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A Methodology to Assess the Sustainability Competencies in Engineering Undergraduate Programs*

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This paper presents a methodology to find out whether or not engineering students perceive sustainability learning throughout their studies at the university. The methodology is applied to students from Barcelona School of Informatics (FIB). The sustainability questionnaire of the EDINSOST project is used as a tool to determine student perception about their sustainability learning. The questionnaire contains 34 questions related to four sustainability competencies: (C1) Critical contextualization of knowledge establishing interrelations with social, economic and environmental, local and / or global problems, (C2) Sustainable use of resources and prevention of negative impacts on the natural and social environment, (C3) Participation in community processes that promote sustainability, and (C4) Application of ethical principles related to the values of sustainability in personal and professional behaviors. The questionnaire was submitted to the students of two first-year subjects and those who complete the Bachelor Thesis, with the aim of determining the initial level of sustainability that students have at the beginning of their studies with regard to that perceived when they graduate. The results show that students declare an improvement in the sustainability learning in the 34 questions analyzed, and that the competency of which they perceive to learn the most is "participation in community processes that promote sustainability". On the other hand, the competency in which they perceive themselves less prepared is the "application of ethical principles related to the values of sustainability in personal and professional behaviors".

Keywords: ESD competencies; competences' assessment; sustainability; education for sustainable development; student surveys; EDINSOST Project; sustainability map; data science

1. Introduction

This study concerning the assessment of sustainability learning in Higher Education (HE) is performed 32 years after the Brundtland report, which was one of the firsts attempts to establish the concept of Sustainable Development (SD) [1]. In that report was assumed a framework for human development capable of integrating economic and technological activities in a more sustainable way, and not only focused on economic issues [2, 3]. Since the Brundtland report, many definitions of SD and sustainability have been published that tend to simplify both concepts while delaying the transformations required to consolidate a real SD [4]. Despite this initial dispersion, academics have worked on frameworks aimed at boosting in a practical way these necessary social and economic changes [5–8]. Meanwhile, some important declarations issued by global institutions such as the United Nations-UN [9–12] and UNESCO [13–15] have raised awareness of the need to promote the transformations required to achieve SD. These initiatives, together with the work carried out by academics and technical specialists, have made SD and sustainability crucial factors for human development, insofar as they constitute a central axis for the resolution of the global challenges facing humanity.

HE plays a key role in overcoming the challenges of achieving SD. UNESCO promotes the continuity of the UN Decade of Education for Sustainable Development, and UN declarations [11] stress that it will be today's young people who will need to be more actively involved in making the necessary transformations, while also emphasizing that HE plays a key role in research and innovation in this area. They also call for a greater level of international collaboration between educational institutions as well as for a better integration of SD as an interdisciplinary component. Although some studies [16–22] show that the integration of SD within university curricula and activity is limited and is also hindered by some barriers, evidence exists of efforts being made to achieve this integration. Ferrer-Balas et al. [17] conducted a compar-

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ison of transformation strategies adopted in seven universities around the world that identified both barriers and drivers. Koehn and Uitto [6] proposed a multidimensional evaluation framework based on practical international examples, providing useful questions and methods to apply to new studies. Ralph and Stubbs [23] semi-structured interviews with university rectors in Australia and England that demonstrated the key role played by university staff in terms of awareness the importance of sustainability. Tassone et al. [24] explored how the relationship between the emergent Responsible Research and Innovation policy agenda [12] and a change in direction of HE curricula could help students to tackle sustainability challenges. Pérez-Foguet and Lazzarini [19] concluded that professional development support programs for faculty have positive effects on integrating sustainability in existent courses and student perception of innovation, according a high value to professional development initiatives focused on small faculty teams. At a governmental level, some HEI have introduced Environmental Management Systems, while others have systematically published sustainability reports [7, 25].

Regarding the more specific topic of assessing the learning in sustainability in HE, evidence exists of the effectiveness of student questionnaires [26], a practice already undertaken by several authors. For example, Clancy et al. [27] use pre-surveys and post-surveys of students in order to assess the increase in their awareness of ethical issues. Azapagic et al. [28] use questionnaires to answer questions such as: how much do engineering students know about sustainable development, what are the knowledge gaps, or what might be the best approach to educating engineering students? The authors conducted a survey of engineering students from around the world and concluded that the students' level of sustainability is unsatisfactory. Drayson et al. [29] conducted a longitudinal study in the UK to learn about students' expectations and experiences regarding SD. The results reveal that most of students believe that SD should be incorporated and promoted by universities, being included in their courses. In the context of the HE Sustainability Initiative, the SULITEST project [30] provides HEI, companies and other global organizations with an online questionnaire that enables them to measure and improve their knowledge of sustainability as well as the individual competencies needed to build a more sustainable future. The biggest drawback of this questionnaire is that almost all the questions focus on the level of knowledge and do not assess higher levels of proficiency. The use of a guided discovery instruction as a tool for teaching environmental sustainability was tested as a complement to questionnaires and a useful method for undergraduate learning in mechanical engineering [20].

