Exploring innovative strategies in problem based learning to contribute to sustainable development: a case study

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Abstract

Purpose – Higher education institutions (HEIs) have a great responsibility to put education for sustainable development at the centre of their work. Curricula should therefore start to incorporate the sustainable development goals (SDGs) and key competencies in sustainability, and research should be carried out to determine effective learning methods for this. This study aims to explore the usefulness of problem-based learning (PBL) approaches to train biomedical students in sustainability and to provide some recommendations for the design and implementation of new PBL-SDG scenarios.

Design/methodology/approach – Two PBL-SDG scenarios were designed, implemented and evaluated for 110 students of human biology degree. Learning outcomes and student perceptions of this approach were analysed through questionnaires, student productions, non-participant observation and focus groups.

Findings – The results show that the PBL-SDG scenarios effectively addressed several SDGs and sustainability competencies in a transversal, collaborative and innovative manner. According to student perceptions, the elements that contributed most to the development of these competencies were emotional involvement with the scenario, reflection on their own actions, freedom to approach the problem and tutors who empowered them with their proposals.

Originality/value – The PBL-SDG approach presented in this study is an example of a pedagogical strategy that can help HEIs educate their learners as key change agents. The findings of this study provide evidence for this important aspect and give guidelines and strategies to successfully designing and implementing such methodologies in biomedical education.

Keywords Sustainable development goals (SDGs), Education for sustainable development, Sustainable competencies, Problem-based learning, Health sciences studies

Paper type Case study

1. Introduction

Preparing students to understand and address complex problems to move towards more sustainable societies is a critical and growing challenge for higher education institutions (HEIs) (including universities). HEIs carry a special responsibility to society for placing education for sustainable development (ESD) at the centre of education, to help develop

students who are new change agents and are capable of transforming their reality (Tilbury, 2011). HEIs should aim to educate their learners to be informed and critically literate, socially connected and respectful of diversity and ethically responsible and engaged (UNESCO, 2017).

ESD should therefore focus on addressing the major challenges facing humanity, defined as the sustainable development goals (SDG) and empowering students to play a role in the transition towards a sustainable knowledge society (O'Riordan *et al.*, 2020). For this, the sustainability competences that university students should develop have been described and revised by several authors over the last decade. These include systems-thinking, anticipatory, normative, strategic, collaborative, critical-thinking, self-awareness and integrated problem-solving competencies. These go beyond the aim of increasing basic literacy. Instead, they respond to the needs of ESD and foster a more integrative, problem-based, interdisciplinary, critical-thinking, reflexive and action-based learning (Wiek *et al.*, 2011; Rieckmann, 2012; Brundiers *et al.*, 2021).

Of note, ESD breaks with the traditional view of pedagogy and fosters more interactive and collaborative teaching and learning practices that shift the role of teachers to being disseminators of content and that mobilise students to question their opinions, ideals and ways of thinking (Wals, 2009; Tilbury, 2011), in other words, ESD enables the development of the sustainability competencies. Problem-based learning (PBL) and project-based learning (PjBL) have been described as some of the most effective pedagogical approaches for this purpose (Lozano *et al.*, 2017).

In this study, it has been explored how to design PBL scenarios for undergraduate education that would enable them to reflect on the cultural, economic and environmental impacts of biomedical advances and to develop sustainable alternatives. In doing so, the authors considered the Human Biology bachelor's degree at the Faculty of Health and Life Sciences of Universitat Pompeu Fabra (UPF) as a case study. This case study has been selected because it allows to study in depth how to integrate the SDGs in PBL scenarios and how to promote key competencies for sustainability during its implementation.

1.1 Literature review

There is a wealth of literature about the appropriate pedagogical settings and methodologies to implement the ESD in the context of HEIs (Ceulemans and De Prins, 2010; Fortuin and Bush, 2010; Hopkinson and James, 2010; Sprain and Timpson, 2012; Lozano *et al.*, 2017). Given that every target, situation and learning environment needs a certain pedagogical approach, one can find a wide variety of proposals. However, there seems to be a general agreement that active, participatory and real-world learning approaches are essential for ESD (Cotton and Winter, 2010; Tilbury, 2011). Some of the most referenced transformative and innovative pedagogical approaches in the ESD literature are PBL and PjBL, case-studies, integrative learning (inter and transdisciplinary), community service learning, research-based learning, reflexive learning and place-based environmental education (Evans, 2019).

For years now, universities, as HEIs, have been committed to foster sustainable development at different levels, including within their pedagogical practices and curricula (Lozano *et al.*, 2013; Lozano *et al.*, 2015). In the context of the Spanish university system, the CRUE-sustainability group created the document *Guidelines for the Introduction of Sustainability in the Curriculum* approved by the plenary of the Rectors' Conference in 2005 and updated in 2012. This, together with the Organic Law 4/2007 (LOMLOU) and the "University Strategy 2015" have promoted the introduction of sustainability in the universities' teaching activity (Geli de Ciurana *et al.*, 2015). However, several studies from different universities from Spain (Tejedor *et al.*, 2019; Busquets *et al.*, 2021) and from around the world (Lozano and

Young, 2013; Watson *et al.*, 2013; Albareda-Tiana *et al.*, 2018), have shown that although there is a certain consciousness and willingness to introduce sustainability into universities' education and syllabuses, there is still much room for improvement.

