Most of the students surveyed perceived the circular economy as an indispensable subject, so it should be implemented in all possible subjects (Q_{28} and Q_{29}). There is controversy about the best methodology for teaching concepts related to sustainability [61]. In our opinion, the circular economy should be implemented as a transversal competence in previous courses in order to put the student in a better position for the acquisition of techniques of the circular economy [62]. In this way, knowledge about the circular economy could be adequately analyzed by students during the realization of the design and development of products [63]. Previous research has supported the use of transverse proposals for the development of competencies such as ethics [61] and the SDGs [64]. Based on these experiences, the circular economy should be promoted throughout the curriculum in a transversal way.

Transversal and multidisciplinary development is fundamental for the fulfilment of the successful teaching of the SDGs [20] and the circular economy. There are three barriers to addressing this multidisciplinary approach: time, evaluation, and teacher training [20].

To face these challenges, a certain asymmetrical bilingualism of university professors should be required [9]. This concept, used by Augusto Hortal in the field of teaching professional ethics [65], has been proposed for the teaching of the SDGs in the university environment recently and implies the need for training of teachers both in new technical tools that promote sustainability and about sustainable human development [9].

In this case, project-based learning has been shown to be a methodology conducive to teaching the SDGs. This is consistent with other studies previously published in the literature related to education for sustainable development ESD [23]. There is a consensus on the importance of using constructivist methodologies [9] in SDG education. Other initiatives have analyzed experiences based on service-learning [66,67], participatory action research [68], etc.

5.3. Implications for Policymakers and Top Managers of Universities

Despite the promising results of the work, we believe that some recommendations could be drawn from it for the policy makers and managers of our universities.

1. It is necessary to introduce active methodologies in the first courses of a university. In this way these competencies can be developed throughout the curriculum.
2. It is necessary to look for the interdisciplinary nature of projects. The experience developed here involves three subjects. It is necessary to move from subject-centered work to learning that places the students' skills at the center. In this way, collaboration between teaching teams should be encouraged.
3. These activities must be carefully planned because they require more time from both students and teachers.
4. Teachers require adequate training. In this sense, the constitution of working groups for teaching innovation can be a magnificent opportunity to foster educational change.
5. There must be a decisive commitment at the political level in the university to promote the teaching of sustainable human development, the SDGs being a strategic commitment of the institution. This commitment must be extended to all university functions.

6. Conclusions

It was found that students' prior knowledge of the circular economy is limited, and it depends on the academic year, because it is not a commonly taught curriculum concept. This is due to the lack of education in these concepts in previous subjects. Additionally, it was observed that the acquisition of knowledge about the circular economy through collaborative projects is valued positively by students.

It was noted that students who have more prior knowledge in these topics have a greater appreciation of the importance of the circular economy in the development and design of products and in the future practice of the profession. Furthermore, the circular economy is considered as a complementary discipline and a transversal competence.

Therefore, the application of circular economy techniques for the design and development of products is appropriate for implementing and improving the analytical capacity of different circular economy strategies. In this way, knowledge relating to energy efficiency, reuse, or eco-design that enriches the solution obtained is acquired by students. In addition, the results show the advantages of implementing the teaching of the circular economy throughout university education, completing the students' training in sustainability.

This study is useful to determine the relevance of the circular economy in the previous training of students and its importance in the design and development of products. In addition, the easiness of assimilating the fundamentals of the circular economy is increased by the implementation of collaborative projects related to product engineering.

Future work should focus on detailing the key points for implementing the concepts of the circular economy in basic formation.

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Appendix A

Table A1. Survey.

	Previous knowledge	
	Question	Response
1	I had knowledge of the circular economy prior to the subjects of the itinerary.	Likert scale 1–5
2	I had previously used circular economy techniques.	Likert scale 1–5
3	Knowing circular economy strategies in previous courses would have modified the projects previously developed.	Likert scale 1–5
4	I had previous knowledge about eco-design.	Likert scale 1–5
5	I had prior knowledge of carbon footprint reduction techniques in product design and development.	Likert scale 1–5
	Difficulty in obtaining knowledge of circular economy techniques	
6	The concept of the circular economy is easy to understand.	Likert scale 1–5
7	There is a specialized bibliography on the circular economy for the design and development of products.	Likert scale 1–5
8	Acquiring skills in circular economy techniques is easy.	Likert scale 1–5
9	Applying circular economy techniques to product design and development has been simple.	Likert scale 1–5
10	I have learned about eco-design by applying circular economy techniques in product design and development.	Likert scale 1–5
11	I have acquired knowledge of product distribution planning by applying circular economy techniques in product design and development.	Likert scale 1–5
12	I have gained knowledge about the importance of energy consumption by applying circular economy techniques in product design and development.	Likert scale 1–5
13	I have acquired knowledge of water consumption efficiency by applying circular economy techniques in product design and development.	Likert scale 1–5
14	I have acquired knowledge about reuse, recycling, and recovery of waste by applying circular economy techniques in product design and development.	Likert scale 1–5
15	The knowledge of the circular economy presented in the subjects of the itinerary is suitable for the design and development of products.	Likert scale 1–5

Table A1. *Cont.*

	Previous knowledge	
	Question	Response
	Utility of circular economy in product design and development	
16	The circular economy is suitable for increasing knowledge in product design and development.	Likert scale 1–5
17	Developing product projects has increased my interest in the circular economy.	Likert scale 1–5
18	The development of the collaborative project succeeds in consolidating knowledge of the circular economy.	Likert scale 1–5
19	Learning based on collaborative projects increases my interest in expanding my knowledge of the circular economy.	Likert scale 1–5
20	Collaborative project-based learning motivates me to apply circular economy techniques to other subjects.	Likert scale 1–5
21	Applying circular economy techniques has modified the initial designs of the product design and development object.	Likert scale 1–5
22	The circular economy improves the quality level of the engineering solution designed collaboratively.	Likert scale 1–5
23	The circular economy and product design and development are complementary disciplines.	Likert scale 1–5
24	Product design and development needs circular economy techniques to improve its results.	Likert scale 1–5
25	Circular economy techniques are essential for the design and development of products in collaborative projects.	Likert scale 1–5
26	Applying circular economy techniques increases the workload required for the project.	Likert scale 1–5
27	The development of the collaborative project succeeds in consolidating knowledge of the circular economy.	Likert scale 1–5
28	The circular economy must be considered a transversal competence in the degree.	Likert scale 1–5
29	The techniques of circular economy are useful for the future practice of the profession.	Likert scale 1–5
30	Product design and development increases the capacity for analysis and implementation of circular economy strategies.	Likert scale 1–5

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