None of the instruments described above is able to quantify the level of sustainability of students, although studies like the one published by Segalàs et al. [22] evaluated the SD learning outcomes in terms of what concepts were learned, and showed that after learning the students linked sustainability more closely with technical factors for solving environmental issues than with social ones. Therefore, in order to quantify the level of sustainability, this paper presents a methodology for assessing the level of sustainability perceived by engineering students at the end of their learning process, as well as the results obtained (it is relevant to highlight that the same methodology can be used with a questionnaire that assesses actual student learning), rather than perceived learning. As described in Section 3, the methodology is based on a statistical analysis of the results of a questionnaire defined by the EDINSOST project [31], which was answered by the students enrolled in the Bachelor Degree in Informatics Engineering of the Barcelona School of Informatics. The results are shown and discussed in Sections 3 and 4, and conclusions are presented in Section 5.

2. Materials and Methods

2.1 Research Question and Objectives

This paper proposes a methodology to assess the sustainability learning achieved along a certain Engineering Degree. The methodological proposal seeks to answer the following research question: What is the improvement in students' sustainability learning after completing an undergraduate engineering degree?

This question operationalizes in the following starting hypothesis: fourth-year students have improved their sustainability competencies compared to first-year students. In this paper, the competencies improvement will be indirectly measured on the basis of the students' perceived learning along their training process. However, the same methodology can be used with a questionnaire that assesses actual student learning, rather than perceived learning.

To answer this research question, the following objectives have been defined:

- Define the instruments to assess the sustainability learning of engineering students.
- Use the instruments with first- and fourth-year students of an engineering degree.
- Compare the results obtained by first- and fourth-year students to analyze the improvement

perceived in sustainability learning by fourth-year students compared to first-year students.

2.2 Instruments

The methodology presented is based on two instruments: The Engineering Sustainability Map and the Engineering Sustainability Questionnaire, both developed by the EDINSOST project.

2.2.1 Engineering Sustainability Map (ESM)

To define the learning outcomes in sustainability expected of Bachelor students of engineering degrees, the EDINSOST project has defined the ESM. The ESM contains the learning outcomes related to sustainability that engineering graduates must have on completion of their studies. The learning outcomes also represent some of the learning objectives described by the Sustainable Development Goals [32].

The ESM is a Competency Map [33] in which the sustainability competency is defined. A Competency Map is a matrix whose cells contain the learning outcomes of a given competency expected for students on completion of their studies. Each row corresponds to a competency unit, and the learning outcomes are defined in three domain levels. EDINSOST uses a simplified version of Miller's pyramid as a taxonomy [34]. The ESM has eight competency units, which refer to the four competencies in sustainability defined by the CRUE [35]. These competencies must be developed in all the HE degrees of the Spanish university system. Table 1 shows these competencies and competency units. The complete ESM, containing the learning outcomes, can be found at [36, 37]. Learning outcomes have not been included in the ESM presented in this paper to make the reading easier, since the results presented in this work refer only to Competencies and Competency Units, and do not analyze learning outcomes.

2.2.2 The Engineering Sustainability Questionnaire (ESQ)

An ESQ has been drawn up according to the learning outcomes defined in the ESM – see [38] for details. The ESQ is formed by 34 questions enunciated in the form of statements to which students agree to a greater or less extent by responding on a 4-points Likert scale: strongly disagree, disagree, agree, and strongly agree. Students can also leave each question blank (N/A). The ESQ has been subjected to a rigorous validation process by a group of experts and a control group, as described in [38]. The 34 questions in the ESQ are very easily adaptable to any Engineering Degree. The questions were adapted to the Bachelor Degree in Informatics Engineering.

The 34 questions correspond to the learning outcomes of each Competency unit and competencies of the ESM, as shown in Table 1. The correspondence of each question with the domain level of each Competency unit is shown in Table 2. The numbers in the cells identify the questions (columns corresponding to the three domain levels: Know, Know how and Demonstrate+do). The "Competency" column identifies the CRUE sustainability competency, as shown in Table 1, and column CU identifies the Competency unit.

2.3 Experimental Design

As said before we try to assess whereas an Engineering Degree training program produces learning on sustainability skills, and the hypothesis to be tested from an operative point of view is whereas fourth-

Table 1. ESM: Sustainability competencies (C) and Competency Units (CU) defined for Engineering Degrees

Engineering Sustainability Map	
Competency	**Competency Unit**
C1: Critical contextualization of knowledge establishing interrelations with social, economic and environmental, local and/or global problems.	
	CU_1.1: Has a historical perspective (state of the art) and understands social, economic and environmental problems, both locally and globally.
	CU_1.2: Is creative and innovative. Is able to see the opportunities offered by Engineering to contribute to the development of more sustainable products and processes.
C2: Sustainable use of resources and prevention of negative impacts on the natural and social environment.	
	CU_2.1: Takes into account sustainability in his/her work as an engineer.
	CU_2.2: Takes into account the environmental impact of his/her work as an engineer.
	CU_2.3: Takes into account the social impact of his/her work as an engineer.
	CU_2.4: Is capable of successfully carrying out the economic management of an Engineering project.
C3: Participation in community processes that promote sustainability.	
	CU_3.1: Identifies when the sustainability of a project can be improved if it is conducted through community collaborative work. Performs responsibly collaborative work related to sustainability.
C4: Application of ethical principles related to the values of sustainability in personal and professional behavior.	
	CU_4.1: Behaves according to the deontological principles related to sustainability.

