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Article

A Methodology to Introduce Sustainable Development Goals in Engineering Degrees by Means of Multidisciplinary Projects

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Abstract: The sustainable development goals (SDGs) reflect the relevance that sustainability is gaining in our societies. Including sustainability-related topics in university curricula requires the revision of the contents, teaching/learning strategies and assessment techniques. Although engineering degrees are starting to introduce them, it may become complex to design significant educational experiences. This partly comes from the fact that sustainability is a highly multidisciplinary issue but, currently, the knowledge is compartmentalised into subjects. In this challenging scenario, concrete activities are required for students to better internalise sustainability issues. This work aims to present a methodology that guides academic staff to materialise the design of sustainability-related multidisciplinary activities. Since the designers of new activities may benefit from knowledge of similar experiences, this article describes one implementation throughout eight subjects within the Bachelor's degree on Industrial Electronics and Automation Engineering at UPV/EHU. The analysis and optimisation of the thermal comfort and energy consumption in the Faculty building became the common thread to design an educational itinerary that covers several subjects along all academic years of the degree, making use of active methodologies. The problem is analysed for every subject from different perspectives. Two questionnaires, carried out before and after the activities, were used for analysing the perception of the students after the activities. Results proved that the multidisciplinary project raised awareness about the SDGs and allowed students to visualise how to apply the acquired skills in problems close to their experience. As a result, more students considered sustainability as a possible future professional activity.

Keywords: sustainable development goals (SDGs); active methodologies; multidisciplinary education; engineering education; indoor environmental quality (IEQ); thermal comfort; energy economy

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1. Introduction

The concepts of sustainable development and the sustainable development goals (SDGs) were defined at the United Nations Conference on Sustainable Development in Rio de Janeiro in 2012 [1] and were adopted in the 2030 Agenda for Sustainable Development at the United Nations General Assembly in 2015 [2]. Currently, an increasing number of educational institutions are incorporating sustainable development into their curricula in order to better prepare students for a changing world, which requires renewing these curricula [3,4]. Unfortunately, this is a complex task [5], since sustainability issues are typically wicked problems, i.e., highly complex, ill-structured and domain-specific problems, which are difficult to approach [6]. Among other issues, sustainable development is inherently multidisciplinary and requires combining approaches from different disciplines, involving social, economic and scientific aspects to implement engineering solutions [7,8]. However, a systematic approach should be followed in order to coherently introduce the SDGs into educative programs. For example, in [9], six SDG transformations are introduced as modular building-blocks to achieve the SDGs. This approach creates groups of SDGs in order to organise their implementation.

Some works present guidelines and experiences that are aimed at guiding institutions to include sustainability in High Education Institutions (HEI) [10]. Other works [11] recommend focusing on the following lines of action: (1) interuniversity collaboration among entities, (2) multidisciplinarity promotion, and (3) adequate selection of real-use cases that illustrate problems as well as possible solutions. Certain authors suggest that engineering students need specific training in transdisciplinary research and conflict resolution to avoid situations in which they collapse in frustration when dealing with real problems [12].

One common problem in engineering studies is that, although design is a fundamental part in engineering sciences, sometimes it may be excluded from the teaching curriculum. Hence, future engineers may lack creativity and have a narrow problem-solving focus, with too much emphasis on mastering mathematical equations [13]. In most cases, incorporating tangible and relevant challenges into the curriculum requires breaking away from the traditional teacher-centred approach, based on lectures and knowledge compartmentalisation into subjects. This trend follows the Barcelona Declaration, signed in 2004 [14], which stated that, nowadays, engineering education should be multidisciplinary, holistic and systems-oriented and it should foster critical thinking and participation. Hence, graduating students should acquire these competences during their studies since they will be required in the future professional practice.

In this context, active methodologies have proven to be effective to motivate students, achieving deeper learning and helping students to better retain knowledge [15–19]. Some works analyse the synergies between sustainability education and active methodologies, such as problem-based learning (PBL) [20,21], challenge-based learning (CBL) [22] or design-centric engineering [4]. According to these studies, active methodologies are particularly suitable for developing the concept of sustainability in educational programs. According to [23], in the case of the PBL methodology, the proposal of problems close to the students' interests produces better results since they benefit from their direct experience.

Consequently, university curricula should be adapted to raise student awareness on the concepts of sustainability and sustainable development. In addition, it is essential to introduce methodological changes aimed at making students more active in their learning processes. In this scenario, the following research questions arise:

RQ1: How to introduce the SDGs in the curricula of engineering degrees by means of concrete activities;

RQ2: How multidisciplinary experiences, which intertwine several subjects, should be designed to engage students;

RQ3: How to make students aware that the skills acquired during the degree may help them to design and develop sustainability-related projects in their future professional activity.

After carefully analysing the current situation towards sustainability in HEIs, this article proposes a methodology that guides professors and instructors to materialise the design of multidisciplinary activities aimed at introducing the SDGs in the curricula of engineering degrees. The presented approach requires that students face a multidisciplinary problem linked to the SDGs, which becomes the common thread to combine knowledge and skills acquired from different subjects in the degree. Several criteria must be satisfied when selecting the problem. Specifically, it must (1) be a real world problem; (2) be relevant to the students; (3) require analysis from different perspectives, promoting multidisciplinary solutions and (4) present an engaging challenge throughout the course of the degree.

In addition, this paper describes the implementation of an experience within the Bachelor's degree on Industrial Electronics and Automation Engineering at the Faculty of Engineering Vitoria-Gasteiz, University of the Basque Country (EIVG). This implementation follows a dynamic and active teaching model, the so-called IKD educational model [24], which promotes the adoption of 12 of the 17 SDGs [25]. The chosen problem involved the assessment of the thermal comfort and energy consumption in the EIVG building and the analysis of measures to reduce energy consumption. This problem satisfies all the requirements stated before. In particular, it allows analysis of the problem from the specific perspectives used in every subject while reducing knowledge compartmentalisation.

In order to scaffold the implementation, a multidisciplinary and multi-course itinerary was designed, which included intertwined activities in different subjects using active methodologies. Throughout the itinerary, students delved into their understanding of the SDGs, becoming aware of their importance. Thus, they may also understand the consequences of incorporating these goals into their future professional endeavours. In the presented implementation case, the activities were focused on the following SDGs [26]:

- Good Health and Well-Being (SDG 3);
- Quality Education (SDG 4);
- Industry, Innovation and Infrastructure (SDG 9);
- Sustainable Cities and Communities (SDG 11);
- Responsible Consumption and Production (SDG 12).

Questionnaires are typically used for evaluating engineering students' awareness of sustainability issues [27]. Hence, as part of the methodology, two questionnaires were designed to analyse the achievement of the research questions and validate the presented approach. The first questionnaire, taken in every subject before the SDG activities, measures the previous knowledge of the students about SDGs and their expectations within engineering studies. The second questionnaire, taken in every subject after the SDG activities, measures the students' satisfaction, the degree of SDG achievement perceived by students and the expectations towards undertaking sustainability-related tasks in the future. In the implementation at the EIVG, the questionnaire results proved that the multidisciplinary activities helped students to learn about the SDGs and motivated them to carry out sustainability-related activities in the future.

Thus, the implementation of the methodology achieved several objectives: (1) students acquired knowledge about the SDGs and their relevance to the society, (2) it introduced a transversal point of view to solve engineering problems, (3) students reflected on how they could design and develop sustainability-related projects by applying the knowledge acquired throughout the degree, (4) it visualised that improving sustainability can be part of the students' future professional careers, and (5) students became aware of responsible use of resources—in particular, energy consumption.

The rest of the article is organised as follows. Section 2 introduces some related works and trends aimed at introducing sustainability in HEIs. Section 3 presents a methodology to implement multidisciplinary activities in engineering degrees. Section 4 shows an implementation example aimed at the Bachelor's degree on Industrial Electronics and Automation Engineering. Section 5 analyses students' assessment of the multidisciplinary experience. Finally, Section 6 exposes the conclusions drawn from this work.

2. Related Work

The commitment to comply with the UN 2030 Agenda and the SDGs by institutions and society in different countries has resulted in their incorporation into the Agendas of Educational Centres, especially HEIs. Thus, the commitment to the SDGs is included in the information provided by the universities themselves. Observing the main university rankings—QS World University Ranking [28], Times Higher Education Ranking [29] and Shanghai Ranking [30]—it can be verified that the world's leading universities endorse and develop this commitment. In addition, both the QS World University Ranking and the Times Higher Education Ranking present a specific ranking on sustainability or on the development of the SDGs [31,32]. In this way, the Massachusetts Institute of Technology (MIT), USA [33], embraces the SDGs at both curricular and research levels, highlighting the applied projects in which they participate. The University of Oxford, UK, for its part, launched the SDG Impact Lab [34] in 2021 to help graduate students attain SDGs. Harvard University, USA, on the other hand, raises both the institution's sustainability objectives and their relationship with educational programs from its Office for Sustainability [35]. The University of California, Berkeley, USA, leads the QS Ranking on Sustainability. The UC Berkeley Office of Sustainability presented a study to "Identify the strengths and weaknesses of UC Berkeley sustainability curriculum" and researched the role that HEIs should play in the development of the SDGs [36]. The Western Sydney University, AU, has regained first place in the Sustainability Ranking of the Times Higher Education in 2023. The document *Unlocking Impact. Sustainability Report 2022* [37] highlights not only the meritorious position obtained in the ranking, but also the enduring work across the CORE (Curriculum, Operations, Research and Engagement) framework.

