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# Problem-Based Learning and Engineering Education for Sustainability

## Where we are and where could we go?

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## Abstract

Education for sustainability demands transformative knowledge, which can be obtained through problem-based, project-organized learning (PBL). However, the integration of PBL and sustainability in higher education has not yet met the needs required due to the lack of application of a systemic perspective and strategy. In this literature review, we present an overview of research trends being developed with PBL in education for sustainability and how PBL is being used to educate students for sustainability. The scientific production of the last 22 years is analyzed, and we verify that the use of PBL as a methodology for education in sustainability is a rather recent innovation, with an emphasis on the environmental dimension. Learning assessment methodologies are based on summative approaches using traditional methods like scoring tests. There is an explicit preference to integrate PBL and sustainability in undergraduate and graduate courses, mainly in engineering. We observe that most of the time, the subject of interdisciplinarity is not discussed. We concluded that there are a few concerns with research on education for sustainability using PBL. Although PBL proposes an innovative form of education, its implementation in education for sustainability has not been fully explored to its full potential, especially con-

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cerning the development of sustainability skills, transformative and holistic education, but rather as a form of content-based assessment.

***Keywords***: PBL, education for sustainability, literature review, research trends

# Introduction

The Sustainable Development Goals (SDG) of the United Nations (UN) provide a framework for action for countries to achieve certain sustainability targets by 2030. Education must prepare and educate its graduates accordingly, with knowledge and competences to act locally and have global positive impacts (Sterling, 1996). In recent years, the commitment of higher educational institutions to education for sustainable development and SDG has increased considerably, leading to strategies to integrate them into educational, research, and outreach activities (Gamage & Silva, 2022). From an educational perspective, two main strategies have been used: adding sustainability to a curriculum in a compartmentalized way (i.e., education about sustainability), and integrating sustainability in a transformative and contextual way (i.e., education for sustainability) (Leicht et al., 2018). Education for sustainability emphasizes more than content, as in add-on strategies. It advocates a holistic approach to education that involves the head, hands, heart, and spirit, with a particular focus on the learning process and the development of competences and values to act for sustainability (Sterling, 2004; Hermes & Rimanoczy, 2018). Working from different frameworks, Annelin and Boström (2023) provided an overview and defined eight key sustainability competences, namely, systems thinking, strategic thinking, future/anticipatory thinking, values/norms thinking, interpersonal thinking, intrapersonal thinking, implementational thinking, integrated problem-solving competencies for sustainability, which are also related to competencies for employability and social transformation toward a sustainable future (Annelin & Boström, 2023, p. 55). That said, educating for sustainability calls for transformative, problem-oriented, contextual, collaborative, and inter- and transdisciplinary knowledge, with participatory and empowering learning environments, such as in problem-based, project-organized learning (PBL) (Guerra, 2017; Gutierrez-Bucheli et al., 2022; Rodríguez Aboytes & Barth, 2020).

PBL emerged from practice in the 1970s that intended to equip students with ready-to-use professional skills, such as problem-solving, teamwork, communication, critical thinking, and lifelong learning (Guerra & Kolmos, 2011). In a PBL environment, a group of students learns by formulating and solving real, authentic problems. The learning process begins with a problem

that can be presented to students in the format of cases or solved through projects. For example, project-organized, problem-based learning is the most common PBL curricular model used in engineering education, whilst medicine organize its PBL curriculum around cases. The role of the teacher shifts from that of a transmitter of knowledge to a facilitator of and for learning. PBL is grounded in principles such as contextual, experiential, and exemplary learning, as well as in democratic, emancipatory, and ownership values (Kolmos et al., 2009).

Although much has been achieved in recent years concerning educating for sustainability, we are still behind in what is necessary to equip future professionals with the qualification profile required to address present challenges and wicked sustainability problems (Annelin & Boström, 2023). The literature shows that most PBL integration is found in higher education and is at the course and program level, lacking a systemic perspective and strategy (Chen et al., 2020), where the main drivers for curriculum change are seldom related to the integration of sustainability but are rather used to equip students with professional skills on demand, lacking the integration of knowledge and competences required for action and contribution to sustainability (see, for example, Guerra et al., 2017). In addition, students in the exact sciences and engineering seem to be least active in participating in activities organized by higher education institutions toward environmental protection, the least aware of the UN's SDGs, and the least inclined to accept a lower salary to work in a job that promotes social and environmental change (Aleixo et al., 2021).