More efforts are needed to fully integrate sustainability competencies into academic practices and programmes and to give more voice to innovative pedagogical strategies for sustainability competency work (Corvers *et al.*, 2016). On the other hand, university teaching is usually disconnected from its immediate environment and many teachers are not prepared to train students on such competencies (Tejedor *et al.*, 2019). And last, but most importantly regarding this study, there is still a lack of research that attempts to directly connect the competencies in sustainability with the different existing innovative pedagogical approaches. Although previous studies suggest that no single pedagogy can cover all sustainability competencies, it has been found that PBL and PjBL learning approaches could be thoroughly planned to do so, as they cover the broadest range of them (Lozano *et al.*, 2017).

PBL and PjBL are two forms of inquiry-based learning approaches that share numerous methodological commonalities, such as engaging students in real-world tasks, working with small groups, putting students at the center, processing multiple information sources, using teachers as facilitators for learning, simulating professional situations and using peer-evaluations. In PBL, students must approach a complex problem through inquiry to understand it in-depth, so learning is guided by the students' questions; in contrast, in PjBL, students must develop a project to solve a real problem, with the learning process guided by the final product that they are going to create. Despite these differences, both approaches are considered to be perfect tools for promoting ESD, as they can be key for switching from a passive to an active learning process, working on real-world problems in a collaborative manner and working on sustainable competencies (Tilbury, 2011; Lozano *et al.*, 2017).

For a while now, several PBL and PjBL courses in sustainability in different parts of the world have been implemented (Brundiers and Wiek, 2013; Wiek *et al.*, 2014; Lozano *et al.*, 2017). The studies in which most experience has been reported are those in the engineering field (Guerra, 2017; Mann *et al.*, 2021). Some authors suggest that to develop sustainability competences, much more emphasis should be put on the problem analysis phase, as we cannot assume that complex problems can be solved through previous methods and theories. To develop this competence the key didactical elements are authenticity (*How to involve/motivate students in professional problems?*), exemplarity (*How to ensure that students find relevant examples from which they can learn strategies and knowledge that they can transfer to other contexts?*) and interdisciplinarity (*How to encourage them to integrate perspectives outside their field?*) (Dobson and Bland Tomkinson, 2012; Thomassen and Stentoft, 2020). Nonetheless, these approaches are still not commonly used, and the few existing cases still are dealing with some remaining challenges. First, the learning objectives of the courses should directly aim at the acquisition of sustainability competencies. Second, settings should be designed to be more participatory, so that students can interact with other stakeholders and develop projects or tackle problems that have an impact on society. And third, more emphasis should be laid on promoting self-directed learning, team-work and solution-oriented research (Brundiers and Wiek, 2013). However, these are just some examples of the numerous current challenges that exist, and the reality is that for the majority of the HEIs, it is truly difficult to offer and implement rigorous, curriculum-wide and cohesive PBL and PjBL sustainability courses (Wiek *et al.*, 2014).

1.2 Focus of the research
To contribute to developing effective learning strategies for emphasizing sustainability in undergraduate biomedicine education, the authors wanted to better understand how to

design PBL to address SDGs and to facilitate the development of sustainability competencies among students. They have called this strategy "PBL-SDG scenarios".

In this context, they hypothesize that there are several elements that can be taken into account when designing and implementing PBL scenarios and that can help to work on all the sustainable competencies. First, presenting real-world, up-to-date and transversal scenarios, in which biomedical issues can be analysed from different perspectives (e.g. cultural, social and environmental) and from different scales (e.g. local and global) helps students not only to be more committed to the problems presented but also to have a systemic and complex perspective of the case (Rowe, 2007; Frisk and Larson, 2011; Larmer and Mergendoller, 2015; Noordegraaf-Eelens *et al.*, 2019) and thus to develop systems-thinking competency. On the other hand, contextualising their scientific knowledge helps students to reflect on the values associated with these problems and the role they can play in addressing them, which in turn helps them to develop normative and self-awareness competencies. Second, the use of emotionally bonding and controversial topics can foster the students' self-awareness, normative and critical thinking and calls for them to collaborate and take action (Segalàs *et al.*, 2010; Wiek *et al.*, 2011; Dlouhá *et al.*, 2019). Third, anticipatory and strategic skills can be worked on through solution and foresight-oriented scenarios that ask for students' opinions and views on such complex topics. At the same time, providing these opinions also requires collaboration, self-awareness, systemic, critical and normative thinking, as well as integrated problem-solving skills (MacKay and McKiernan, 2004). And last but not least, using innovative, eye-catching and dynamic materials to present the scenarios are useful not only to deeply engage students but also to draw them in, stimulate their creativity and empower them to actively, critically and autonomously respond to the proposed problems.

Hence, for the general purpose of educating biomedical students on the SDG and sustainable competencies, this case study aims to design, implement and evaluate new PBL teaching aids to work on 8 of the 17 SDGs (1, 3, 5, 10, 12, 13, 14, 15) and on the key competencies in sustainability. Ultimately, it intends to make substantial contributions and recommendations for designing authentic, exemplary and interdisciplinary PBL scenarios that integrate the SDGs in a stimulating way and for developing strategies that promote key competencies for sustainability during their resolution.