Beyond the institutional scope represented by the universities that lead the rankings, many studies present systematic reviews collecting the results of the SDG implementation experiences in the HEIs. Some examples highlight the advantages that the incorporation of the SDGs provides in the preparation of the future graduates [38–42]. Other works present experiences about the integration of the SDGs into university curricula. For example, the work developed by Mori et al. [43] describes the commitments to the SDGs made by the Royal Melbourne Institute of Technology (RMIT) University, AU, on a university-wide project that began in 2018. The project provides students with the knowledge and skills needed to deal with the challenge that the development of the SDGs supposes in the HEIs, improving sustainability and social inclusion. This study concludes that, although SDGs are being incorporated into the organisation strategies, few of the programs measure and communicate their impact. Mawonde and Togo [44] describe the SDG implementation in the science campus in Johannesburg of the University of South Africa, ZA. This distance education institution has developed many initiatives to promote the SDGs in its near environment. As a result, most of the SDGs are covered by many successful projects supported by the university community. Purcell et al. [45] studied different ways to define sustainability strategies on three universities of different typologies in terms of their status (public or private), size or research dedication. The chosen universities—Plymouth University in UK, American University in Bulgaria and Harvard University in USA—develop many of their sustainability initiatives through "Living Labs" experiences. These Living Labs are open innovation environments that allow innovation, creation, validation, testing and development of new products, systems and services in real-life environments.

Sustainable development is a multidisciplinary problem that requires combining approaches from different disciplines in order to obtain a global comprehension. Through a multidisciplinary approach, students can obtain many skills: problem-solving, analysis and research methodologies, critical thinking and development of integrated perception of these problems. Some of these skills are similar to the "transferable skills" that Assister [46] defined as "the metaskills, the second-order skills which enable one to select, adapt, adjust and apply one's other skills to different situations, across different social contexts and across different cognitive domains".

In his study about multidisciplinarity in engineering education, Marques [47] proposed the inter-/multidisciplinary approach as an effective way to counterbalance the excessive specialisation that may be happening in engineering studies. It provides a global vision about the application of engineering methods and techniques: "The increasing specialisation of engineering curricula has led professors, researchers and students to become more and more circumscribed in their specific technical areas. The ensuing fragmentation of knowledge can be related to the difficulties felt by the students in mastering physics, mathematics and engineering topics in an integrated way". Aboelela et al. [48] highlight that multidisciplinarity "uses study design and methodology that is not limited to any one field; and requires the use of perspectives and skills of the involved disciplines throughout multiple phases of the research process".

In addition to a multidisciplinary approach, many studies have shown the benefits that the use of active methodologies applied to sustainability education provide to students [49–52]. Within these methodologies, PBL is a widely accepted educational method that focuses learning on the student. Mixing this educational methodology, along with a multidisciplinary approach, is a commonly used bundle when introducing sustainability into HEI curricula. This is the case of Hansen et al., who present a study conducted in 2012 by a multidisciplinary group to investigate the possible incorporation of sustainability in engineering and science education at the Faculty of Engineering and Science of Aalborg University, DK [53]. This work describes the methodology of the study and presents its results and some recommendations to the different agents of the faculty. The work in [54] presents a degree on Sustainable Design Engineering at the University of Aalborg that is organised around design projects. In [55], Thomas presents a study focused on the sustainability of education itself. Approaching the field of engineering, Thomas presents an approach to sustainability through design-based learning (DBL) with mechanical engineering students. The study was successful, and the data obtained showed that both the sustainability topic and the applied methodologies favored the development of the students' abilities. The author also introduced the problems that may arise with the application of this proposal, such as the lack of motivation by the students or difficulty in finding appropriate professors.

Bertel et al. [56] studied the potential of large-scale projects based on PBL, the so-called megaprojects [57]. These megaprojects allow students to work together across programs and semesters to solve complex problems linked to one or more SDGs while respecting the curriculum of the targeted subjects. These megaprojects systematically integrated principles of education for sustainable development (ESD), specifically multi-/interdisciplinarity, at the PBL level. The results showed the potential of the megaprojects to motivate students on issues related to sustainability and to develop important professional competences. In turn, Gupta understands sustainable development as providing sustainable educational programs [58], that is, providing broader access to quality education with experience-value learning opportunities. With this purpose, he proposed the use of PBL and DBL to improve learner-centric, team-based and problem-solving environments in the software engineering course within the Bachelor of Tech-Computer Science and Engineering discipline.

Other authors evaluate how the activities carried out affect the students' perception of sustainability. In the case of the College of Engineering and Physical Sciences of Aston University, UK, active learning methodologies were applied to carry out an interdisciplinary module aimed at solving complex projects related to sustainable development [59]. For one week (2018–2019), 80 students, supervised by academic and professional staff, worked around real-life problems from Engineers without Borders, UK, in which key knowledge related to SDGs was provided. The initiative was assessed through two questionnaires (one pre-project and another post-project) that considered aspects related to sustainability, teamwork and user-centred design. The results pointed out that students improved their ability to understand others' viewpoints and their capacity to evaluate the consequences of their professional decisions. Alvarez et al. [60] carried out a study on the Civil Engineering degree at the Faculty of Engineering Bilbao, University of the Basque Country (UPV/EHU). This work illustrated the benefits of the transversal and active-based approach, although it was a smaller experience in terms of number of subjects and courses involved in the project when compared with the present one.

One pioneering and interesting initiative aimed at reorienting university curricula to address sustainability was the RUCAS-Tempus project initiative [61]. This project developed a methodology to support the introduction of Education for Sustainable Development issues in Higher Education. The project followed a multidisciplinary and systemic approach by adopting three stages: (1) what to teach and how to teach it; (2) how to design and implement a course and (3) how to ensure that students are learning what is being expected. It promoted changes in the sustainability curriculum in 12 universities from 8 countries in which almost 4000 students participated. As an application example, this methodology was used to design an M.Sc. programme on ICT in education for sustainable development [62]. More recently, the DeCoRE+ methodology [63] was designed to help the transition from theory to praxis when curriculum adaptations are made. This methodology includes the phases of Diagnostic Evaluation, Deconstruction, Construction, Reconstruction, Implementation and Summative Evaluation that allow the redefinition of the curriculum and the evaluation of the results.

Therefore, it can be concluded that HEIs play a relevant role in the implementation of the SDGs, mainly due to their involvement in teaching, researching and knowledge transfer. In the case of engineering degrees, solving SDG issues implies multidisciplinarity, avoiding the fragmentation of subjects that has traditionally marked their curricula. For this reason, it is necessary that a transversal and holistic approach encompasses several subjects by intertwining concrete activities in engineering degrees. In this context, PBL has proven to be a suitable approach to develop multidisciplinary projects. Most analysed papers describe specific implementations in concrete institutions, which can hardly be replicated in other institutions or degrees. Therefore, it would be useful to (1) have a methodology to guide the incorporation of sustainability concerns in the curriculum in engineering degrees and (2) include mechanisms to assess how the actions carried out influenced students.

3. Methodology

This section presents a methodology aimed at introducing sustainability issues in the curricula of engineering degrees by means of multidisciplinary experiences. Figure 1 shows the major implementation stages. These stages are described in higher detail below.

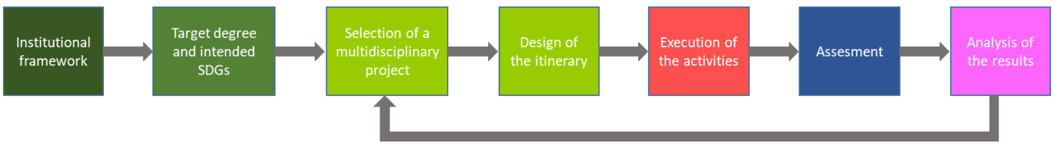

Figure 1. Implementation stages for the multidisciplinary activity.

3.1. Institutional Framework

An increasing number of universities are developing different programs aimed at raising student awareness of sustainable development. In most cases, these programs promote methodological changes aimed at making students more active in their learning and offer generic frameworks for implementing activities aimed at introducing SDGs in Higher Education. It is convenient to adapt the multidisciplinary activity to align with the institutional framework.

3.2. Target Degree and Intended SDGs

The contents and skills to be acquired during the target degree must be analysed in detail before designing multidisciplinary experiences. Students of engineering degrees should learn to design and create new systems aimed at solving problems demanded by society. Unfortunately, teaching others how to design these new systems is not an easy task. In practice, this is a common problem for all engineering degrees [15]. In addition, the proposed projects must help students to delve into their understanding of the SDGs, or a set of SDGs, and, at the same time, make them aware of their importance. Finally, one must analyse how students are expected to incorporate the selected SDGs into their future professional endeavours.