Recent literature reviews have reported on different aspects of education for sustainable development in higher education, namely the conceptualization of transformative learning and operationalization (Rodríguez Aboytes & Barth, 2020), experiences in higher education regarding the UN's SDGs in different activities areas (e.g., research, education, outreach, and management) (Serafini et al., 2022), the relationship between pedagogies, content, and development of specific "sustainability outcomes" (Probst, 2022), key sustainability competences and survey assessment tools (Annelin & Boström, 2023), pre-service teaching education for sustainability (Lorente-Echeverría et al., 2022), and professional development of teachers to foster the integration of sustainability in university curricula (Fischer et al., 2022).

The studies refer, explicitly or implicitly, to the need for problem-oriented pedagogies, such as PBL, to educate for sustainability. However, they seldom refer to the links between PBL, specific education contexts, and sustainability, as well in which this pedagogy has contributed to its development.

The research questions (RQs) that will guide this work are the following:

1. What are the research trends in PBL and sustainability in education?
2. How is PBL being used to educate students for sustainability?

We intend to answer both questions with a literature review.

## Methodology

To begin with, we focus on sustainability, and from that, we seek to explore the ways that PBL and the integration of sustainability have been studied over the last 22 years. The search covers all levels of education, without distinction of disciplines, was made to verify insights and practices in general. This study is a literature review, with a systematic approach that was inspired by the Prisma 2020 model (Page et al., 2021). This methodology is a guideline for the preparation of systematic reviews and meta-analyses, through 27 checklist items, seeking standardization with the purpose of, among other things, facilitating the replication and updating of reviews.

For this study, as it is a review and not a meta-analysis, we did not use the full rigor of the methodology as we understood that certain items were unnecessary or not applicable to answer our research questions without, however, compromising the quality of the review. In this way, we fail to address items such as assessment of risk of bias, effect measures, or statistical treatments. We also did not perform sensitivity analyses to assess the robustness of the results found or confidence in the body of evidence. The studies analyzed were, in general, not discussed individually, unless they presented particular characteristics relating to our research question. In this research, we briefly present a flow diagram describing the results of the search and selection process. The approach is described below.

In response to the research questions, which focus on sustainability and PBL, we propose two search blocks, as shown in Table 1. Search block 1 includes keywords synonymous with PBL, while search block 2 includes keywords synonymous to sustainability.

| Database | Search | Retrieved records |
|---|---|---|
| SCOPUS | BLOCK 1: PBL OR Problem-oriented OR Project-oriented OR Problem-based learning OR Project-based learning ***AND*** BLOCK 2: Sustainability OR Sustainable development OR Sustainable development goals OR SDG. | 97 |
| Web of Science | BLOCK 1: PBL OR Problem-oriented OR Project-oriented OR Problem-based learning OR Project-based learning ***AND*** BLOCK 2: Sustainability OR Sustainable development OR Sustainable development goals OR SDG. | 711 |

*Table 1. Strings used to search for each database and the number of records retrieved.*

The SCOPUS database was searched on July 2, 2022, and the Web of Science database was searched on July 15, 2022. The search strings used for each database can be found in Table 2 and were used in the fields "article title," "abstract," and "keyword."

We used SCOPUS and the Web of Science as search databases. These databases are multidisciplinary, and article indexing goes through an evaluation process to ensure that minimum quality standards are met, including peer-review procedures and the provision of ethical and malpractice statements (Borrego, Foster, & Froyd, 2014).

The search included the inclusion and exclusion criteria shown in Table 2.

| Criterion | Inclusion | Exclusion |
|---|---|---|
| Type of documents | Peer-reviewed articles, reviews, and conference papers | Books and book chapters |
| Years | 2000 to the present | Under the year 2000 |
| Databases | Scopus and the Web of Science | Other databases |
| Subject area | All | No restriction |
| Languages | English | Other languages |
| Fields | article title, abstract, and keywords | Other fields |
| The focus of the analysis | PBL was used to educate about Sustainability | Other methodologies than PBL, other themes than sustainability |
| Meaning of sustainability | Meet the needs of the present without compromising the ability of future generations to meet their own needs | Other meanings |

*Table 2. Criteria for the selection of articles.*

The search result, using the inclusion and exclusion criteria and screening by abstracts, provided a total of 129 articles, as shown in Figure 1. The number of exclusions is high because, in our database search, there were no limitations regarding the subject area. In addition, because the search term PBL is an acronym, articles in other subjects that also use PBL but with a different meaning were also identified by the search.