Table 2. Correspondence between ESQ questions and the domain levels of each Competency unit

Competency	CU	Domain Levels		
		Know	**Know how**	**Demonstrate + Do**
C1 (Critical contextualization of knowledge) – context				
	CU_1.1	1	2	3
	CU_1.2	4	5	6
C2 (Sustainable use of resources) – impact				
	CU_2.1	13	9, 28	11
	CU_2.2	8, 12	7	10
	CU_2.3	14, 15, 16	17, 18, 19	20, 21, 22, 23, 24
	CU_2.4	25	26	27
C3 (Participation in community processes) – participation				
	CU_3.1	29	30	31
C4 (Ethics)				
	CU_4.1	32	33	34

year students have improved their perceived sustainability learning compared to first-year students, or, in other words, if the sustainability competencies of a fourth year student are higher than those in first year. This scenario corresponds to a pre-post study framework where following the degree training program parallels the intervention (or treatment in the health domain). For these studies, two main designs can be used: Paired designs assume same students evaluated at the beginning and the end of their training program. Non-paired designs work with independent samples before and after, so, different groups of students from the initial and final courses are compared. The estimation of the amount of learning is the same under both designs. The significance of this difference is the one that might change. In paired designs, the variance of the estimates is smaller as they eliminate individual variability. So, significances might arise where a non-paired design cannot detect them. In non-paired designs, the confidence intervals are more conservative and bigger differences between pre, and post data are required to establish a significance. This means that getting a significant difference in a non-paired analysis guarantees the effect of the treatment, provided that the two samples are homogeneous (as is the case when talking about students populations separated only few years). An extensive experimental setting is developed in [39] to assess differences between paired and non-paired designs, and although it states a preference for paired designs, it concludes that "one should note that the estimated difference does not depend on whether one assumes that methods for matched samples or methods for independent samples should be used". Thus, as in our case the levels of significance of the differences in sustainability learning before and after the Degree are so high, using a non-paired design allows avoidance of waiting the four years to conclude the study required until the students evaluated at the beginning of their Bachelor degree complete their training program.

Learning perceived by students in each competency and competency unit is measured using the correspondence defined in Table 2. The learning perceived by students during their Bachelor studies is measured by analyzing the difference between the learning that fourth-year students declare and that declared by first-year students. The assumptions implicit in this design are discussed in Section 2.4.

The sustainability learning can be analyzed at different levels of granularity. In particular, the analysis can be performed at the following levels:

- For each single question (at item level).
- For each Competency unit.
- For each Sustainability competency.
- A global view.

In order to perform numerical statistical calculations based on the different values of the Likert scale used to answer the questionnaire, the following numerical equivalences have been used 0 (strongly disagree), (1) disagree, (2) agree, (3) strongly agree, 0 being the non-learning scenario and 3 the full achievement of the stated objectives.

According to the previous discussion, the proposed methodology designs a pre-post study based on independent samples that can be conducted in a single academic year. This can be assumed, providing that the training programs remain stable in the Bachelor degree and no significant changes occur in the student's population characteristics. When this condition holds, the amount of learning between the first course and the Bachelor Thesis of the same group of students is similar to that of a first course group and another group of different students engaged in the Bachelor Thesis.

The proposal of this work is to conduct a pre-post analysis by comparing the distribution of the answers to each question between the group of students engaged in the first-year courses (G1) and the group of students involved in the Bachelor Thesis (GB). The reliability of the results will increase with the coverage of the G1 and GB in regard to the entire student population and the number of academic courses included in the study, as is usual in classical statistical analysis.

2.3.1 Assessing the Sustainability Learning at Item Level

The first step is to perform a basic descriptive statistic of each question (item). Eventual pre-processing must be applied, including terminology normalization and missing data treatment, if required. A complete pre-processing methodology for tackling most of the issues encountered with raw original data is proposed in [40].

For those questions showing significant differences between G1 and GB, the visual inspection of the bar chart is used to identify the meaning of the differences. Eventually, the percentages of answers "agree" (2) and "strongly agree" (3) will be compared for groups G1 and GB by means of the classical two-sample t test of proportions.