3.3. Selection of a Multidisciplinary Project

This is a key stage, since selecting a "good" multidisciplinary project is a challenging issue, as it must fulfill several requirements simultaneously. Namely, the project should (1) focus on a real world problem, so students may learn from their experience to face future professional tasks; (2) be relevant to the students, in order to motivate them; (3) require analysis from different perspectives, to promote multidisciplinary solutions that intertwine several activities and (4) present an engaging challenge throughout different courses of the degree. In all, the selected multidisciplinary project becomes a common thread to acquire different skills along several subjects of the degree. One important issue is that the multidisciplinary project must be able to introduce SDGs coherently. In this sense, the work in [9] proposes six transformations that may be used to identify problems that group several SDGs.

3.4. Design of the Itinerary

In order to scaffold the experience, after choosing the project, it is necessary to carefully select the subjects in which it is developed. The definition of the itinerary allows analysis of a multidisciplinary problem from the different perspectives used in every subject. Thus, the itinerary must cover a broad number of subjects along the course of the degree.

3.5. Execution of the Activities

This stage involves the design and execution of all designed activities for every subject. Again, this is a challenging issue for several reasons: (1) frequently, the syllabus of the subjects are very tight, making it difficult to not omit important contents and (2) all activities must be intertwined within the multidisciplinary project. For these reasons, the authors recommend leaving flexibility to the coordinators of every subject to design activities of different duration. The proposed activities are included in the syllabus of every subject as new tasks. Typically, their weight in the final qualification of the subject is proportional to the number of classroom hours

3.6. Assesment

As part of the methodology, the authors designed two questionnaires for assessing whether the multidisciplinary experience produced changes in the student's perception about sustainability issues and the SDGs. The first one is taken before the activity (pre-activity, see Appendix A) and the second one after the activity (post-activity, see Appendix B). These questionnaires must be issued in the classroom to all participant students in every subject. Since it is important to obtain sincere information about the experience, the responses to the questionnaires must be treated strictly anonymously. In order to guarantee the anonymity, confidentiality and privacy of the data obtained, the pre- and post-activity questionnaires were designed in such a way that they only collected data directly related to the students' perception about the activities as well as about sustainability issues.

The pre-activity questionnaire measures the generic knowledge about the selected SDGs. In addition, it collects the perception of the students about the importance of introducing the SDGs in engineering degrees in general, as well as in every particular subject. Table A1, in Appendix A, shows the pre-activity questionnaire used in the implementation example within the Bachelor's degree on Industrial Electronics and Automation Engineering at the EIVG. This questionnaire may be used as a template to design questionnaires adapted to other implementations, which may involve different activities and SDGs. With the purpose of guiding the implementation stage, the questions that depend on the specific project are highlighted in blue, those dependent on the institution are marked in orange and those related to the SDGs covered by the project are emphasised in green.

The post-activity questionnaire measures students' satisfaction with the activities carried out in every subject. In particular, it evaluates the connection of the proposed activity with the selected SDGs. Also, it collects the students' opinions about performing sustainability-related tasks in their future professional careers. Table A2, in Appendix B, shows the post-activity questionnaire, used in the implementation example. Again, this questionnaire could be adapted for other implementations involving different activities and SDGs. Those parts that depend on the proposed project are highlighted in blue, whereas those related to the SDGs covered are emphasised in green.

A Likert scale of 7 was used ain both questionnaires to provide a good graduation degree in the responses. All responses indicate students' degree of agreement with the proposed questions, which range from 1, meaning the lowest value of the response (totally disagree), to 7, meaning the maximum value (totally agree).

3.7. Analysis of the Results

Designing and implementing multidisciplinary experiences that intertwine several subjects is challenging, especially when it is required (1) to increase the knowledge about the SDGs after the activities; (2) to be close to the students' experiences to engage them and (3) to make students aware of how to apply learned skills in their future professional life. The authors assess the completion of the research questions stated in the Section 1 by analysing selected questions of the questionnaires issued to the students.

4. Implementation Example

The presented methodology was followed to implement a multidisciplinary project that was aimed at introducing sustainability issues into the Bachelor's degree on Industrial Electronics and Automation Engineering at the EIVG (UPV/EHU). The next subsections describe the implementation details at every stage.

4.1. Institutional Framework

In the UPV/EHU, the IKD educational model supplies a framework by means of the so-called i3KD educational innovative projects [24]. These projects can be used to integrate SDGs into the competences of different degrees following the EHUagenda 2030 for sustainable development [25]. In this work, an i3KD project provided the framework to integrate some SDGs in a multidisciplinary way into the competences of the Bachelor's degree on Industrial Electronics and Automation Engineering taught at the EIVG Faculty, UPV/EHU.

4.2. Target Degree and Intended SDGs

One of the objectives of the selected degree is aimed at developing industrial applications by means of creating full systems that involve designing and programming electronic systems under the Industry 4.0 paradigm. Throughout the degree, students obtain a solid background on several areas such as computing, networking, control engineering, automation, electronic systems and instrumentation. In addition, students acquire fundamental concepts of other domains such as thermal engineering, electrical technology or mechanical systems.

The knowledge acquired in this degree has practical applications in strategic sectors that use electronics and automation devices intensively, such as machinery, automotive, aeronautics or energy production and management systems. It also may be applied to other fields like medicine, agriculture or traffic-management systems. Although a broad number of SDGs may be related to the students' future professional careers, the multidisciplinary activity is required to be focused on the following SDGs:

- Good Health and Well-Being (SDG 3);
- Quality Education (SDG 4);
- Industry, Innovation and Infrastructure (SDG 9);
- Sustainable Cities and Communities (SDG 11);
- Responsible Consumption and Production (SDG 12).

These SDGs are mostly covered in one of the transformations proposed in [9], namely, the third one, which addresses energy efficiency in buildings and constructs.

4.3. Selection of a Multidisciplinary Project

The proposed multidisciplinary project stemmed from the idea of incorporating into the curriculum of the target degree the outcomes of two previous projects developed by the authors. These projects were carried out under the Campus Bizia Lab (CLB) program, aimed at improving sustainability at UPV/EHU. Particularly, they involved optimising the consumption of energy at the EIVG and implementing measures to improve the sustainability of the thermal system of the EIVG. The main objective of the proposed project was for students to tackle the challenge of analysing and improving the sustainability of the EIVG building. Thus, students were expected to perform the following actions: (1) to analyse energy consumption, (2) to evaluate thermal comfort, (3) to reduce unnecessary consumption, (4) to raise awareness among the university community and (5) to propose concrete actions that could be applied to other public buildings.

The authors considered this project to be an appropriate challenge to introduce sustainability-related actions into undergraduate teaching through active methodologies. The selection of the problem presented to the students satisfies the requirements stated above, including the capability of serving as glue to group the selected SDGs, as stated above in the subsection *Target degree and intended SDGs*. Furthermore, it allows students to (1) acquire knowledge about the SDGs and their relevance; (2) analyse an engineering problem in a transversal way; (3) make a reflection on how design and develop sustainability related projects with their skills; (4) visualise sustainability as part of their professional future activities and (5) be aware of responsible use of resources.

4.4. Design of the Itinerary

In this experience, an itinerary across the four academic years of the Bachelor's degree on Industrial Electronics and Automation Engineering is proposed (see Figure 2). This itinerary must coherently combine the chosen SDGs along several subjects. In the implementation example, the problem of improving energy efficiency in public buildings was chosen. Thus, the proposed itinerary involved subjects related to energy consumption, measurement and control of mechanical devices. This itinerary is expected to grow in the future by including additional subjects such as electrical consumption and the sources used for generating required energy.

This itinerary allows, optionally, the completion of final degree projects related to thermal comfort and energy economy topics.

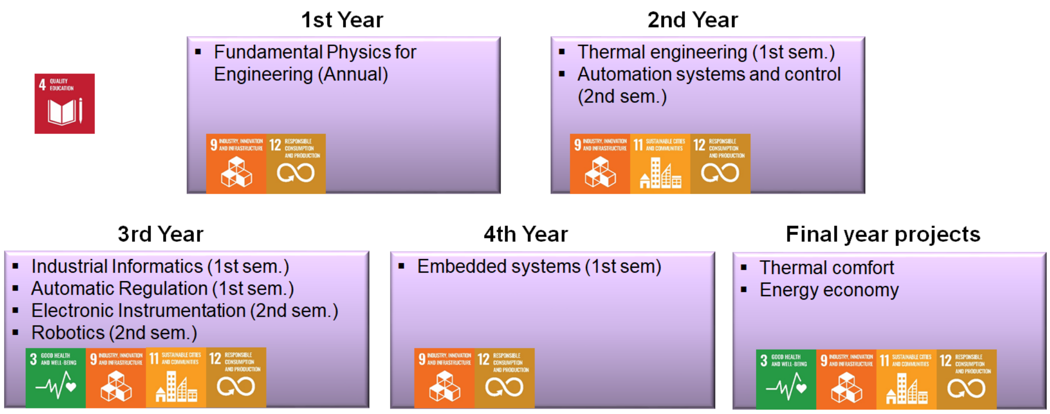

Figure 2. Itinerary along the degree on Industrial Electronics and Automation Engineering.