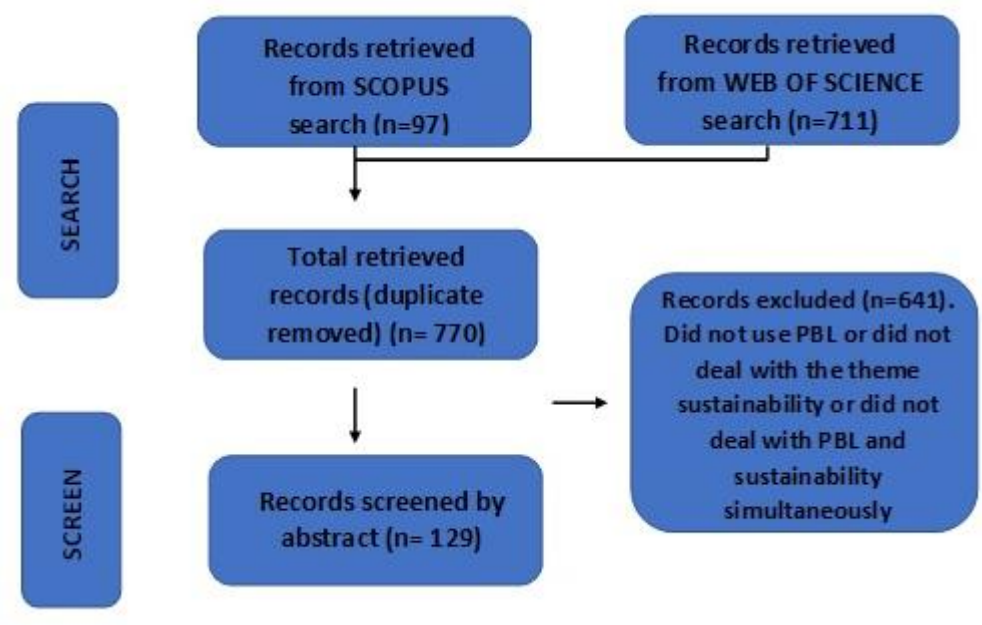


*Figure 1. The flow chart for the searching and filtering process (N=129).*

Before analysis, information from each of the 129 articles was extracted and documented. These articles served as the basis for the discussion of the metadata.

Database searches, filtering, and extraction of information from articles were carried out by only one of the authors. However, the other authors participated collaboratively in the discussion, validating the requirements established for inclusion and exclusion.

Among the 129 articles that met the inclusion/exclusion criteria, several were related to the description of activities where sustainability was just a subject for the development of the PBL methodology, without delving into the issue of sustainability. Others focused only on one topic, leaving the other in the background. However, for us to answer the questions in this paper, our focus needs to be on articles that integrate PBL with sustainability in a deeper way.

A table was created using Microsoft Excel, and, taking the guiding questions into account, the below analytical criteria were established, and developed for each article that integrates PBL with sustainability:

1. The type of research design
2. Type of RQs
3. PBL model and level of implementation
4. Level/type of sustainability learning

To construct the co-authorship network, the NodeXL program was used, which functions as a complement to Excel. This program creates a structural image of networks, to verify the existence of connected components, which are either related or not, making it possible to visually determine central components.

# Results

This section presents the analysis for each of the questions and other relevant findings.

## Research integrating PBL and sustainability (RQ1): Who and when has been researching? (N=129)

From 770 articles, 129 articles were selected using filtering, equivalent to 16.6% of the total group of articles that have PBL and sustainability as main themes.

Although our search was carried out from 2000 onwards, we identified the emergence of production from 2007 onwards (Figure 2), when articles began to appear in which PBL and sustainability are the themes or PBL is used as a main approach to integrating sustainability in the curriculum. An increase was also found in the concern to include the theme of sustainability in the curricula. We also observed a constant increase from 2014 onwards in the number of publications related to the theme (2022 shows an expected decrease because the search was carried out in the middle of the year). We also verified that more than twice as many articles as conference papers (89 articles/40 conference papers).