2.3.2 Assessing the Sustainability Learning at Competency Unit Level

The procedure described in the previous section enables to quantify the average improvement perceived by the students for each question of the ESQ to be quantified. However, considering the Likert nature of all the variables, it makes sense to describe *the proficiency* of a group of students for a certain competency by considering the proportion of the group with perception of high achievement (H_{CU}) in the competency (let us say, answers "agree" (2) and "strongly agree" (3)). For a competency C, each Competency unit ($CU_1, \ldots, CU_n$) is measured through a set of items of the ESQ ($I_{1u}, \ldots I_{nu}$), as shown in Table 2. The proficiency of a group of students in a certain Competency unit, P_{CU}, is defined in Equation (1).

$$P_{CU} = \frac{H_{CU}}{\sum_{\forall\, CU \in C} n_u} = \frac{\sum_{\forall CU \in C} \sum_{\forall\, u\, \in CU} card\{I_u \in \{2,3\}}{\sum_{\forall\, CU \in C} n_u}, \quad (1)$$

where *card* is the cardinal of the set of responses where $I_u \in \{2, 3\}$

The improvement perceived by students during the degree, for a certain Competency unit, (LP_{CU}) can also be measured by comparing the proficiency in the Competency unit of Bachelor thesis students ($P_{CU \cdot GB}$) with first-year students ($P_{CU \cdot G1}$). Equation (2) measures this improvement.

$$LP_{CU} = P_{CU.GB} - P_{CU.G1} \quad (2)$$

Assessing the significance of LP_{CU} of such an improvement requires the use of two independent proportion tests between $P_{CU \cdot GB}$ and $P_{CU \cdot G1}$.

The same expressions are also valid at any level of granularity of the ESM, and can be applied either to individual items of the questionnaire or to competencies.

A similar analysis can be performed to determine the sustainability learning according to the domain levels of the taxonomy.

2.3.3 Assessing the Sustainability Learning at Competency Level

A second level of granularity in this analysis consists in identifying the sustainability competencies that register a significant improvement throughout the Bachelor degree. This is addressed by building an aggregated indicator for each competency by combining the results of each of its Competency units.

The sustainability knowledge in each competency (K) of a group of students (G1 or GB) is quantified as the average normalized scores of its corresponding Competency units (see Table 1). In other words: given a competency C, and its n corresponding Competency units ($CU_1, \ldots, CU_n$), each Competency unit is measured through a set of n_u normalized items of the ESQ ($T_{1u}, \ldots T_{nu}$), each codified between 0 and 1. The knowledge level perceived in a competency C, K_C, is quantified as the average of the learning in all the items involved with C, as presented in Equation (3).

$$K_C = \frac{\sum_{\forall CU \in C} \sum_{\forall\, u\, \in CU} T_u}{\sum_{\forall\, CU \in C} n_u}, \quad K_c \in [0,1] \quad (3)$$

The competencies in which a higher level of knowledge is perceived can be identified by analyzing both means and boxplots. $K_{C.G1}$ is computed on the measurements obtained by first-year students (G1) over items involved in competency C, and $K_{C.GB}$ is computed on the measurements of the same items obtained over GB. As an example, and according to Table 2, the knowledge perceived in competency C1 (context) averages the results obtained in the first 6 items of the ESQ (according to Table 1, C1 decomposes into two competency units, CU_1.1 - Historical perspective - and CU_1.2 – Is creative and innovative - and, according to Table 2, CU_1.1 is evaluated through the questions 1, 2 and 3 and CU_1.2 through questions 4, 5 and 6); 6 items in total.

A two independent sample test comparing $K_{C.G1}$ and $K_{C.GB}$ will assess the significant difference between the G1 and GB knowledge levels. Competencies with significant tests mean that the global level of learning perceived throughout the Bachelor degree is significant in that competency. This level of learning is estimated on average by computing the difference between the average of student knowledge in the first year with respect to average of student knowledge in the fourth year (note that not all items in the ESQ have the same weighting, since each competency has a different number of Competency units, and each Competency unit has a different number of questions assigned). Thus, the learning perceived in a competency (L_C) between G1 and GB is measured by using Equation (4).

$$L_C = \bar{K}_{C.GB} - \bar{K}_{C.G1}, \quad (4)$$

where

$$\bar{K}_{C.G1} = (\sum_{\forall i} K_{C.G1_i})/n$$

and

$$\bar{K}_{C.GB} = (\sum_{\forall i} K_{C.GB_i})/n,$$

n being the number of the competency units involved. Following the previous example, the learning in competence C1 (context) is computed as the difference $\bar{K}_{C.GB_1} - \bar{K}_{C.G1_1}$

2.3.4 Assessing the overall learning in sustainability

The overall learning in sustainability (L) is assessed by building an overall sustainability level indicator of the Bachelor degree, which is computed as the average of the learning in the four competencies (L). Equation (5) expresses this calculation.

$$L = \frac{\sum_{\forall CU \in C} L_C}{4} \quad (5)$$

In this formalization, we assume that all competencies have an equal impact on the overall learning in sustainability, which would be not the case in some specific context. A more general approach that does not make this assumption is to consider the possibility of assigning a different weight to each competency, as shown in Equation (6):

$$L = \frac{\sum_{\forall CU \in C} w_C L_C}{4}, \text{ provided that } \sum_{\forall CU \in C} w_C = 1 \quad (6)$$

As shown in Equation (6), in this work we assume that $w_c = 1$.

2.3.5 Global Analysis

A multivariate analysis by means of a principal components analysis of the ESQ items can provide a global view of how the different items and competencies interact mutually.