Figure 2 also presents the SDGs that were considered most relevant in each academic year. SDG 4, Quality Education, concerns the whole itinerary; this is why it was not assigned to a specific academic year.

4.5. Execution of the Activities

Table 1 presents the time, in hours per subject, that students spent in the classroom performing the proposed activities in the implementation during the selected degree. All proposed activities analysed the problem from different perspectives and depth, focussing on the following tasks: (1) analysis of the energy consumption; (2) design of monitoring and controlling systems and (3) selection of electronic devices, including sensors and actuators, as well as monitoring and control platforms. Appendix E describes in detail every subject and the activities taken.

Table 1. In-class hours to carry out the proposed activities of the educational innovative project.

Subject	Year	Semester	# of Class Hours
Fundamental Physics for Engineering	1st	Annual	4
Thermal Engineering	2nd	1st	6
Automation Systems and Control	2nd	2nd	4
Industrial Informatics	3rd	1st	30
Automatic Regulation	3rd	1st	4
Electronic Instrumentation	3rd	2nd	6
Robotics	3rd	2nd	8
Embedded Systems	4th	1st	4

Most activities were carried out in laboratory sessions, but some of them required support from several lectures to explain certain concepts in the classroom.

4.6. Assesment

To guarantee that they only considered the opinions of students taking part in the activities, questionnaires were issued in the classroom. Before starting the activity, students were informed about the reasons for this research and the voluntary nature of the surveys. Throughout the process, the confidentiality of the information collected was adequately safeguarded.

The pre-activity questionnaire measured the initial knowledge about SDG 3 (Good Health and Well-Being), SDG 4 (Quality Education), SDG 9 (Industry, Innovat ion and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production). It also collected the opinions of the students about the contribution of every particular subject to the selected SDGs. This questionnaire is available in Appendix A, in Table A1.

The questionnaire taken after the activity measured students' satisfaction with the activities carried out, as well as the connection of the proposed activity with the selected SDGs. Finally, it collected the opinions of the students about carrying out sustainability-related tasks in their future professional careers. All questions are available in Appendix B, Table A2.

4.7. Analysis of the Results

The results obtained after the multidisciplinary experience were, in general, positive since (1) the implementation incremented students' perception towards the SDGs; (2) students considered that the proposed activities were close to their experiences; (3) the evaluation of the activities was positive in general and (4) students considered that sustainability could become their future professional task. These results are analysed in detail in Section 5.

5. Results and Discussion

This section presents the results obtained from the questionnaires taken before and after the multidisciplinary activities in each subject and discusses the results obtained during the project implementation. Students responded while present in the classroom to the questionnaires, in the first and last sessions of the activities taken in every subject. The objectives of both questionnaires are described in Section 3.6. Questionnaires are available in Appendices A and B, respectively.

5.1. Questionnaire Results

The pre-activity questionnaire was answered 360 times in 8 subjects, while the post-activity questionnaire was answered 285 times. It can be noted that the number of responses to the questionnaire taken after the activity is lower than the number before the activity. This happened because some students reduced their attendance to the lectures at the end of the semester, which is a common situation in the EIVG. We consider that the number of responses obtained is meaningful. Table 2 summarises the number of enrolled students and questionnaire responses per subject. The summary of responses to the questionnaires taken before and after the activity are available in Appendix C, Table A3, and Appendix D, Table A4.

Table 2. Number of enrolled student per subject and responses to the questionnaires before and after the SDG activity.

Subject	Year	Enrolled Students	# of Questionnaires Pre-Activity	# of Questionnaires Post-Activity
Fundamental Physics for Engineering	1st	196	155	87
Thermal Engineering	2nd	70	25	15
Automation Systems and Control	2nd	88	75	59
Industrial Informatics	3rd	36	31	31
Automatic Regulation	3rd	31	23	23
Electronic Instrumentation	3rd	36	25	24
Robotics	3rd	44	21	21
Embedded Systems	4th	10	5	5

The next subsections describe in higher detail the characteristics of every subject as well as questionnaire-execution issues. The responses to some selected questions, before and after the execution of the activities, are also presented for each subject.

5.1.1. Fundamental Physics for Engineering

This subject is taken by a broad number of students since it is common to several Bachelor's degrees in Industrial Engineering (namely, Industrial Electronics and Automatics, Mechanical Engineering and Industrial Chemical). As part of the implementation, a special laboratory session was included to introduce the SDGs to the students and discuss how students could use their knowledge to achieve them. The surveys provided to the students were carried out during laboratory sessions.

As expected, students did not know the SDGs very well before the activity. After the introductory session, the questionnaire results proved that they knew all SDGs much better in general (Q1A: 2.9; Q1B: 4.1), as well as all selected SDGs (Q3B–Q7B). In general, students considered that the activity included the SDGs appropriately (Q13B: 4.4). This activity made students aware of the importance of achieving thermal comfort while ensuring appropriate heating usage (Q10B: 4.4). Finally, students considered that their future professional tasks could be connected to enhancing sustainability and achieving the SDGs (Q12B: 4.6).

5.1.2. Thermal Engineering

This subject is also common to several Bachelor's Degrees in Industrial Engineering, being taken by a broad number of students. In the subject of Thermal Engineering, the proposed activity was carried out during the last six weeks of the semester. Students worked in groups, thus promoting the development of transversal competences such as collaborative work and critical thinking.

The results of the pre-activity and post-activity surveys showed that the majority of the students who completed the task considered that this activity connected especially well with the following SDGs: SDG 9 (Q4B: 4.7), SDG 11 (Q5B: 4.4) and SDG 12 (Q6B: 4.2). They also considered appropriate the way that these SDGs had been integrated into the subject (Q8B: 5.1). In addition, students thought that this activity allowed them visualising how to contribute to achieving the SDG targets from engineering studies (Q9B: 5.1). Overall, the majority of students considered the activity as a good example to develop the SDGs through the skills and competences of the subject.

5.1.3. Automation Systems and Control

This subject is also taken by a broad number of students since it is common to several Bachelor's degrees in Industrial Engineering. According to the results of the survey, it can be concluded that, at the beginning of the activity, students had a general understanding of the SDGs (Q1A: 4.4). This might be because this subject was taught during the second semester and most students had already taken the Thermal Engineering subject during the first semester of the same academic year. They considered that achieving the SDGs affected them (Q8A: 5.1) and, consequently, should be included in engineering degrees (Q9A: 5.2) by means of experiences close to students (Q2A: 5.2). Students felt that this particular subject might contribute mostly to achieve SDG 9 (Q16A: 5.4).

After the activity, students considered that they had a better understanding of the SDGs in general (Q1B: 4.6), and, in particular, of SDG 9 (Q4B: 5.0), SDG 11 (Q5B: 4.9) and SDG 12 (Q6B: 4.8). Students felt that this subject could contribute to improve sustainability (Q7B: 5.2), and considered that, overall, the inclusion of the SDGs in the subject was appropriate (Q13B: 5.1). They also thought that the activity provided a good example to enhance sustainability (Q9B: 5.0), raising awareness of the balance between achieving thermal comfort and ensuring appropriate heating usage (Q10B: 5.1).

5.1.4. Industrial Informatics

This subject is taken in the third year of the degree, in the first semester. It can be observed that students had a moderate general understanding about the SDGs (Q1A: 3.7). However, they considered that these goals affect them personally (Q8A: 5.1) and, consequently, should be included in the engineering studies (Q9A: 5.5). In particular, they pointed out that sustainability-related aspects, such as responsible use of resources, should be considered in the design of engineering solutions (Q11A: 6.3), preferably by means of activities close to students' interests (Q10A: 5.1). Before the activity, they felt that this subject could contribute particularly to SDG 9 (Q16A: 5.8).

After the activity, they considered that the tasks proposed in this subject connected best with SDG 9 (Q4B: 4.6). They found that it was appropriate to integrate the proposed SDGs in the subject (Q8B: 5.1) since the activity carried out in class raised awareness of achieving thermal comfort while ensuring appropriate heating usage (Q10B: 5.1). Finally, students felt that their future professional tasks could be somehow related to enhancing sustainability (Q12B: 5.1). In general, students said that the overall inclusion of the SDGs in the subject was appropriate (Q13B: 4.8).

5.1.5. Automatic Regulation

This is also a third-year, first-semester subject. Before the activity, students indicated that they knew SDG 9, SDG 11, and SDG 12 best, with values of 4.1 (Q5A), 4.1 (Q6A) and 4.0 (Q7A), respectively. After the activity, the students declared that the proposed activity connected the course with the aforementioned SDGs with values of 5.0 (Q4A), 4.8 (Q5A) and 4.5 (Q6A), respectively, which shows a positive impact of the activity among the students. These results prove that students deepened their knowledge of these SDGs and that there is a direct link between the Automatic Regulation course and the mentioned SDGs.