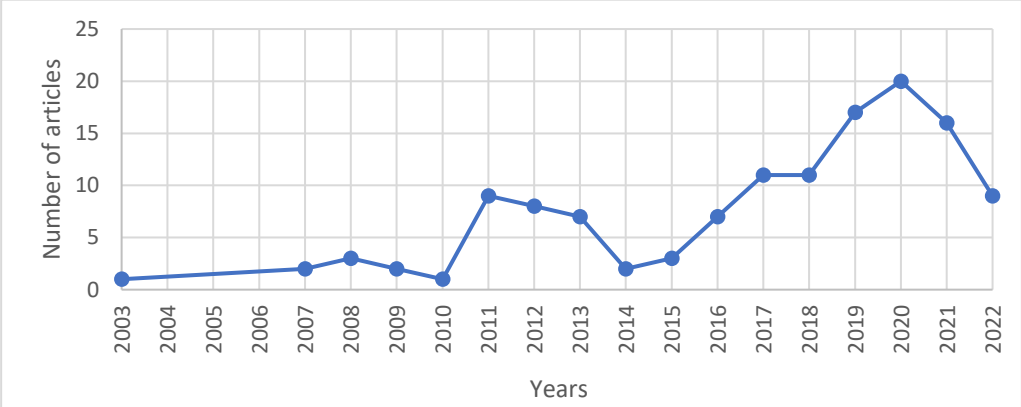


*Figure 2. The distribution of articles per year (N=129).*

We found that 54 authors were published more than once, out of a total universe of 384 authors. Even so, of these 54 authors, 15 have more than two publications in the set (Aida Guerra, n=4; Esther García-González, n=4; Bartlomiej Gladysz, n=3; Elisabete Alberdi, n=3; Elzbieta Jarzebowska, n=3; Heriberto Pérez-Acebo, n=3; Irantzu Álvarez, n=3; Isabel Eguia, n=3; Jens Myrup Pedersen, n=3; María José García Gonzalez, n=3; Mohamed Elzomor, n=3; Mónica Fernández-Morilla, n=3; Paulo Etxeberria, n=3; Sílvia Albareda-Tiana, n=3; and Stephanie Luster-Teasley, n=3). Of these, only Aida Guerra (2012, 2016, 2018, and 2021) and Mohamed Elzomor (2016, 2017, and 2021) show a regular history of publications on the subject. The others' publications were restricted to a few years, and some have not been published on the subject since 2011 or 2020. This may be an indication that this subject does not characterize a line of research but only produces results derived from isolated research projects that are abandoned. Furthermore, in general, the authors of the publications identified belong to segregated groups that do not collaborate among themselves. A group representing Spanish universities has emerged recently, showing publications after 2021, such as Esther García-Gonzáles, Sílvia Albareda-Tiana, Paulo Etxeberria, and María José García, who were co-authors of two papers developed at two Spanish universities.

It is commonly understood that the number of citations of an author reveals his or her importance as a researcher in the given field. Therefore, among the authors with more than 10 citations, we found that the two most cited references are not articles but official publications by UNESCO and the UN. This can be explained by the fact that they are a mandatory reference for the SDGs and sustainability-oriented education. Arnin Wiek has 40 citations, followed by Katja Brundiers with 33 citations, and Anette Kolmos, with 24. The complete list is presented in Figure 3. This clarifies the relationship between the cited publications and the articles' themes. These authors have many publications on PBL, sustainability, and both together.

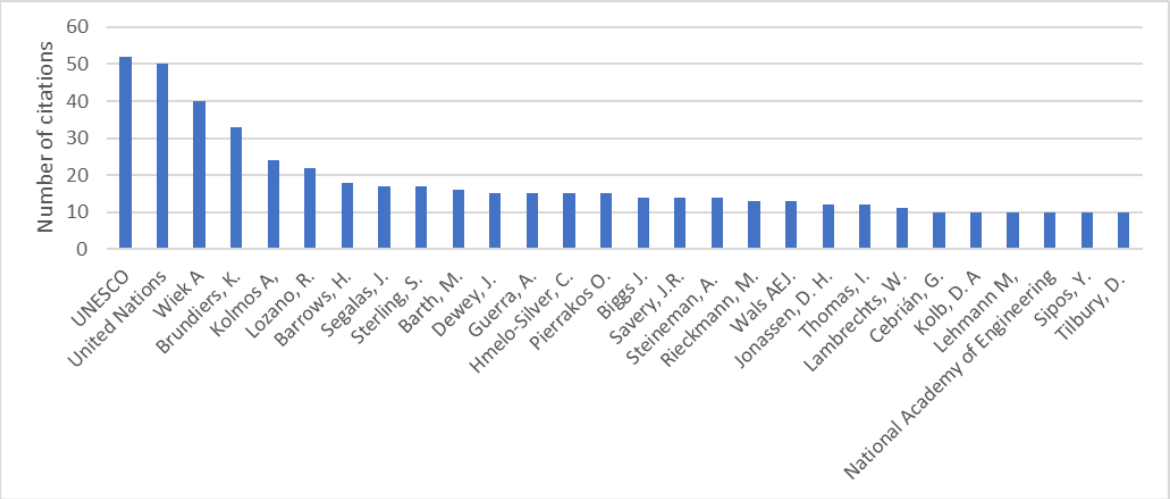


*Figure 3. The number of citations per author with more than 10 citations.*

Figure 4 shows the three universities that emerge as the largest producers of knowledge in PBL and/or sustainability since they are the affiliations of researchers who were cited more than 10 times.