First of all, the working matrix is built by combining all the students together and taking advantage of the fact that the set of questions is the same for G1 and GB. This is a suitable operation that needs no previous population homogeneity check since the multivariate methods require no distributional assumptions.

Next, the K-nearest neighbor method is used to impute all missing values, since the factorial methods are not able to deal with them.

Next, an additional qualitative variable indicating the course of the student is added to the resulting data matrix (it shows two values, GB and G1).

The principal component analysis is performed by using the 34 Likert items of the ESQ (T_{1u}, . . . T_{nu}), as active variables.

The aggregated scores measuring the average proficiency on each competency C are then projected onto the factorial plane as illustrative variables. They are represented as arrows, as is usual. The angles between arrows assess the relationship between the variables. The angles with the factorial axes assess the contribution of the variables to those factorial components.

Finally, the qualitative variable "Course" is projected as an illustrative qualitative variable by representing the centroids of their modalities in the factorial map. Proximity indicates association, whereas distance reveals difference.

3. Results

This section presents the results of applying the methodology described in Section 2 to a case study. These results are discussed at Section 4.

3.1 Case Study

The case study is conducted in the Bachelor Degree in Informatics Engineering at the Barcelona School of Informatics (FIB) at UPC (Universitat Politècnica de Catalunya – BarcelonaTech). At the FIB, the sustainability competency is assigned to a set of subjects that make up the "sustainability itinerary". The sustainability training given in these subjects is coordinated by a teacher who is in charge of distributing the sustainability learning outcomes between the subjects of the itinerary, in addition to helping the teachers of the subjects to develop activities so that the students achieve these learning outcomes. In addition, students must include a sustainability report in their Bachelor Thesis.

The questionnaire was issued in March, 2018, in two of the first-year subjects (G1). The students starting their Bachelor degree and who participated

Table 3. Details of the sample

Semester	Group	Subject	Enrolled	Answers
1	G1	Introduction to Computers (IC)	544	111
2	G1	Computers Organization (CO)	315	110
8	GB	Project Management	238	227

in this analysis were studying subjects from two different semesters. Provided that sustainability is formally developed in no subject of the first semester of the curriculum, it can be assumed that sustainability competencies of students from the first and second semester of the Bachelor degree are similar.

The responses obtained from G1 correspond to students attending the lectures on the date when the ESQ was distributed. Responding to the question-

Table 4. Proficiencies and average improvement per question

	$H_{T,G1}$ [1]	$P_{T,G1}$ [2]	$H_{T,GB}$ [3]	$P_{T,GB}$ [4]	pVal-2Prop [5]	LP_T [6]	Signif. [7]
1	39	0.351	143	0.630	1.24e-06	0.279	√
2	37	0.333	152	0.670	4.99e-09	0.336	√
3	51	0.459	171	0.753	8.86e-08	0.294	√
4	52	0.468	158	0.696	4.22e-05	0.228	√
5	55	0.495	159	0.700	1.92e-04	0.205	√
6	63	0.568	166	0.731	1.87e-03	0.164	√
7	59	0.532	156	0.687	3.75e-03	0.156	√
8	20	0.180	83	0.366	4.00e-04	0.185	√
9	46	0.414	163	0.718	6.55e-08	0.304	√
10	35	0.315	112	0.493	1.42e-03	0.178	√
11	34	0.306	132	0.581	1.77e-06	0.275	√
12	19	0.171	75	0.330	1.65e-03	0.159	√
13	45	0.405	157	0.692	4.29e-07	0.286	√
14	39	0.351	149	0.656	1.08e-07	0.305	√
15	49	0.441	140	0.617	1.68e-03	0.175	√
16	47	0.423	178	0.784	4.61e-11	0.361	√
17	41	0.369	134	0.590	1.07e-04	0.221	√
18	55	0.495	181	0.797	1.41e-08	0.302	√
19	69	0.622	203	0.894	3.47e-09	0.273	√
20	45	0.405	162	0.714	4.55e-08	0.308	√
21	54	0.486	141	0.621	1.27e-02	0.135	√
22	37	0.333	115	0.507	1.92e-03	0.173	√
23	63	0.568	185	0.815	1.29e-06	0.247	√
24	68	0.613	187	0.824	2.05e-05	0.211	√
25	25	0.225	152	0.670	1.92e-14	0.444	√
26	39	0.351	150	0.661	7.02e-08	0.309	√
27	32	0.288	103	0.454	2.57e-03	0.165	√
28	31	0.279	118	0.520	2.39e-05	0.241	√
29	32	0.288	161	0.709	2.47e-13	0.421	√
30	44	0.396	165	0.727	4.35e-09	0.330	√
31	37	0.333	173	0.762	2.89e-14	0.429	√
32	16	0.144	90	0.396	2.43e-06	0.252	√
33	28	0.252	88	0.388	9.63e-03	0.135	√
34	27	0.243	94	0.414	1.56e-03	0.171	√

[1] $\mathbf{H_{T,G1}}$: High achievement level at G1: Number of students of Group G1 choosing levels 2 and 3 per item T.
[2] $\mathbf{P_{T,G1}}$: Proficiency of group G1 in item, according to Equation (1).
[3] $\mathbf{H_{T,GB}}$: High achievement in group GB per item T.
[4] $\mathbf{P_{T,G1}}$: Proficiency of group GB in item, according to Equation (1).
[5] **pVal-2Prop**: p-value of the two independent proportions statistical test. When <0.05, the difference in proficiencies after the training is significant.
[6] $\mathbf{LP_T}$: Average level of learning associated to the training program for item T.
[7] **Signif**: √ Indicates that the test is significant.

naire was voluntary. 859 students were surveyed, and 221 responses were obtained (25.72%). The following paragraph details how the GB group was built.