2. Methodology

2.1 Research context

This case study has been developed in the Faculty of Health and Life Sciences of UPF, in the Human Biology bachelor's degree. This faculty has extensive experience in working with PBL and PjBL methodologies since 2004 (Carrió *et al.*, 2016; Rodríguez *et al.*, 2019), and the current Human Biology curricula has interdisciplinary PBL subjects every year, called Integrated Biomedicine. Therefore, teachers and students are trained in this methodology, and the PBL-SDG scenarios could be implemented in a natural way in these subjects.

In 2018, UPF launched the Planetary Wellbeing Initiative, an institutional strategy whose main objective is to increase knowledge and understanding of the set of complex, interrelated and systemic issues that affect the well-being of humans, animals and the planet itself as a global ecosystem and to identify innovative and integrated interdisciplinary solutions for them. Thus, the concept of planetary well-being takes an integrated approach to the individual, societal and planetary dimensions, which is consistent with the plurality of concerns and values expressed through the 17 SDGs (Anto *et al.*, 2021).

In accordance with this initiative and the attempt to introduce for the first time PBL scenarios that would specifically deal with SDGs and sustainability competencies in the human biology degree, the authors designed, implemented and evaluated new PBL-SDG

scenarios. Thus, this case study was based on collecting and analysing different types of data about the students' learning process and their opinions to understand in depth the aspects that were key to their engagement and to the learning outcomes obtained.

2.2 The problem-based learning approach

Two PBL scenarios were designed and implemented in a face-to-face format and in the context of the two existing compulsory subjects: Integrated Biomedicine I (for first-year students) and Integrated Biomedicine II (for second-year students).

The PBL scenarios were carried out over four 2-hour sessions (once a week), in groups of 7–10 students with a tutor who had the role of a learning facilitator, as following:

(1) in the first session, students discussed the scenario, decided the main themes they wanted to investigate and organized the teamwork;

(2) in the second session, students discussed the research they had done and agreed upon the topics they wanted to further explore;

(3) in the third session, the students prepared an oral presentation with the conclusions of their research and their proposals for action; and

(4) in the fourth session, the groups presented their final projects in front of the other students and an assessment committee.

The topic of the PBL-SDG1 scenario was "Global crisis on plastics: capitalism, human health and environmental degradation". It was presented as an infographic poster that gathered the life stories of different people, from different parts of the world and diverse socioeconomic groups, who are directly affected by plastics. The topic of the PBL-SDG2 scenario was "Contraceptive pills: impact on human health, the environment and menstrual stigma". It was presented as a series of "Instagram Stories" that addressed the environmental and health issues of contraceptive pills with a gender perspective. Both scenarios were designed according to the previously hypothesised criteria – that is, to be transversal, up-to-date, emotionally bonding, solution-oriented and eye-catching. Table 1 summarizes the topic, the SDG included and the main learning outcomes of the two PBL-SDG scenarios designed.

2.3 Participants

The study was carried out during the 2019–2020 academic year with the students of Integrated Biomedicine-I and II from the first and second year of the Human Biology degree.

All students were asked to complete a pre- and a post-intervention survey:

- The Integrated Biomedicine-I course comprised 70 students, organized into 7 groups. The pre-questionnaire was answered by 69 students (98.5%; 58 women and 11 men), and the post-questionnaire by 70 students (100%) (59 women and 11 men). After the course, a focus group with seven students was performed (7 women).

- The Integrated Biomedicine-II course comprised 41 students, also organized into 7 groups. The pre-questionnaire was answered by 40 students (97.5%) (33 women and 7 men), and the post-questionnaire by 35 (85.4%) (28 women and 7 men). The post-course focus group contained 9 students (7 women and 2 men).

2.4 Data collection and evaluation instruments

Data were collected through three main instruments: pre- and post-intervention questionnaires, focus groups (FG) and student productions. To complement the data, the principal investigator

Topic	Learning outcomes	SDG
Global crisis on plastics: capitalism, human health and environmental degradation	a) Explain which are the main types of plastics and how they are degraded	12, 13
	b) Identify plastics as potential POPs (Persistent Organic Pollutants) and their relationship with the Stockholm Convention	13, 14, 15
	c) Describe the mechanical, chemical and microbiological effects of plastics in the human body	3
	d) Analyze how plastics alter both aquatic and terrestrial ecosystems	14, 15
	e) Acquire a broad and critical vision of the pejorative effects of the plastics' cycle on human and environmental health	1, 10, 13, 14, 15
	f) Evaluate the different ways that exist to address the current conflict of the overuse of single-use plastics	12
Contraceptive pills: impact on human health, the environment and menstrual stigma	a) Explain the physiology of the menstrual cycle and its effects in the whole body	3
	b) Know the composition, the mechanism of action and the effects of the contraceptive pills used to delay or remove the menstrual cycle	3
	c) Analyze the effects that synthetic estrogens, as endocrine disruptors, have in aquatic and terrestrial ecosystems	14, 15
	d) Relate the existing social stigma of menstruation with the use of extended and continuous-use oral contraceptives	5
	e) Propose ways of addressing the conflict of the use of oral contraceptives to eliminate the menstrual cycle with a scientific and a gender perspective	3, 5, 12

Table 1.
PBL-SDG scenarios

Notes: Summary of the topics, the tackled SDG and the main objectives of the two PBL-SDG scenarios designed for the first- and second-year students

made non-participant observations of PBL sessions and took field notes, which were triangulated with the other data. Table 2 outlines the data collection strategy.