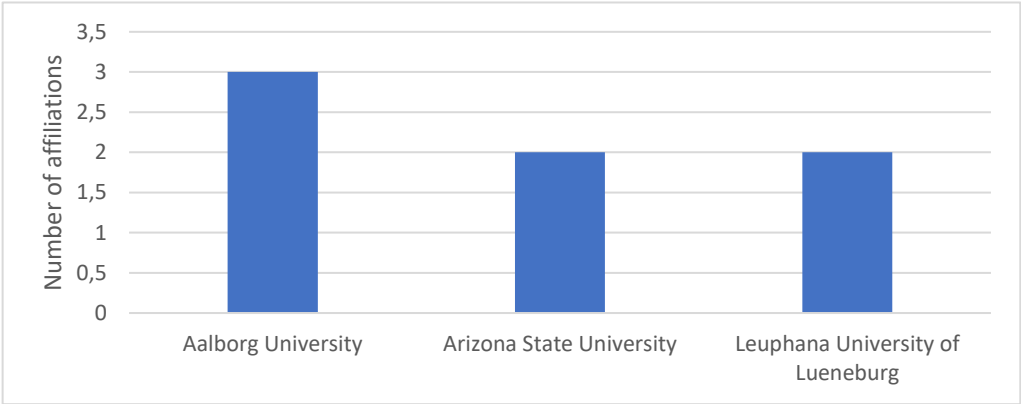


*Figure 4. Universities with the highest number of researchers were cited more than 10 times.*

On the other hand, we observed that Aalborg University and Arizona State University are significant knowledge producers since they are affiliations of authors cited more than 10 times, but Leuphana University did not produce any article that had both PBL and sustainability as themes. Comparing the number of affiliations with the number of articles, we note the normalization that best represents the importance of the university. As shown in Figure 5, some universities have many affiliations but a low number of articles, meaning that many authors from the same university were co-authors of the same work. In this context, Aalborg University established itself as the university with the largest number of researchers working on the subject of PBL and/or sustainability, and with the largest number of articles.