The FIB has a specific final year subject, named Project Management (PM), in which all the students working on their Bachelor Thesis must be enrolled. It is a blended subject of four weeks duration [41]. In PM, students start their Bachelor Thesis and are evaluated from the initial milestone (FIB's Bachelor Theses are evaluated in 3 milestones: the initial milestone, the follow-up milestone, and the final milestone). One of the assignments that students are obliged to deliver on arriving at the initial milestone is the initial sustainability report. For writing this report, students have access to several documents that they may consult and apply during their Bachelor Thesis. The ESQ is submitted to them and should be answered before the initial Milestone is reached. Both the initial sustainability report and the questionnaire have a bearing on the mark obtained by students in PM, so that although responding to the ESQ is voluntary, practically all PM students answer the survey, thereby reducing any bias in the responses. During each academic year, two PM courses are held in the two semesters of that year. On this occasion, the ESQ was answered by 136 students from the first PM course of 2018 (March-April) and 91 students from the second course (September-October) 2018.

Table 3 shows the breakdown of students by group and subject, indicating the number of students enrolled in each subject and the number of responses obtained.

3.2 Detailed Results

Table 4 shows the average improvement in sustainability *proficiency* in each particular item of the ESQ. The column $\mathbf{LP_T}$ quantifies the increase in *proficiency* of the group (the proportion of answers "agree (2)" or "strongly agree (3)") at the end of the Bachelor degree.

Fig. 1 shows graphically the average level of learning, LP_T. Distributions of items in G1 and GB are shown for significant items in order to interpret the sense of significance based on the 2-independent proportions test presented below. Data had no coding problems, and the presence of missing answers is maintained in very small percentages as an ordinary modality, provided that the variables treated are qualitative.

The sense of the significant differences is explored in order to interpret when the learning occurs; that is, if the level of knowledge is greater or lower at the end of the training. It suffices to check the distributions of the answers.

At competency level, the evaluation of the aggregated items provides a numerical average scoring for the competency learning between 0 and 1. Table 5 shows the proficiency of the students in the four competencies in G1 and GB, as well as the improvement throughout the training.

Fig. 2 shows the average proficiency improvement (LP_C) for the four competencies.

A similar kind of analysis could also be performed at the intermediate level of a competency unit. The items aggregation would follow the subgroups of items described in Table 1, and results per competency unit would be reported. For the purpose of this paper, replicating the results to this

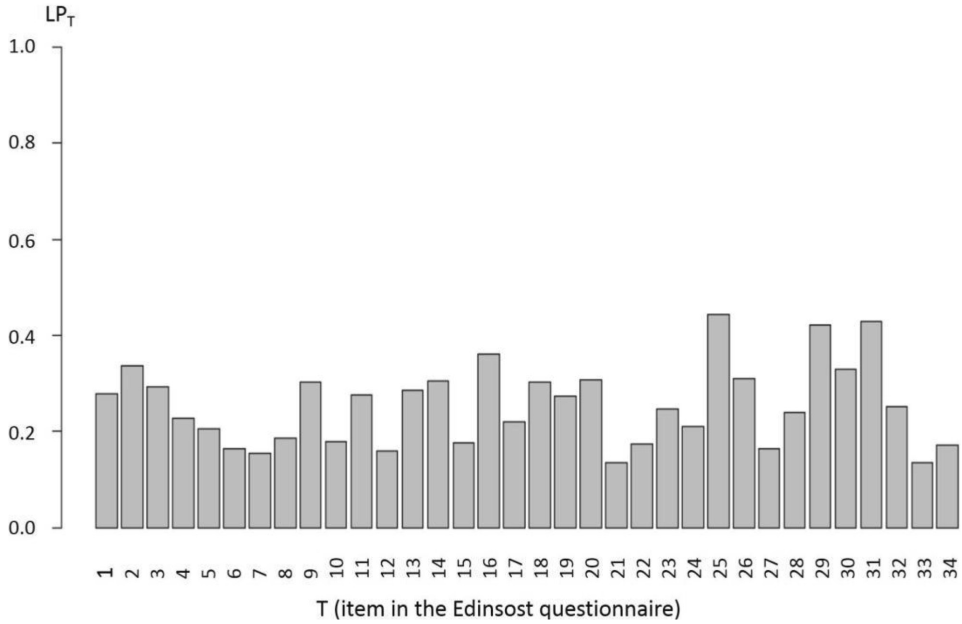

Fig. 1. Visualization of LP_T (quantification of learning in ESQ items).