The initial expectation of the students regarding how much the Automatic Regulation course can contribute to raise awareness of the SDGs in general is 4.9 (Q13A); at the end of the intervention, the students considered it adequate (with a 5.3 in Q13B), in terms of how the SDGs had been introduced in the course. In the opinion of the authors, this result indicates that the activity proposed in the Automatic Regulation course contributed positively to raise awareness and train students in the SDGs. Finally, it is noteworthy that students considered that their future professional tasks could be related to sustainability, with a mark of 5.5 (Q12B).

5.1.6. Robotics

This subject is taught during the third year, second semester. Consequently, most of the students took it after Industrial Informatics and Automatic Regulation. The results of the questionnaires proved that the activity developed in this subject incremented knowledge about the SDGs in general (Q1A: 4.3 vs. Q1B: 4.6). In particular, it increased the knowledge of most of the selected SDGs: SDG 3 (Q3A: 4.0 vs. Q2B: 4.8); SDG 4 (Q4A: 4.0 vs. Q3B: 4.1) and SDG 11 (Q6A: 4.5 vs. Q5B: 4.8).

In the pre-activity questionnaire, students considered that achieving SDGs was a matter that affected them (Q8A: 5.0) and, consequently, that they should be included in the engineering degrees (Q9A: 5.5) by means of activities close to student interests (Q12A: 6.0). Finally, they considered that Robotics was mostly connected to SDG 9 (Q16A: 5.7). In the post-activity questionnaire, students felt that the Robotics course could contribute to improve sustainability (Q7B: 5.3) and that the proposed SDGs were appropriately integrated in the subject (Q8B: 5.3). Again, after the activity, students considered that their future professional tasks could be linked to sustainability issues (Q12A: 5.1).

5.1.7. Electronic Instrumentation

Most students took this subject in parallel with Robotics, during the second term of the third academic year. The responses to the questionnaires showed that, similarly to other subjects, the degree of general knowledge about the SDGs was incremented after the activity: 3.6 (Q1A) vs. 5.1 (Q1B). The same happened with all the selected SDGs: SDG 3 (Q3A: 3.5 vs. Q2B: 4.7); SDG4 (Q4A: 3.8 vs. Q3B: 4.2); SDG 9 (Q5A: 4.1 vs. Q4B: 4.8); SDG 11 (Q6A: 3.9 vs. Q5B: 4.8) and SDG 12 (Q7A: 3.6 vs. Q6B: 4.7). Additionally, they considered that it would be necessary to introduce activities close to students' interests (Q12A: 5.3).

The post-activity questionnaire shows that the contents of this subject could contribute to improve sustainability (Q7B: 5.6) and that it was appropriate to integrate SDGs in the subject (Q8B: 5.6). Students considered that, overall, the inclusion of the SDGs in this subject was appropriate (Q13B: 5.4) since it allowed visualisation of how to contribute to improving the SDGs through engineering studies (Q11B: 5.1).

5.1.8. Embedded Systems

This is an elective subject taken during the first semester of the fourth academic year of the degree. This is a quite specific subject that introduces common tools used in industry. In the Industrial Electronics and Automation Engineering degree, students may choose between attending some elective subjects or undertaking practical work in local companies, which is the most common option. For this reason, the number of students enrolled in this elective subject was small.

The results of the questionnaires were in parallel with other subjects. In general, the activity increased the general knowledge about the SDGs (Q1A: 2.4 vs. Q1B: 4.8). The same happened regarding the selected SDGs: SDG 3 (Q3A: 2.4 vs. Q2B: 4.2); SDG 4 (Q4A: 2.0 vs. Q3B: 4.6); SDG 9 (Q5A: 2.6 vs. Q4B: 4.6); SDG 11 (Q6A: 3.2 vs. Q5B: 4.4) and SDG 12 (Q7A: 2.2 vs. Q6B: 4.8). In addition, they would welcome the introduction of activities close to students' interests (Q12A: 6.0), particularly connected with the responsible use of resources (Q11A: 5.2).

The post-activity questionnaire showed that students believed that this subject could contribute to improving sustainability (Q7B: 5.0) and that the inclusion of the SDGs by means of the proposed activity was appropriate (Q13B: 5.2). Finally, the activity helped students to consider sustainability as a possible future professional domain (Q12B: 5.0).

5.1.9. Final-Year Project

Several final degree projects continued some of the tasks identified in the different subjects involved in this implementation. These final degree projects developed more deeply some issues related to the proposed case study. This approach enriched the activities of the innovative educational project and, at the same time, allowed students to learn how to continue until reaching, for example, a final product that could be marketed. As a matter of example, one final degree project already carried out involved the evolution of some of the activities proposed to the students in the multidisciplinary itinerary.

In particular, it involved using the OpenFog standard (IEEE 1934-2018) to combine artificial intelligence techniques, particularly Fuzzy logic, with IoT technologies to improve indoor comfort, safety and environmental conditions inside the Faculty building. The results were published in [64,65].

5.2. Discussion

The presented implementation illustrated the application of the methodology to materialise the introduction of several SDGs (namely, SDG 3, SDG 4, SDG 9, SDG 11 and SDG 12) in the curricula of the Bachelor's degree on Industrial Electronics and Automation Engineering in the Faculty of Engineering of Vitoria-Gasteiz (UPV/EHU). For this purpose, a multidisciplinary project, involving eight activities during the degree, as well as, optionally, the final degree project, was designed.

The results of the pre-activity questionnaires proved that, before doing the activities, students had a moderate understanding of the SDGs in general (Q1A: 3.6/7.0) and about the particular SDGs considered in this implementation (Q3A–Q7A).

Students perceived that the achievement of these goals had important influence in their lives (Q8A: 4.7/7.0) and, consequently, should be introduced into their engineering degrees (Q9A: 4.8/7.0). However, they considered that, currently, SDGs were superficially addressed by the UPV/EHU (Q10A: 3.9/7.0). Students felt that sustainability-related topics, such as responsible use of resources, should be included in the design of engineering solutions (Q11A: 5.2/7.0), preferably by means of activities (projects or problems) close to the students' experiences (Q12A: 5.5/7.0). In particular, they showed the highest interest in SDG 9 (Q16A: 5.1/7.0).

The results of the post-activity questionnaires (see Appendix D, Table A4) showed that, in general, the proposed activities allowed a better understanding of the SDGs in general (Q1B: 4.4/7.0). Students also considered that the proposed activities connected the subjects with the SDGs selected in the project relatively well (Q2B–Q6B). In most cases, the values obtained for the questions related to these specific SDGs (Q2B–Q6B) increased when compared to the values obtained before carrying out the activities (Q3A–Q7A). Particularly, they considered that the presented activities had a special connection with SDG 9 (Q4B: 4.7/7.0). In fact, this was precisely the original motivation of the CBL project from which this educational innovative project stemmed. In general, students considered that the contents of the subjects could contribute to improve sustainability (Q7B: 4.9/7.0). Moreover, students felt that the proposed activities allowed for visualisation of how to contribute to improving the SDGs through engineering studies (Q11B: 4.7/7.0). Actually, the overall inclusion of the SDGs in these subjects was considered appropriate (Q13B: 4.8/7.0). Finally, according to the responses from the students, they thought that their future professional endeavors could involve enhancing sustainability issues and achieving the SDGs (Q12B: 4.9/7.0).

Figure 3 summarises the major findings obtained after analysing the results of selected questions of the questionnaires. The responses to the questionnaires after the implementation allow the authors to answer the research questions:

RQ1: How to introduce the SDGs in the curricula of engineering degrees by means of concrete activities. In the implementation example, several SDGs (namely, SDG 3, SDG 4, SDG 9, SDG 11 and SDG 12) were included in the curriculum of the Bachelor's degree on Industrial Electronics and Automation Engineering by means of activities intertwined in several subjects.Figure 3a comprises all responses to questions Q1A and Q1B, related to the general understanding towards the SDGs before and after the concrete activities. Also, when students were asked for particular SDGs before (questions Q3A–Q7A) and after (questions Q2B–Q6B) the obtained results proved that the project implementation always achieved an increment in all SDGs and, particularly, with some of the selected SDGs, namely, SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 12 (Responsible Consumption and Production). From these responses, the authors conclude that implementing this kind of multidisciplinary activity, covering several subjects, is a suitable way of introducing the SDGs in the curricula of engineering degrees;

RQ2: How multidisciplinary experiences, which intertwine several subjects, should be designed to engage students. Figure 3b shows the responses to question Q12A in all subjects. Obtained results confirm that students clearly demand the introduction of activities related to their interests in order to include sustainability in the curricula since all responses have high values. This encourages academic staff to find engaging activities. Figure 3c shows that students consider that the inclusion of the SDGs by means of the intertwined activities carried out in every subject was appropriate (question Q13B). This may be used as an indicator to show that the presented methodology and the proposed activities engaged students;

RQ3: How to make students aware that the skills acquired during the degree may help them to design and develop sustainability-related projects in their future professional activities. Finally, question Q12B, shown in Figure 3d, has been used as an indicator of the students' awareness towards using the skills acquired during the degree in their future tasks. In general, the responses were positive, especially in the most technical subjects, taught in the third and fourth years (i.e., Industrial Informatics, Automatic Regulation, Electronic Instrumentation, Robotics and Embedded Systems). From the obtained results, the authors conclude that the activities, based on real problems, close to the students, motivated them to consider sustainability-related tasks as a possible future professional activity.