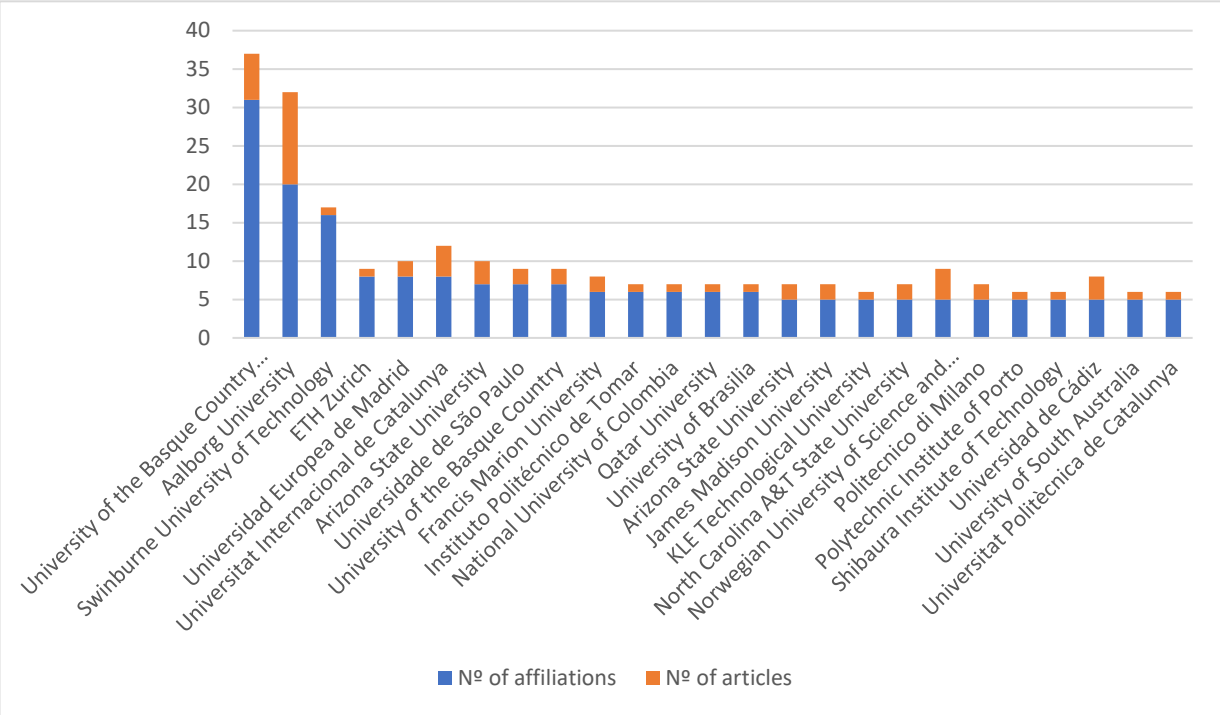


*Figure 5. The number of affiliations per institution x number of articles per institution.*

The co-authorship network shows how the authors interact with each other. In this work, we carry out a network analysis by institution (Figure 6), due to the low number of publications by authors. Of the 144 universities to which the authors were affiliated at the time of publication, 36 had no relationship with any other university, and 13 were related to more than 3 other institutions. These data show that institutions interact very little with each other, working, in an isolated and segregated way, for the most part. This tendency may perhaps explain the small number of publications on the subject, suggesting that these are not lines of research as such, but rather sporadic works carried out for a particular purpose.

As shown in Figure 6, a network analysis of the institutions shows a tendency away from collaborating with other institutions. However, in opposition to this tendency, the Norwegian University of Science and Technology and Aalborg University are collaborators with institutions from different parts of the world. When we analyze the graph of relationships, we see two connected components that are not related. One relates to relationships between universities in Spain, and the other is composed of two groups of universities, with the Norwegian University of Science and Technology as the central institution that connects the two groups.

Norwegian University of Science and Technology emerges as the central university linking two related components and works based there have the

highest number of collaborations. However, these are largely European institutions, in general with Nordic and Eastern European countries. This difference refers to the existence of different schools of thought. However, concerning the publications, we noticed that the Norwegian University has only three publications, two of which are related to the European Engineering Team project, which proposes a transnational teaching structure using PBL, with engineering students from four countries (Gladysz et al, 2018; Gladysz et al. 2020). Another work was related to the construction of a summer school, bringing together students from three Scandinavian countries (Buser et al., 2017). Therefore, the network within the Nordic countries can be explained not as the result of a line of thought, but as the result of a regional nature.

On the other hand, as we analyze the two interconnected networks, we see a tendency for the Norwegian University of Science and Technology group to focus more on the development of the PBL methodology, while the Aalborg University group is concerned with both methodology and sustainability-oriented education. The University of Aalborg also appears as a collaborator with researchers from Asian, European, North American, and South American institutions, with a more robust global collaboration network.

The production of interconnected groups rooted in Spanish universities has been recent, beginning in 2018, with no production in 2022. This year coincides with the creation of the EDINSOST project by the Spanish government, whose objective is to innovate in universities so that future graduates acquire the skills necessary for a sustainable society; nine Spanish universities are participating in this project. All of these groups' work is related to the EDINSOST project, which uses a rubric for assessing skills in sustainability, justifying the establishment of this disconnected network (Albared-Tiana et al., 2018; Tejedor et al., 2019; Albareda-Tiana et al., 2019).