Table 5. Proficiencies and average improvement per competency

	G1			GB			Improvement			
C[1]	$H_{C,G1}$[2]	$P_{C,G1}$[3]	$K_{C,G1}$[4]	$H_{C,GB}$[5]	$P_{C,GB}$[6]	$K_{C,GB}$[7]	pVal-2Prop[8]	LP_C[9]	L_C[10]	Signif.[11]
1	8	0.072	0.447	53	0.233	0.611	7.43e-11	0.161	0.165	√
2	5	0.045	0.426	31	0.137	0.580	2.22e-09	0.091	0.153	√
3	14	0.126	0.39	92	0.405	0.666	2.65e-14	0.279	0.274	√
4	7	0.063	0.290	28	0.12	0.419	4.08e-05	0.060	0.129	√

[1] C: Compentency.
[2] $H_{C,G1}$: High achievement level at G1: Number of students of Group G1 choosing levels 2 and 3 in competency C.
[3] $P_{C,G1}$: Proficiency of group G1 in competency C, according to Equation (1).
[4] $K_{C,G1}$: Average level of scoring for competency C in group G1.
[5] $H_{C,GB}$: High achievement in group GB per competency C.
[6] $P_{C,GB}$: Proficiency of group GB in competency C, according to Equation (1).
[7] $K_{C,GB}$: Average level of scoring for competency C in group GB.
[8] pVal-2Prop: p-value of the two independent proportions statistical test. When <0.05, the difference in proficiencies after the training is significant.
[9] LP_C: Average improvement in proficiency associated to the training program for competency C.
[10] L_C: Average level of learning in competency C.
[11] Signif: √ indicates that the competency learning is significant.

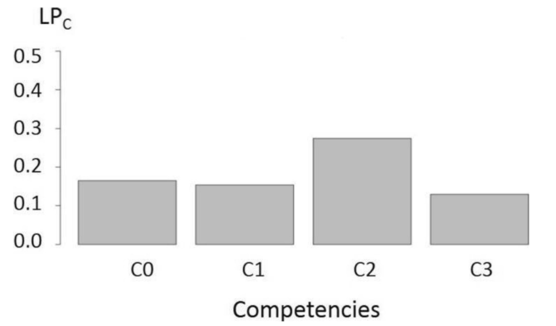

Fig. 2. Visualization of LP_C (quantification of learning by competencies).

intermediate level of aggregations does not add any particular contribution. Thus, we only report the analysis at the level of items and competencies.

Finally, the principal components analysis is carried out according to the stated methodology, with the factorial plane displayed in Fig. 3. The first factorial plane keeps about 47.77% of the total inertia of the dataset.

4. Discussion

Table 4 shows that all p-values of ESQ items are lower than 0.05, indicating significant learning between the general level of sustainability knowledge in the first year, with regard to last year of the training program. This occurs for all the items in the ESQ. The percentage of students choosing levels 2 or 3 of knowledge of each item of the ESQ is significantly higher in all items at the end of the Bachelor degree, as compared with the beginning. These results make sense with the conclusion in [28] that the level of sustainability of students is unsatisfactory, and with what was observed in [27] while adding – in some way – to the curriculum content on sustainability has a positive effect on the perception of their learning.

From Fig. 1, one may observe that the items in which improvement is greater are Q25 (I know the process of managing a project, project planning techniques, social economy, and the common good economy), Q29 (I know the concept, examples and tools of collaborative work in the ICT field), and Q31 (I know how to use collaborative work tools related to ICT projects).

As may be seen in Fig. 2, the competency with the highest learning is "C3: Participation in community processes that promote sustainability", whereas the other competencies show a similar significant (but moderate) level of learning. This result would fit in with the conclusions reached in

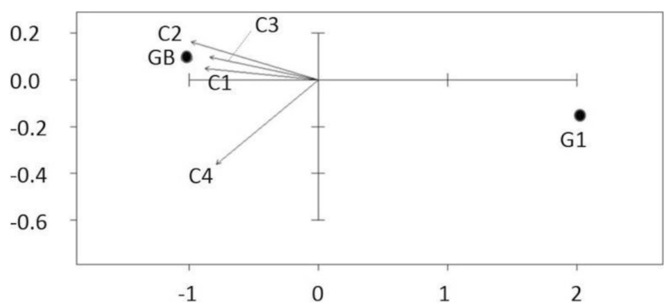

Fig. 3. First factorial map of the competencies.

[28] as students believe that sustainable development is important for engineers (as C3 shows), but find it difficult to move from theory to its practical application (according to the moderate level of C1 and C2). The competency where students declare less learning is "C4: Application of ethical principles related to the values of sustainability in personal and professional behavior", being this increase in perceived knowledge compatible with what was observed in [27], which also studied about the perceived learning of ethical aspects. Furthermore, the fact that C4 is the competence with the lowest level of perceived learning could be related to some of the inconsistencies referred to in [27]. In general, the results show a certain coherence with the observations of Segalas et al. [22], while their study showed that students had an initial perception of sustainability that was very much related to technology (as a tool for solving environmental problems) and little related to social aspects. The suggested fit lies in the fact that C3 would be the competence most linked to project management (a more technical part in which the greatest increase is shown) and that the rest of the competences are more related to the social and human dimension.