2.4.1 Pre- and post-intervention questionnaires. To assess students' perceptions of their learning, pre- and post-intervention anonymous questionnaires with Likert-type formats were given to the students. The questionnaires had two parts:

(1) knowledge acquisition related to the PBL-SDG topic; and

(2) reflections about the SDGs and sustainability competencies. In the post-intervention questionnaire, open questions about the PBL-SDG learning experience were added (Appendix 1).

2.4.2 Focus groups. At the end of both of the PBL courses, an extra 2-hour "focus group" was organized to gather student opinions about the overall PBL-SDG experience. Students from different groups were selected according to their participation scores. The moderator gave voice to all the students to ensure equal participation from all of them. Views and opinions from all the group representatives were evenly gathered. The questions discussed during the FG can be seen in Appendix 2.

2.4.3 Student productions. To gather evidence of the students' acquisition of sustainable competencies and knowledge, we analysed the student productions by taking notes during the oral presentation sessions and thoroughly going through their presentation support

	Instrument	Data collected
Pre-intervention	Pre-questionnaire	– Students' perceptions of their knowledge about the topic before the PBL intervention – Students' perceptions of their skills in sustainability before the PBL intervention
PBL-SDG-Implementation	Non-participant observations	– How are the SDGs identified from the PBL scenario? – How do students work on the SDGs and SC during the PBL sessions? – How do the group sessions develop?
Post-intervention	Students' productions	– Which SDGs have students incorporated in their productions and how?
	Post-questionnaire	– Students' perceptions of their knowledge about the topic after the PBL intervention – Students' perceptions of their skills in sustainability after the PBL intervention – Students feelings towards the experience
	Focus group	– Students suggestions and recommendations for future experiences – Students' perceptions of their sustainability competencies development

Table 2.
Data collection
diagram

materials afterwards. The analysis was aimed at looking for evidence of students having worked on a specific set of SDGs and the pre-defined learning objectives of the course.

2.5 Data analysis
Quantitative data were analysed with SPSS. To compare pre- and post-intervention survey results, answers were grouped according to group and gender and then, under the assumption of normality of the distribution of the means (Norman, 2010), were compared with paired samples Student's *t*-test. Given that a parametric test was used to analyse Likert-scale data and that this can be controversial, a non-parametric Wilcoxon signed-rank test was also carried out to proof the robustness of the results.

To analyse the qualitative content of the answers to the open-ended survey questions and the transcripts of the FG, the Atlas.ti software was used. An iterative process was carried out to define and refine the final codes and categories that summarize the data (Elo *et al.*, 2014). The two researchers conducted an independent reading of the data. They first identified emerging topics and concepts using an inductive strategy, then searched for patterns across and within data sources, and finally defined codes and categories together (Bingham and Witkowsky, 2022).

3. Results
3.1 Impact of the interventions in the sustainable development goal knowledge acquisition and the sustainability competencies development
3.1.1 Students perception on knowledge acquisition and sustainability competencies development. The main results of the comparative analysis between pre and post intervention surveys to assess students' perception of knowledge and sustainability competencies acquisition during the implementation of the PBL-SDG scenarios are shown in Figure 1.

Both first and second year students perceived that they had more knowledge about the main topics discussed in the PBL-SDGs after the interventions. Indeed, statistically significant differences ($p < 0.001$) were found between all pre- and post-intervention questions in terms of knowledge acquisition [Figure 1(a) and 1(c)].

Students also perceived that they significantly improved their sustainability competencies. Correspondingly, the students' ratings were higher for all items regarding sustainability competencies in the post-intervention surveys than in the pre-intervention ones. Statistically significant differences ($p < 0.001$) were found between all pre- and post-intervention items, except for one question for first year students regarding the plastics crisis, related to the systems thinking competency ($p > 0.05$) [(Figure 1(b) and 1(d)]. The high ratings of the post intervention questionnaire indicated that most students felt that they have developed these competences to a high level.

3.1.2 Evidence of incorporation of the sustainable development goal in the student productions. To assess the incorporation of specific SDG in students' productions, a qualitative analysis of their presentations was carried out (Figure 2).

On the one hand, the PBL-SDG1 aimed to address seven SDGs, namely, 1, 3, 10, 12, 13, 14 and 15. However, not all the groups worked on every one of them. Specifically, while the SDGs 3, 12, 14 and 15 were incorporated in all projects, the SDG10 was present only in three projects, and SDGs 1 and 13, only in two. The main topics through which these SDGs were incorporated into the students' projects were as follows: the mechanical, chemical and microbiological effects of plastics in aquatic and terrestrial ecosystems and the human body; the effects of endocrine disruptors from plastics in terrestrial and aquatic ecosystems, as well as in the human body; and the unequal effects of plastic production, manufacturing and disposal on humans and the environment.