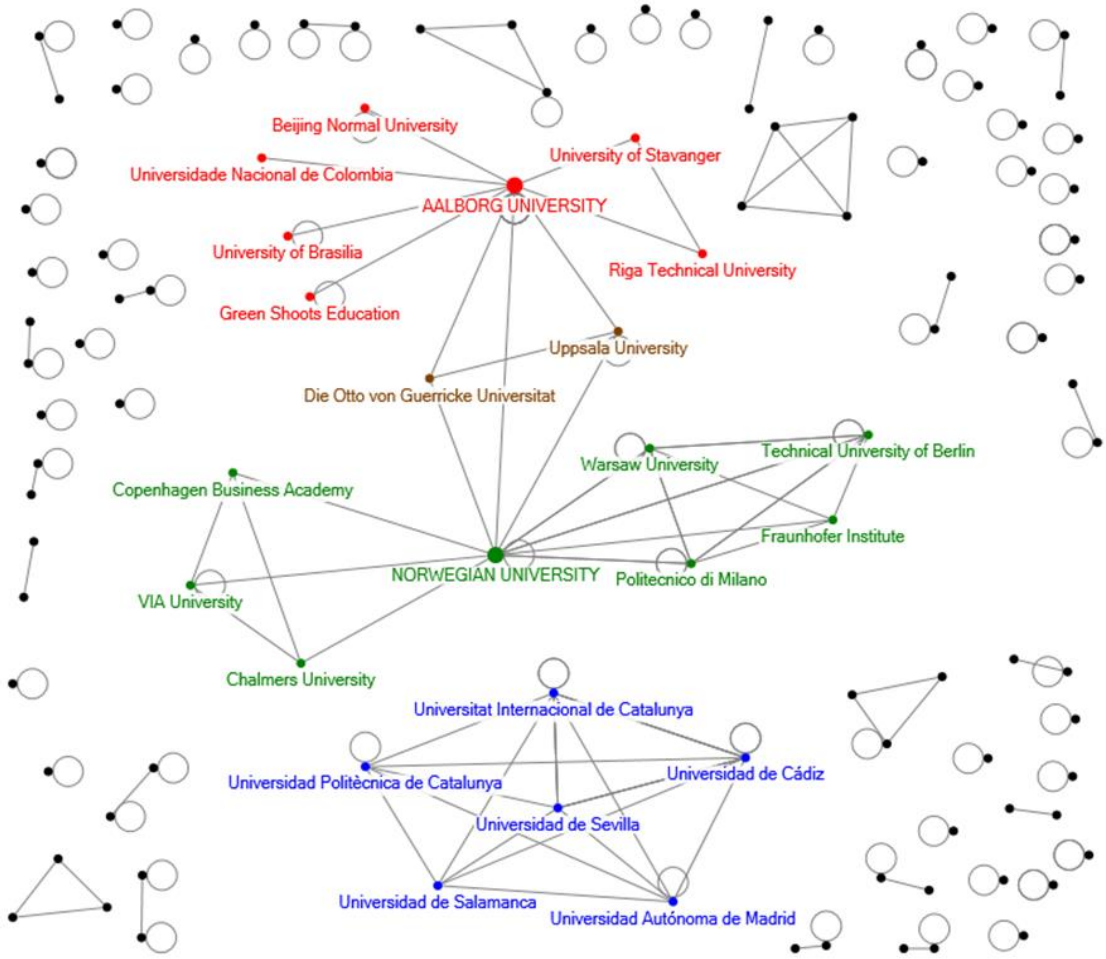


*Figure 6. Co-authoring networks between institutions. Dots represent institutions, and lines are the connections between them. Circles represent co-authorships from the same institution.*

When analyzing the countries where the articles were produced about the authors' affiliations at the time of publication, we identified a worldwide agreement of PBL suitability to educate for sustainability, with all continents represented (Figure 7). Although no African sources are shown in the figure (only countries with five or more affiliations were tabulated), there are four authors affiliated with universities in South Africa and one in Tanzania. We observe a predominance of the richest countries in the production of works.

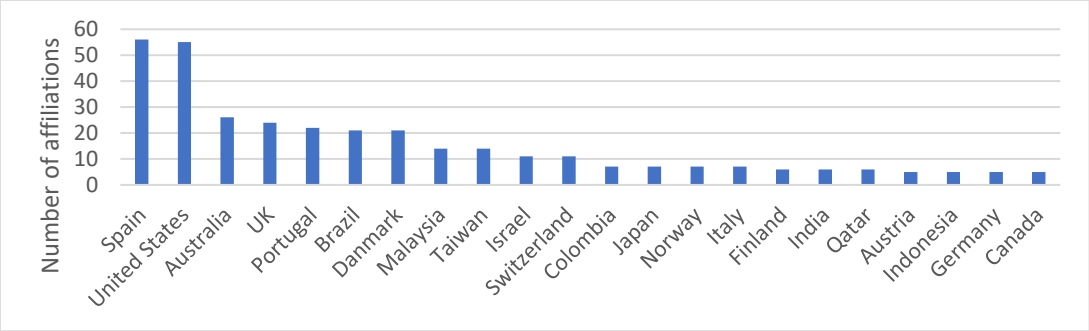


*Figure 7. Number of times a country appears in article affiliations. Only countries with five or more affiliations are represented here.*

We partially concluded that there was an increase in interest in the proposed themes from 2014 onwards. On the other hand, the subject does not present itself as an established line of research. We found that authors usually work in fixed groups, even if from different institutions, but do not collaborate with researchers outside these groups. One exception is the University of Aalborg. Furthermore, this university, together with Arizona State University, is the largest producer of knowledge on the subject. We also verified that the topic is of global interest.