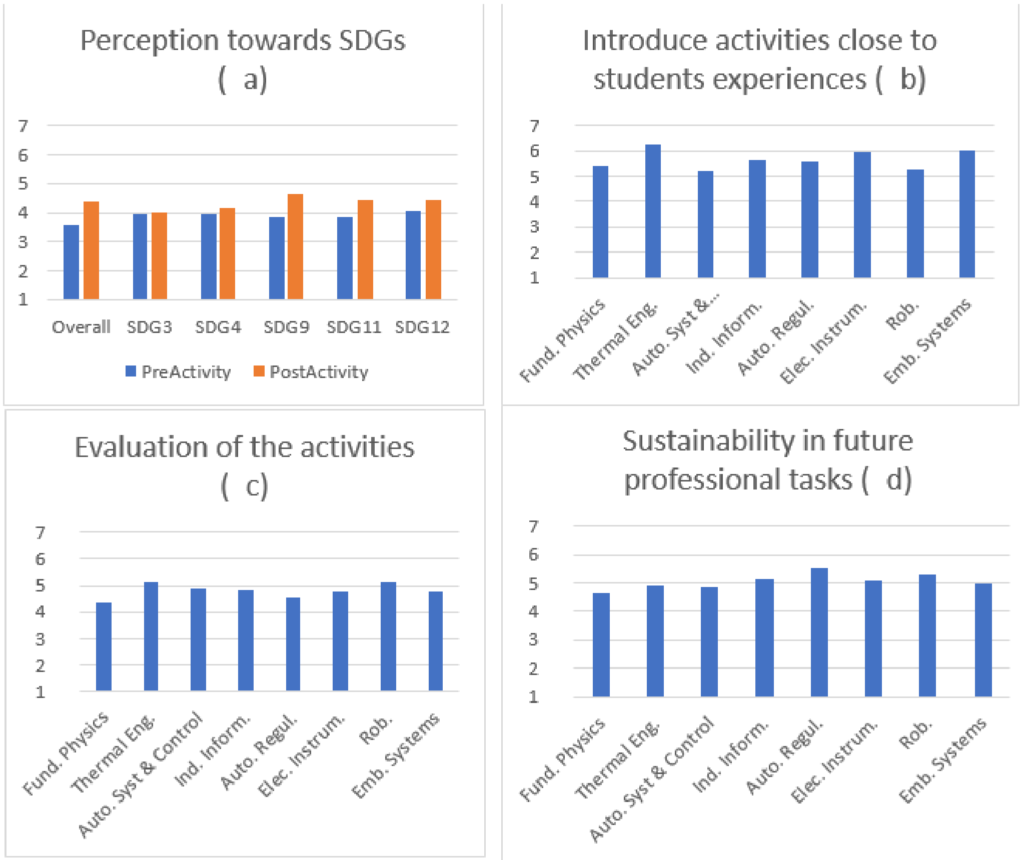

Figure 3. Summary of the mean values obtained from selected responses of the questionnaires. Students' responses always range from 1 to 7. (**a**) shows the overall perception about SDGs as well as about the selected SDGs, before and after the activities. (**b**) shows that students demand activities close to their experiences. (**c**) shows the overall evaluation of the activities carried out in each subject. (**d**) shows the perception by students towards carrying out sustainability related tasks in their future professional activity.

Obtained results proved that, in general, the implementation of the multidisciplinary experience was successful. However, it is important to note, that, although the project is designed to cover the whole degree, the 2022/23 academic year was the first time it was carried out. Activities in all courses were simultaneously implemented during the same academic year. Consequently, the responses obtained from the questionnaires are not necessarily correlated with the expected progression along the degree itinerary.

6. Conclusions and Future Work

The introduction of sustainability issues in engineering degrees is a complex task and, currently, it is still incipient in a broad number of Higher Education Institutions. One of the reasons is that sustainability applications in engineering are typically multidisciplinary and the current design of the curricula compartmentalises the knowledge into subjects.

In this scenario, it is necessary to materialise the introduction of the SDGs in the curricula of engineering degrees following a systemic approach (RQ1); design multidisciplinary experiences, intertwining several subjects, which engage students (RQ2) and make students aware that the skills acquired during the degree may help them to design and develop sustainability related projects in their future professional activity (RQ3).

This article tries to guide academic staff to materialise the introduction of sustainability-related multidisciplinary experiences by means of concrete activities that group several SDGs in a coherent way. For that purpose, it presents some principles and guidelines that may help professors and instructors to design new educational activities.

Since professors and instructors may benefit from knowing multidisciplinary experiences carried out in different institutions, this work also presents the implementation of a multidisciplinary experience into the Bachelor's degree on Industrial Electronics and Automation Engineering at the EIVG (UPV/EHU) throughout the 2022/23 academic year. This experience was aimed at increasing knowledge about the SDGs and proposing specific actions to contribute to their achievement. The authors used active methodologies for implementing the activities since, according to the literature, they have been found particularly suitable for developing the concept of sustainability in educational programs. The authors selected a problem close to the students' context, following recommendations for implementing active methodologies, since this facilitates their understanding. Specifically, the authors chose the problem of analysing the thermal comfort in the EIVG Faculty building and proposing actions to optimise energy consumption, this background allows us to introduce one of the transformations proposed in [9]. Namely, it is related to decarbonisation of energy systems by improving energy efficiency and final energy use in public buildings.

Along this experience, the authors designed an educational itinerary across eight courses throughout the four academic years of the degree program, involving issues related to energy consumption, measurement and control of mechanical devices. Thus, the proposed problem became the common thread to introduce multidisciplinarity and gain a deeper understanding about one problem from different perspectives. The presented approach reproduces in the classroom the conditions that students will face in their future professional work, where they will have to tackle tasks holistically. Thus, the compartmentalisation of knowledge in separate courses is reduced. Various activities of different duration and complexity were proposed in each of the involved courses, ranging from 4 to 30 classroom hours. These activities were aimed at solving specific problems using active methodologies.

In each course, two surveys were conducted: one at the beginning of the activity to assess students' perception towards the SDGs and their connection to the taught subjects, and another at the end of the activity to evaluate the conducted activity. The analysis of the questionnaire results proved that the understanding of the SDGs increased after performing the multidisciplinary activities (RQ1), that the proposed activities, which were close to the experience of the students, were engaging (RQ2) and that these activities motivated students to consider that sustainability-related tasks may become part of their future professional activity (RQ3). These results proved that, in general, the implementation of the multidisciplinary experience was successful.

The implementation in the Bachelor's degree on Industrial Electronics and Automation Engineering is a preliminary experience for introducing sustainability-related issues in engineering degrees by means of multidisciplinary activities. Currently, this study presents certain limitations. On one side, it was only implemented during one year and over one engineering degree. After analysing the questionnaire results, the authors consider that the implementation during the first year was successful; however, it is necessary to evaluate a longer implementation period. Also, it would be convenient to test the presented approach in other engineering degrees. Another limitation comes from the fact that, traditionally, the engineering teaching curricula tend to be compartamentalised into subjects, at least in our Faculty. The presented approach tried to mitigate this inconvenience, but the implementation was challenging for several reasons: (1) it should coordinate a broad number of subjects as well as professors and instructors; (2) the syllabus of every subject was very tight, making it difficult to include all important contents and (3) the proposed activities were intertwined within the multidisciplinary project. Other issues may arise when modifications in the syllabus of the subjects are required since the contents are more intertwined.

Overall, this experience is expected to continue for several years and, consequently, it must be able to adapt to new scenarios. Currently, the authors are trying to balance the interrelation among the proposed activities in terms of the number of hours and qualification weight. Ideally, there should also be more subjects involved in order to provide more perspectives of the same problem. At present, the authors are working to include subjects related to electrical technology in the multidisciplinary experience. Finally, the authors consider it important to include not only the technical issues involved in the selected subjects, but also the related social issues.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board (or Ethics Committee) of the Faculty of Engineering of Vitoria-Gasteiz, on 16 May 2022.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

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

Appendix A. Pre-Activity Questionnaire

This Appendix includes the questions asked in the questionnaire taken in each subject before undertaking the activities proposed in the project. All responses indicate students' degree of agreement with the proposed questions, which range from 1, meaning the lowest value of the response (totally disagree), to 7, meaning the maximum value (totally agree). This questionnaire is aimed at evaluating the degree of knowledge about the SDGs, as well as the experiences of the students.

Table A1. Questionnaire taken before the activity.