On the other hand, the PBL-SDG2 aimed to address five SDGs, namely, 3, 5, 12, 14 and 15. Again, not all groups included all SDSs in their projects. While the SDGs 3, 4, 14 and 15 were present in all projects, SDG12 only appeared in three of them. The main topics they were incorporated in the students' projects were as follows: the effects of endocrine disruptors from contraceptive pills in terrestrial and aquatic ecosystems, as well as in the

Figure 1.
Quantitative results of the impact of the PBL-SDG interventions regarding knowledge and sustainability competencies acquisition, obtained through the pre- and postintervention surveys' responses from the PBL-SDG1 (A and B) and PBL-SDG2 (C and D) students
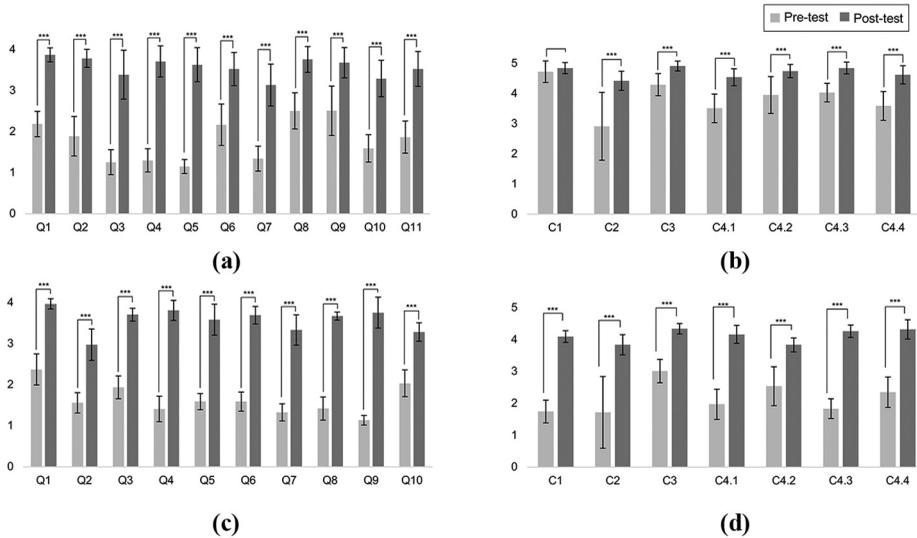
Notes: Data are expressed as mean and SD of each variable on Lickert scales 1-4 (A and C) and 0-5 (B and D); *$p < 0.05$ **$p < 0.01$ ***$p < 0.001$

human body; the physiology of the menstrual cycle and the effects of using extended or continuous oral contraceptives; social, religious and cultural view of menstrual stigma; sexual education and awareness; and how publicity and the commercialization of oral contraceptives to suppress menstruation perpetuate menstrual stigma.

3.2 Students' perceptions about the problem-based learning-sustainable development goal learning experience
The students' PBL-SDG learning experience was assessed through qualitative methods, including students' responses to open-ended post-intervention questions (OQ) and FG. From the analysis of all this data, four categories were identified:

(1) the PBL-SDG proposals;
(2) sustainability competencies development;
(3) the learning process; and
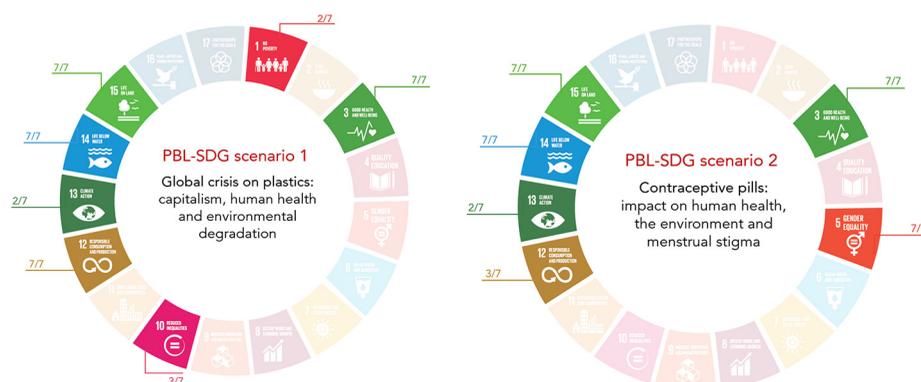(4) satisfaction, and limitations and suggestions.

3.2.1 The problem-based learning-sustainable development goal proposals. This category referred to students' opinions about the design of the two PBL-SDG proposals. Specially for these scenarios, this referred to the topics and the transversal character of the cases; for instance, the fact that they not only tackled biology-related issues but also incorporated other perspectives, such as cultural, socioeconomical, political and/or environmental ones. Students found the scenarios attractive, original, familiar and creativity prompting:

> I really liked the way it was presented. It aroused our curiosity. It was striking and it made you go deeper into the story and it was interesting [FG1].

The topics chosen were considered to be awareness-raising, interesting and necessary. This led to a high level of student engagement:

> I think that the proposed topic was very interesting, and it directly affected me. I was very dedicated and motivated [FG2].

The students believe that the transversality fostered their critical thinking, helped them to contextualise scientific concepts, was enriching, raised awareness, broke the monotony and

Figure 2.
Frequency in which the first- and second-year students' groups have incorporated the SDG into their projects ($n = 7$ for number of students' groups for each year)

Note: Data obtained through field notes taken during oral presentation sessions and the analysis of the students' projects

gave a global vision of the problem. However, some students felt slightly overwhelmed by the diversity of sub-themes:

> Doing this work opened my eyes. We dealt with it from different points of view and then we knew a lot more [. . .]. Normally I wouldn't have got involved and in this way I got into it and became very aware of myself and how present it is in our lives [FG1].