In the factorial analysis presented at Fig. 3, "C4: Application of ethical principles related to the values of sustainability in personal and professional behavior", is the competency that evolves more orthogonally than the others, whereas the other three competencies tend to be quite closely associated (students proficient in one competency are also proficient in the other two). Text CG1 and CGB represent the centroids corresponding to students belonging to the groups G1 and GB. The factorial plane shows a clear significant difference between the *proficiency* of both groups. While the levels of proficiency tend to be high at the end of the training, they are on the opposite side of the plane for the first-year students. This signifies a clear impact on the *proficiency* of sustainability competencies throughout the Bachelor degree training.

Ethics is the less developed competency in the curricula, but is a fundamental competency for any professional, and engineers are no exception. All professional associations have a code of ethics that includes ethical principles related to the profession. One of the ways of introducing ethics in engineering studies is to introduce the profession's code of ethics into the curriculum, so that engineering students apply it to the projects they develop during their university studies.

In the Engineering context, Education for Sustainable Development (ESD) will enable engineers to develop sustainable products and provide sustainable services, To train engineers in Higher Education institutions (HEI), it is vital that subjects such as the circular economy, sustainable design, green computing or environmental engineering be included in the engineering curricula. For these subjects to be taught properly, the teachers must be previously trained.

The EDINSOST2-SDG Project will continue the work presented in this paper. The sustainability questionnaire and maps have been updated to include the SDGs. On the other hand, the EDINSOST project was an analysis project, while the EDINSOST2-SDG project is an intervention project, aimed at using the results obtained in EDINSOST 1 to improve ESD in a reduced set of degrees.

This work has certain limitations that must be taken into account when assessing the results obtained in the case study. First, the student sample is small. It would be convenient to validate the results with a larger sample consisting of all the first-and fourth-year students belonging to a given course. As regards the sample, first-year students belong to two subjects that are taught in the first two semesters. In this work it is assumed that the second semester students did not receive any training in sustainability during their first semester at the university. Although this training was not carried out at the university, it could well have taken place outside the university.

Second, the first-and fourth-grade students are different. This implies the firm assumption that the levels of achievement in sustainability learning remain more or less stable in a given course over the years, and do not depend on a particular generation of students enrolled in that specific course. Thus, the differences in sustainability learning found between two independent groups of students will be similar to those found with the same group of students measured before and after completing their Bachelor degree.

Third, the ESQ measures student perception of their sustainability learning, not their real learning, so a bias in the responses may exist, as suggested by Kruger and Dunning [42].

Finally, in this formalization, we assume that all competencies have an equal impact on the global learning of sustainability, which would be not the case in some specific context (see Equation (6)). A more general approach that would not make this assumption is to consider the possibility of assigning a different weight to each competency.

5. Conclusions

This work presents a methodology for assessing the progress in sustainability of undergraduate students in engineering Degrees. The starting hypothesis is that fourth-year students have improved their sustainability competencies compared to first-year students. The methodology is applied to a case study: The FIB's Bachelor Degree in Informatics Engineering. In this paper, the sustainability improvement is indirectly measured on the basis of the students' perceived learning along their training process. However, the same methodology can be used with a questionnaire that assesses actual student learning, rather than perceived learning. This methodology can be applied to any engineering degree. It can also be applied to any other university (and non-university) degree other than engineering, simply by changing the questionnaire used to survey students.

The instrument used in this paper is the Engineering Sustainability Questionnaire designed by the EDINSOST project. The questionnaire consists of 34 questions concerning the four sustainability competencies defined by the CRUE, which must be developed in all the degrees of the Spanish university system.

The methodology enables the progress in sustainability to be analyzed independently for each of the 34 items in the questionnaire. It also allows a study of the learning perceived by students in each competency. To this end, aggregate indicators are used; these indicators take into account in each competency all the questions related to said competency. The methodology can also be used to analyze sustainability learning from other perspectives, such as the point of view of the competency units or domain levels in the taxonomy.

Regarding the case study analyzed, the results show that, in the 34 questions of the questionnaire, the students declare that they have improved their learning, therefore validating the starting hypothesis. However, the learning perceived in the four sustainability competencies is not the same. Here, the students declare that they feel more competent in C3 (Participation in community processes that promote sustainability), and state that the competency in which they have learned less is C4 (Application of ethical principles related to the values of sustainability in personal and professional behavior). However, the learning they declare in C3 is 0.274 over 1, while in C4 it is 0.129. As can be seen, both values are very far from the desired value (1).

The results of the factorial analysis indicate that "Application of ethical principles related to the values of sustainability in personal and professional behavior" is the competency that evolves more orthogonally than the others, whereas the other three competencies tend to be quite closely associated (students proficient in one competency are also proficient in the other two).

Much work remains to be done, and it is essential to do it soon, since our students are the engineers of the future, and the destiny of humanity lies in their hands. Because the future will be sustainable, or it will not be at all.

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