#	Question
Q1A	I have a general understanding of the United Nations' Sustainable Development Goals (SDGs)
Q2A	I believe that society shares and embraces these SDGs
	I am familiar with the following SDGs:
Q3A	a. Good Health and Well-being (SDG 3)
Q4A	b. Quality Education (SDG 4)
Q5A	c. Industry, Innovation, and Infrastructure (SDG 9)
Q6A	d. Sustainable Cities and Communities (SDG 11)
Q7A	e. Responsible Consumption and Production (SDG 12)
Q8A	I believe that the development of these goals personally affects me
Q9A	I think that the engineering studies should include the SDGs
Q10A	I believe that currently, UPV/EHU adequately incorporates the SDGs in the engineering degrees
Q11A	I think that sustainability-related aspects, particularly the responsible use of resources, should be considered in the design of engineering solutions.
Q12A	I believe that it is necessary to introduce activities (projects or problems) close to students' experiences to explore how sustainability can be improved.
Q13A	I think that the content of THIS SUBJECT could contribute to raising awareness about the SDGs in general.
	I believe that THIS SUBJECT can contribute to achieving each of the following SDGs:
Q14A	a. Good Health and Well-being (SDG 3)
Q15A	b. Quality Education (SDG 4)
Q16A	c. Industry, Innovation, and Infrastructure (SDG 9)
Q17A	d. Sustainable Cities and Communities (SDG 11)
Q18A	e. Responsible Consumption and Production (SDG 12)

Appendix B. Post-Activity Questionnaire

This Appendix includes the questions asked in the questionnaire taken in each subject after undertaking the activities proposed in the project. All responses indicate students' degree of agreement with the proposed questions, which range from 1, meaning the lowest value of the response (totally disagree), to 7, meaning the maximum value (totally agree). This questionnaire is aimed at evaluating whether the activities taken in every subject have improved the understanding of the SDGs as well as the degree of student satisfaction with the proposed activities.

Table A2. Questionnaire taken after the activity.

#	Question
Q1B	The activity carried out in class allows for a better understanding of the SDGs in general.
	The proposed activity connects the subject with the following SDGs:
Q2B	a. Good Health and Well-being (SDG 3)
Q3B	b. Quality Education (SDG 4)
Q4B	c. Industry, Innovation, and Infrastructure (SDG 9)
Q5B	d. Sustainable Cities and Communities (SDG 11)
Q6B	e. Responsible Consumption and Production (SDG 12)
Q7B	I believe that the content of THIS SUBJECT can contribute to improving sustainability.
Q8B	I think it is appropriate that the proposed SDGs are integrated into THIS SUBJECT.
Q9B	The proposed activity is a good example of how to enhance sustainability and promote the SDGs through the knowledge and skills acquired in THIS SUBJECT.
Q10B	The activity carried out in class raises awareness of achieving thermal comfort while ensuring appropriate heating usage.
Q11B	The proposed activity allows for visualising how to contribute to improving the SDGs through engineering studies.
Q12B	I believe that my future professional tasks may be related to enhancing sustainability and achieving the SDGs.
Q13B	Overall, I consider the inclusion of the SDGs in THIS SUBJECT to be appropriate.

Appendix C. Results of the Pre-Activity Questionnaire

Table A3. Summary of responses obtained from the questionnaire taken before the activity.

Subject		**Q1A**	**Q2A**	**Q3A**	**Q4A**	**Q5A**	**Q6A**	**Q7A**	**Q8A**	**Q9A**	**Q10A**	**Q11A**	**Q12A**	**Q13A**	**Q14A**	**Q15A**	**Q16A**	**Q17A**	**Q18A**
Fundamental Physics for Engineering	Average	2.9	3.6	3.4	3.6	3.3	3.4	3.7	4.4	4.4	3.9	4.9	5.4	4.3	4.3	4.1	4.7	4.3	4.4
	Stand. Dev.	1.7	1.3	1.9	1.9	1.8	1.8	1.9	1.5	1.7	1.4	1.5	1.7	1.5	1.3	1.5	1.5	1.6	1.5
Thermal Engineering	Average	4.1	4.1	4.3	4.0	4.2	4.0	4.4	4.4	4.9	4.1	5.5	6.3	5.2	3.7	4.0	5.3	5.0	5.0
	Stand. Dev.	1.7	1.4	1.5	1.7	1.7	1.8	1.7	1.7	1.4	1.1	0.9	1.2	1.4	1.6	1.4	1.4	1.5	1.4
Automation Systems and Control	Average	4.4	4.3	4.9	4.7	4.4	4.4	4.7	5.1	5.2	3.9	5.3	5.2	4.5	4.2	4.8	5.4	4.7	5.0
	Stand. Dev.	1.6	1.2	1.3	1.4	1.4	1.3	1.5	1.3	1.5	1.5	1.1	1.4	1.5	1.5	1.3	1.2	1.2	1.4
Industrial Informatics	Average	3.7	4.1	4.1	4.4	4.3	4.1	4.2	5.1	5.5	3.7	6.3	5.6	4.6	3.9	4.7	5.8	4.9	4.9
	Stand. Dev.	1.9	1.3	1.8	1.7	1.8	2.0	1.8	1.7	0.9	1.2	0.7	1.2	1.1	1.4	1.3	0.8	1.5	1.6
Automatic Regulation	Average	4.5	4.4	4.3	4.4	4.1	4.1	4.0	5.3	5.3	4.3	5.3	5.6	4.9	4.1	4.2	5.7	5.2	4.7
	Stand. Dev.	1.7	1.2	1.6	1.7	1.5	1.6	1.7	1.2	1.1	1.3	1.3	1.4	1.3	1.5	1.7	1.1	1.2	1.5
Electronic Instrumentation	Average	4.3	4.2	4.0	4.0	4.6	4.5	4.5	5.0	5.5	3.9	5.7	6.0	4.5	3.7	4.0	5.7	4.7	5.0
	Stand. Dev.	1.7	1.2	1.6	1.8	1.5	1.5	1.6	1.2	0.9	0.8	1.3	0.9	1.2	1.7	1.5	0.9	1.4	1.4
Robotics	Average	3.6	3.5	3.5	3.8	4.1	3.9	3.6	5.2	4.8	3.4	5.2	5.3	4.1	3.8	3.9	4.9	4.3	3.9
	Stand. Dev.	1.4	1.0	1.7	1.6	1.5	1.9	2.1	1.6	1.5	1.7	1.9	1.4	1.8	1.7	1.6	1.5	1.7	1.7
Embedded Systems	Average	2.4	2.6	2.4	2.0	2.6	3.2	2.2	4.0	4.6	2.6	5.2	6.0	3.2	1.8	3.0	4.4	2.6	3.0
	Stand. Dev.	0.9	1.1	1.1	1.0	1.3	1.6	1.1	1.7	1.5	1.3	0.8	2.3	1.6	1.3	2.0	1.8	1.5	1.9
All responses	Average	4.4	4.0	4.1	4.7	4.4	4.4	4.9	5.0	4.7	4.7	4.7	4.9	4.8	4.4	4.0	4.1	4.7	4.4
	Stand. Dev.	1.4	1.6	1.4	1.4	1.5	1.4	1.3	1.3	1.3	1.5	1.3	1.4	1.4	1.4	1.6	1.4	1.4	1.5

Appendix D. Results of the Post-Activity Questionnaire

Table A4. Summary of responses obtained from the questionnaire taken after the activity.

Subject		Q1B	Q2B	Q3B	Q4B	Q5B	Q6B	Q7B	Q8B	Q9B	Q10B	Q11B	Q12B	Q13B
Fundamental Physics for Engineering	Average	4.1	3.6	4.1	4.3	4.0	4.2	4.4	4.5	4.1	4.4	4.4	4.6	4.4
	Stand. Dev.	1.3	1.6	1.4	1.5	1.6	1.4	1.3	1.4	1.4	1.4	1.2	1.4	1.4
Thermal Engineering	Average	4.3	3.3	3.6	4.7	4.4	4.9	4.9	5.1	5.0	5.1	5.1	4.9	4.4
	Stand. Dev.	1.5	1.6	2.1	1.9	2.1	2.0	1.4	1.2	1.3	1.8	1.6	1.3	1.8
Automation Systems and Control	Average	4.6	4.5	4.7	5.0	4.9	4.8	5.2	5.1	5.0	5.1	4.9	4.9	5.1
	Stand. Dev.	1.3	1.3	1.2	1.3	1.3	1.4	1.1	1.2	1.2	1.3	1.5	1.2	1.3
Industrial Informatics	Average	3.9	3.5	3.5	4.6	4.1	4.1	4.8	5.1	4.8	5.1	4.8	5.1	4.8
	Stand. Dev.	1.3	1.5	1.1	1.5	1.5	1.3	1.2	1.2	1.2	1.4	1.1	1.1	1.3
Automatic Regulation	Average	4.4	3.6	3.8	5.0	4.8	4.5	5.2	5.1	5.0	5.0	4.5	5.5	5.3
	Stand. Dev.	1.6	1.5	1.5	1.5	1.6	1.6	0.9	1.4	1.2	1.4	1.2	1.0	1.4
Electronic Instrumentation	Average	4.6	4.8	4.1	4.6	4.8	4.1	5.3	5.3	4.8	4.1	4.8	5.1	4.6
	Stand. Dev.	1.6	1.2	1.5	1.5	1.5	1.3	1.3	1.4	1.3	2.0	1.5	1.6	1.4
Robotics	Average	5.1	4.7	4.2	4.8	4.8	4.7	5.6	5.6	5.1	5.0	5.1	5.3	5.4
	Stand. Dev.	1.2	1.5	1.5	1.2	1.1	1.3	1.1	1.4	1.3	1.2	1.1	1.5	1.3
Embedded Systems	Average	4.8	4.2	4.6	4.6	4.4	4.8	5	4.8	4.6	4.4	4.8	5.0	5.2
	Stand. Dev.	0.8	0.8	0.5	0.5	1.1	0.4	0.7	1.3	0.5	0.9	1.3	1.2	1.1
All responses	Average	4.4	4.0	4.1	4.7	4.4	4.4	4.9	5.0	4.7	4.7	4.7	4.9	4.8
	Stand. Dev.	1.4	1.6	1.4	1.4	1.5	1.4	1.3	1.3	1.3	1.5	1.3	1.4	1.4