3.2.2 Development of sustainability competencies. Students noticed that they have developed all the key competencies in sustainability. They clearly perceive that they improved their systems-thinking competency by analysing the problem from different domains (society, environment, economy, etc.) and at different scales (local and global) and considering their interconnections:

> I think it is important to do this project because it opens your eyes. You deal with it from different points of view and then you can see things in a different way [FG1].

> This was a very strong point of this PBL, which allowed us to see other problems that also involve the topic and this is something that I liked very much [. . ..] I spent a week researching a topic and then when we shared it with group mates, I suddenly realized that there were a lot of things that were interrelated [FG2].

> We commented that the future that we will have is the present that many parts of the world are living now [FG1].

In some cases, they found that the problems were much more complex than they had thought, and although after the PBL they felt that while their knowledge to make informed decisions had increased, they also had more uncertainties. This suggests that they were also developing critical thinking competency:

> I have had the feeling that they make you believe that you have information and you see the problem but I don't see alternatives [. . .]. Now I don't feel fully prepared, a little bit more, but I should go much deeper [FG1].

They are also aware of having worked on anticipatory competency, by analysing possible future scenarios and possible change actions towards more sustainable models, especially within the PBL-SDG1. This led them to question their own actions and to initiate changes in their own lives, revealing that they had developed the self-awareness competency. In general, they had more hope in individual actions than in collective ones and, in some cases, admitted that this resulted in frustration:

> I used to think a lot about future situations, about what will happen, what I could do, and I got frustrated. For example, at home I could try not to consume plastic, but seeing the political situation, the more I knew, the more frustrated I got because I saw that it is very difficult to do anything [FG1].

> It made me think about my actions, I'm very ecofriendly but I'm using pills that are damaging the environment [FG2].

Students commented that they would like to work more on strategic competency. They proposed several initiatives, but they felt that having an opportunity to put them into practice was lacking. They also claimed to have addressed normative competency by identifying the values and beliefs that are involved in these complex problems and the collaborative competency, which they found to be implicit in any PBL:

It also depends a lot on culture and religion and what values will depend on the vision of menstruation [FG2].

Finally, students felt that their knowledge, either in general or in specific areas, had increased a lot. This raised their self-awareness, their collective awareness and their critical spirit; it opened their minds and gave them a more global and transversal view of science.

3.2.3 Learning process. This category was based on the students' opinions about the tutors, the evaluation process and the group dynamics. Overall, tutors were perceived as supportive and guiding. However, some students claimed that knowing that the tutors expected them to accomplish certain learning outcomes limited their curiosity and originality. Some students were satisfied with the evaluation process, but others felt that originality was not properly valued. The perception of the group dynamics was diverse, while some students were highly satisfied while others found that there was a lack of collaboration and efficiency:

> You know that the tutors have very specific learning outcomes and that the evaluation is based on them [. . .]. I would prefer more open objectives and give people room to develop what they are most interested in [FG2].

3.2.4 Satisfaction, limitations and suggestions. Under the "satisfaction, limitations and suggestions" categories, we gathered the main findings that made students satisfied with the proposals, and the suggestions about aspects that could be improved. In general, students were satisfied with the projects, the theme, the proposed scenario and the PBL-SDG approach, all of which the students believed gave them a wider understanding of the subject and increased their critical thinking and knowledge acquisition.

Some of the constraints identified by the students were lack of time, lack of freedom to make decisions and the large amount of information to be assimilated. They suggested the following improvements:

- more time allocated for debate between groups; and
- encouraging students to either make real proposals that address the problem or to carry out service-learning projects.

> I've found it a very interesting topic and very necessary to talk about. The format of the scenario was very suitable too [OQ1].

> I would have liked to have more time because it was a very interesting topic but also very extensive [FC2].

> It could be a good idea to do something to raise awareness about the topic in the general population [FG1].

4. Discussion
4.1 Usefulness of problem-based learning approach for sustainable development competencies
This study analyses the acquisition of SDG-related knowledge and the development of Key Competencies in sustainability through two PBL scenarios in biomedical education. Quantitative results from students' questionnaires suggest that the PBL-SDG approaches had a positive impact on students' knowledge in SDGs and sustainability competencies development, which reinforces previous studies suggesting PBL as an optimal methodology

for ESD (Lozano *et al.*, 2017; Tejedor *et al.*, 2019). To go deeper into this matter, quantitative data were triangulated and enriched with qualitative results from students' questionnaires, FG and the analysis of students' productions.

Qualitative analysis from the students' productions is consistent with quantitative results, indicating that there had actually been a gain of both knowledge and competencies in sustainability (as perceived by the students). As stated in the results, not all SDGs that were supposed to be covered were tackled by the students. This could either be because there were too many topics to work on, or because the scenarios themselves did not make it sufficiently clear that those SDGs had to be covered. Regarding the development of sustainability competencies, qualitative data are also consistent with the quantitative data, indicating an improvement. On the one hand, students perceived that the intervention helped them to work in-depth on systems, normative and critical thinking, self-awareness and collaboration competencies and, to a lesser extent, anticipatory and strategic competencies. Interestingly, students in the FG stated that gaining knowledge about sustainability helped them develop these competences. This suggests that, in this context, PBL promoted reflective and self-regulated learning, as previously described for other contexts (Larmer and Mergendoller, 2015), and that the students became aware of which knowledge and skills relate to sustainability.

4.2 Recommendations for implementing problem-based learning scenarios for developing sustainable development competencies

Based on the evaluation of the two PBL interventions and on gathering and analysing students' opinions and experiences, this study aimed to produce some recommendations for the design and the implementation of PBL scenarios that address all sustainability competencies.

Regarding the design of the scenarios, several studies highlighted the importance of presenting real-world, up-to-date and transversal problems to work on the systemic and normative thinking, the integrated problem-solving and the self-awareness skills (Frisk and Larson, 2011; Corres, 2020). In this study, the two scenarios included multidisciplinary perspectives and integrated individual, societal and planetary dimensions. According to this, students stated that having worked on such types of projects helped them contextualize the scientific knowledge, gave them a wider perspective of the problem and raised their awareness. When it came to the complexity of the topic, students reported feeling slightly overwhelmed by it. However, it is also true that they stressed they would like to have more time to develop their projects, so it is important to provide the time needed to integrate so many different perspectives. It should also be noted that working with these competencies involves opening up the debate about students' values, futures and uncertainties and frustrations, so tutors must be prepared and to deal with these issues. This requires training tutors in emotional competencies, so that they can promote spaces for sharing experiences, emotional openness and resonant understanding, but so far they have received little attention (Corres *et al.*, 2020).

Another element that students identified as key for them to develop their self-awareness competency and their normative and critical thinking were the emotionally bonding and controversial topics. They aroused their interest and perceived that they were closely affected by them. This raised their eagerness to carry out projects that could have a real impact on society. However, as these PBL scenarios were not clearly action-oriented, they were not able to develop anticipatory and strategic skills as much as the other competences.

The original and familiar way of presenting the scenarios was important in generating emotions, helped to capture the students' attention and engage them. They also felt that

prompted their creativity and motivated them to face the problems proposed. At first sight, this is something that is not directly related to the development of the competencies in sustainability, but it can actually be a really powerful tool to drive students deep into the scenario.

Switching to the implementation of scenarios, students reported the importance of having their own voice and freedom, as well as learning from reflecting on their experiences. According to previous studies, letting students have their own voice creates a sense of ownership in them (Larmer and Mergendoller, 2015). It is actually important that they have the opportunity to decide on certain things when solving the scenario, as well as they have a space to share their ideas and opinions on the discussed topics, thus working on both the collaborative and the critical thinking competencies. It is also crucial for students to have time and moments to reflect on what they are learning and how they are doing it and it is, in fact, another way to work on their self-awareness and normative-thinking skills. All these aspects should be facilitated by the tutors through questions that challenge them individually and as a group. In this study, for instance, students perceived that while they could really reflect on what they were doing and learning, their freedom and voice were not fully taken into account, as their creativity was not recognised in the assessments. This situation raises another important point: the effect of the assessment process on learning. It is essential that assessment is geared towards facilitating and empowering students in the development of such competences which include creativity (Dlouhá et al., 2019).

Students also missed opportunities to discuss and reflect on their projects between groups. As others have noted, open discussion and debate dynamics between students, whether from the same or different degrees, are highly enriching (Tilbury, 2011; Lozano et al., 2017; Evans, 2019) and can be combined with PBL to reinforce working on several competencies, such as the normative and critical thinking or the collaborative one.

The last element that seemed to be of crucial importance regarding the dynamics of the course were the role of the tutors. Students perceived that tutors should be guiding, supportive, engaged and motivating figures, rather than evaluators. Such findings are consistent with Tejedor et al. (2019) and prove, one more time, that there is still a need to train teachers on this new approach of PBL and on the strategies to convey the sustainability competencies to the students.

Moreover, the overall experience of the FG showed that apart from being a great tool for data gathering, FG can be a transformative resource to foster critical thinking and awareness of what has been learned and how. Being PBL and focus group methodologies key boosters of self and collective awareness makes them, once again, pretty suitable for working on the SDG and the sustainability competencies (Tilbury, 2011; Lozano et al., 2017).

So given the students' comments about their interest in being able to have a real impact, it might be a good idea to explore hybrid forms of PBL-PjBL (Brundiers and Wiek, 2013; Corvers et al., 2016). This would mean keeping the inquiry process of the PBL, together with the open and systemic character of the scenarios, but producing or planning applicable results. This would, once again, require more time to develop the projects. Related to that, students also suggested that developing service-learning would be something engaging for them and that would also give even more sense to their projects. This is something that, again, supports Lozano et al. (2017) findings and, according to them, it would be a great opportunity to work on strategic action, personal involvement and collaboration. This, together with the previous proposals of designing hybrid PBL and PjBL scenarios and combining them with FG, opens the door to the idea of experimenting and exploring hybrid forms of PBL with other active learning and participatory pedagogical approaches to convey the whole set of sustainability competencies.

All in all, the elements that seem to make the PBL approaches more suitable to work on the sustainability competencies are the following:

- original yet familiar scenarios;
- topics that are emotionally bonding, transversal and up-to-date;
- the students' voice and freedom;
- peer-work and feedback between groups;
- learning from reflecting on experiences;
- developing and applying projects that could have a real impact in society;
- combining different active-learning pedagogical approaches; and
- having engaged, supportive, guiding and motivating tutors.

All of these elements are key for students to contextualize scientific knowledge and to gain skills in sustainability.