Appendix E. Itinerary and Activities per Subject

Appendix E.1. Fundamental Physics for Engineering

This is a core subject that introduces basic physical principles. It is taught annually during the first year. Among other physical concepts, the subject introduces fundamental principles of physics related to thermodynamics and electricity. Additionally, this subject introduces the SDGs and their relationship with energy.

As part of the educational innovation project, a 4 h class activity was designed. Students measured the heat dissipated in an electric resistor using calorimetric techniques. This laboratory activity illustrated that any operating electrical device dissipates energy in the form of heat. This fact represents wasted energy in most cases, contributing negatively to global warming. The proposed activity involved conducting an energy balance to estimate the dissipated energy in the form of "non-useful" energy, using Ohm's law, Joule's law and the principle of energy conservation.

Appendix E.2. Thermal Engineering

This is a compulsory semester-long subject taught during the first semester of the second year. The subject builds upon previously acquired thermodynamics concepts. One of the learning objectives is to analyse energy consumption in different applications, promoting their rational and sustainable use, as well as their economic impact.

Within the framework of the educational innovation project, a 6 h class activity is proposed to precisely characterise the behaviour of radiators, which act as heat-emitting units, in order to adjust heat production to the demand for climate control in the most efficient way.

Specifically, the geometry of a heat-emitting unit, as well as the necessary data of the supply water, desired ambient temperature, outdoor temperature and thermal characteristics of surfaces near the radiator were given to the students. The behaviour of a heat-emitting unit was simulated using the student version of ANSYS 2020 R2 Fluent software.

This simulation allowed students to understand the effect of water flow rate and supply temperature on the total emitted power, temperature distribution of the radiator and temperature field of the room's air.

Appendix E.3. Automation Systems and Control

This is a compulsory semester-long subject taught in the second semester of the second year. The subject introduces basic concepts related to automation and control systems, as well as the commercial industrial devices that perform these tasks.

In this subject, a 4 h class activity was proposed to automate the operation of a ventilation system consisting of a casement window and a CO_2 meter. Limit switch sensors were used to determine the window position, and a safety sensor was also employed. The CO_2 meter allowed monitoring of the air quality in the room. The system had two operating modes: automatic and manual. In manual mode, the window operation was controlled by two command buttons: one to open the window and another to close it. In automatic mode, the window would open or closed based on the measurements obtained from the CO_2 sensor.

For the development of this activity, commercial industrial devices were used. Specifically, Siemens programmable logic controllers (PLCs) and their corresponding programming and simulation tools.

Appendix E.4. Industrial Informatics

This is a compulsory semester-long subject taught in the first semester of the third year. This subject introduces computer tools oriented towards monitoring and control tasks in industrial applications. There is a special emphasis on application programming and communications.

Within the framework of the i3KD project, an activity was designed for students to develop along all the laboratory sessions of the course (30 h). The proposed project applied the PBL methodology to build an IoT system that allows monitoring of some environmental variables in the Faculty of Engineering Vitoria-Gasteiz using existing communications infrastructure based on WiFi technology. Specifically, temperature, humidity, CO_2 and luminosity were monitored in the laboratory classroom where the practical exercises took place. A custom-designed Smart sensor prototype based on Arduino MKR WiFi boards was used. The data acquired by the smart sensors were transmitted to centralised devices, based on Single-Board Computers like Raspberry Pis. These devices evaluated the thermal comfort of the Faculty building at different locations and analysed the energy consumption. A part of the project focused on data analysis of the acquired climatic variables. It involved visualising and analysing, both online and offline, the acquired climatic variables acquired with the Python programming language.

This project aimed to raise awareness among the university community at EIVG about the energy consumption in the classroom.

Appendix E.5. Automatic Regulation

This is a compulsory semester-long subject taught in the first semester of the third year. This subject introduces concepts of systems theory, including the modelling, analysis and design of control systems.

Throughout the subject, temperature control is used to introduce concepts related to system modelling, analysis and design of automatic controllers. As part of the innovation project, a 4 h activity was conducted to introduce the computer as a control element. This activity was designed to allow students to visualise the characteristics, functions and advantages of digital systems based on microcomputers in process control tasks. The activity also included an initial approach to use a controller to implement a discrete Proportional–Integral–Derivative controller (PID) in a temperature control system. To illustrate the implementation, a pseudo-language program was developed with the objective of implementing a discrete PID.

Appendix E.6. Robotics

This is a compulsory semester-long subject taught in the second semester of the third year. This subject provides an introduction to general concepts related to mechanical structure, programming, motion generation, robot control, operation of robotic systems and their applications in industrial environments.

As part of the educational innovation project, an 8 h activity was designed. This task continued the activity developed in the Automatic Regulation subject. More specifically, the task involved simulating the design of an automatic control system to open and close the windows of a motorised installation in the laboratory where the practical exercises were conducted. The control system used measurements from CO_2 and temperature sensors to generate the window opening reference within a range of 0 to 40 cm. Subsequently, using a PID controller, the task was to generate the control signal that activated an electric motor to regulate the window opening in the laboratory.

This application serves as a guiding thread to develop the subject's content related to modelling robotic systems and designing PID controllers to control the motion of electric motors that actuate robotic manipulators.

Appendix E.7. Electronic Instrumentation

This is a compulsory semester-long subject taught in the second semester of the third year. This subject is aimed at designing electronic systems applied to the measurement, monitoring and recording of various physical quantities.

As part of the educational innovation project, a 6 h activity was designed. The objective of the activity was to record the temperature of a room or the outdoors (ambient temperature) over a period of time.

Different temperature sensors were used to measure the temperature. In this way, students were able to verify that, depending on the conditioning and temperature range to be measured, it is more convenient to use certain sensors over others. Students had to consider the desired sensitivity and the trade-off between simplicity and cost of the solution used. In the activity, students were asked to record the data for a full day using National Instruments' LabVIEW 2021 software.

Students followed the procedure described in [15] to condition the sensor and record temperatures. They were asked to analyse the temperature data obtained from different sensors to identify the best sensors for each type of application. This approach aims to encourage students to make reasoned choices when selecting sensors for specific applications.

Appendix E.8. Embedded Systems

This is an elective semester-long subject taught in the first semester of the fourth year. This subject focuses on the design and implementation of equipment based on modern microcontrollers from the Cortex-M family, using a set of commonly used advanced tools.

In the context of the innovation project, a 4 h activity was designed. The proposed activity aimed to analyse the energy consumption generated by electronic devices that use these microcontrollers, which are commonly used in IoT applications. It also aimed to teach students how to minimise energy consumption by programming different low-power modes. In the initial phase, a theoretical study was conducted to examine the impact on consumption using the energy analyser provided in the STM32CubeIDE programming environment. After that, experimental measurements of the current consumed in different low-power modes were taken. The experimental measurements were compared with the values provided by the manufacturer. During the activity, the direct relationship between the clock speed used in the microcontroller and the energy consumption of the device was observed. Additionally, the different ways to exit low-power modes in each case were analysed.

This approach raised awareness about the consumption of IoT devices and allowed for the estimation of battery life.

This is the only elective subject covered in the project. Typically, these kinds of subjects complement, in a practical way, theoretical concepts already introduced in previous compulsory subjects. Consequently, all students participating in the multidisciplinary project are aware of the problem of the energy consumption of IoT devices, but the students that take this subject learn to use advanced tools to reduce it.

Appendix E.9. Final-Year Project

The approach followed in the i3KD educative innovation project approach is aimed at having students carry out Bachelor's final degree projects, worth 12 ECTS credits, on the project's theme: thermal comfort and energy economy. Currently, several final degree/Master's projects are being conducted that develop comprehensive solutions based on different technologies. One of these works was an evolution of some of the activities proposed to the students. In particular, it involved using the OpenFog standard (IEEE 1934-2018) to combine artificial intelligence techniques (Fuzzy logic) with IoT technologies to improve indoor comfort, safety and environmental conditions inside the Faculty building. The results were published in [64].

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