5. Conclusions

This study provides evidence on how PBL can be used with biomedical students to develop key competencies for sustainability through transversal scenarios, whereby several SDGs can be addressed simultaneously. This strategy incorporates perspectives that go beyond the discipline itself, such as social, cultural, economic and environmental ones. This study revealed that students found the PBL-SDGs to be relevant and useful for their integral education, both as individuals and as future health professionals. Through this study, some challenges have also been identified to improve the development of sustainability competencies with PBL-SDG strategies, such as training of tutors in management of emotions and uncertainty, seeking the possibilities of linking PBL-SDG with some actions in the community and promoting debate among several students from the same discipline as well as from other disciplines.

Thus, the PBL approaches presented in this study show a pedagogical strategy that universities can use to educate their students as key agents of change, capable of facing the challenges of the future with an ethical, critical and committed spirit. The findings of this study not only provide evidence in this regard, but also provide guidelines and strategies for the successful implementation of such methodologies. Ultimately, we hope that it will set a precedent and engage the teaching community in this rewarding, urgent and necessary task of educating for sustainable development.

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Appendix 1

PBL-SDG1: Global crisis on plastics	PBL-SDG2: Contraceptive pills

1. Knowledge acquisition (1, I don't know; 2, I have some idea; 3, I know it; 4, I can explain it to a colleague)

PBL-SDG1: Global crisis on plastics	PBL-SDG2: Contraceptive pills
Q1. What are plastics, and what types of plastics exist?	Q1. How does the physiology of the menstrual cycle work?
Q2. What is the lifecycle of plastics?	Q2. Which effects do the menstrual cycle hormones have on other organs and systems of the human body?
Q3. What is the Stockholm Convention?	
Q4. What are POPs (Persistent Organic Pollutants)?	Q3. What types of oral contraceptives exist?
Q5. Which is the relationship between plastics and POPs?	Q4. What is the chemical composition of the existing oral contraceptives?
Q6. How do plastics enter the human body?	Q5. How do oral contraceptives alter the physiology of our body?
Q7. Which are the molecular and physiological effects of plastics in our bodies?	Q6. What are extended and continuous-use oral contraceptives?
Q8. How do plastics get into both aquatic and terrestrial food webs?	Q7. What are the physiological consequences of delaying or stopping the menstrual cycle with extended and continuous-use oral contraceptives?
Q9. How do plastics alter ecosystems?	
Q10. In which ways does each one of the different parts of the plastic cycle affect people and the environment?	Q8. What are synthetic estrogens?
Q11. What are the existing strategies to manage the plastics conflict?	Q9. What are the effects of synthetic estrogens in both aquatic and terrestrial ecosystems? And in humans?

2. Reflecting about the SDGs and SC (0, strongly disagree; 1, disagree; 2, partially disagree; 3, partially agree, 4, agree; 5, strongly agree)

PBL-SDG1: Global crisis on plastics	PBL-SDG2: Contraceptive pills
C1. I am able to analyze the plastics conflict by keeping a focus on the production processes, as well as on its consumption, the management of its residues and its presence in the environment	C1. I can discuss the beneficial and harmful effects in human bodies of the use of extended and continuous-use oral contraceptives from a critical point of view
C2. I am capable of linking and critically analyzing the relationship between the different stages of the plastic life cycle with their harmful effects to both humankind and the environment	C2. I can draw a link between the suppression of the menstrual cycle and the historical stigmatization of menstruation, and I can give grounded arguments about it
C3. I understand that the increase in both plastic production and consumption generates health, environmental and social conflicts and I am able to discuss them	C3. I understand that the use of oral contraceptives in suppressing the menstrual cycle generates scientific, health, environmental and gender conflicts and I am capable of discussing them
C4. I can analyze different ways of tackling the plastic conflict with critical thinking and...	C4. I can think about different ways of coping with the conflict about the use of oral contraceptives to suppress the menstrual cycle...
C4.1. from a scientific perspective	C4.1. from a scientific perspective
C4.2. from a social perspective	C4.2. from a gender perspective
C4.3. from an environmental perspective	C4.3. from an environmental perspective
C4.4. from a health perspective	C4.4. from a health perspective

3. Open questions (added in the post-intervention questionnaire)
1. If you had to carry out this PBL again, is there anything that you would like to be different?
2. After these weeks, do you feel you have gained resources to talk about the subject from a critical and a grounded perspective? Do you feel this case should have been oriented in a different way?
3. Do you feel like you have learned about different concepts related to biology in a transversal manner? Please explain in which ways (if at all) this experience has enriched you

Table A1.
Pre- and post-intervention questionnaires for PBL-SDG1 and PBL-SDG2

Appendix 2

Focus group script
Theme 1: development of key competences in sustainability
Which sustainable competencies did you develop?

Theme 2: problem-based learning-sustainable development goals scenario
What did you think about the presentation of the scenario? Was it innovative? Was it engaging? Why or why not?

Do you think that the covered topic closely concerned you? Had you heard about it before? Did you find it interesting? Why or why not?

Do you think that the systemic approach of the topics was enriching or did it simply present an additional difficulty?

Theme 3: problem-based learning-sustainable development goal sessions
Did you find the tutorial sessions useful? How were the group dynamics? Do you think that the diversity of subtopics to cover helped to engage everyone in the group according to their interests?

What did you think about the projects from the other groups? Did you find that a space for debate was missing?

Theme 4: personal impact
Do you think that this project has changed something for you?

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