## Research integrating PBL and sustainability (RQ1): What type of research has been reported? (N=129)

The vast majority of these articles take a scholarly approach to teaching (n=65) and studying reports (n=64), as shown in Figure 8. These works deal with the application of PBL in practical terms, characterized by a scholarly approach to teaching and learning PBL implementation at the course level, followed by the evaluation of course changes and their impact on student learning. This application is mostly carried out through small proposals that involve the elaboration of research on a certain topic that is related to sustainability. For example, Xi and Wang (2022) use PBL in a landscape architecture course for a project aimed at pro-environmental awareness, and, through questionnaires, the results indicated that the PBL approach had a positive influence on values, knowledge, and pro-environmental attitudes in students. Likewise, Teff-Seker, Portman, and Kaplan-Mintz (2019) carried out research where students had to identify problems in their city and offer an EP solution. Using pre- and post-questionnaires, students reported a positive change in environmental behavior.

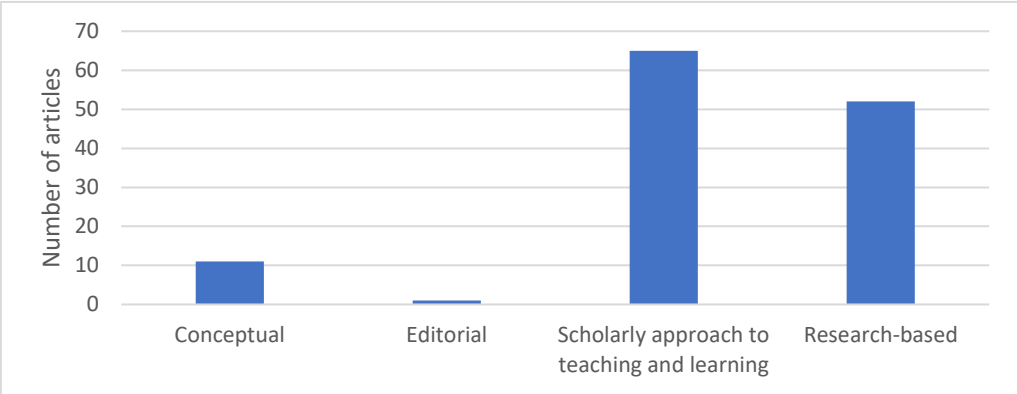


*Figure 8. Types of research designs presented in articles (N=129).*

Pre- and post-questionnaires are the most commonly used methodology for evaluating students' learning. Interviews, technical reports, self-assessments, product reviews, final exams, peer reviews, etc. are also mentioned as forms of evaluation (Figure 9). Of the total number of papers, 46 used two or more assessment methodologies.

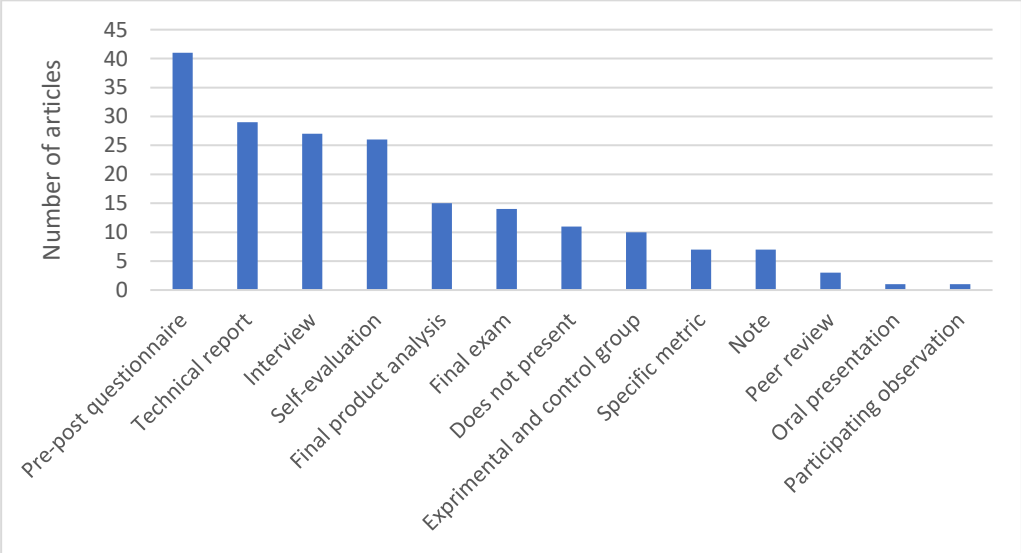


Figure 9. Methodologies were used to assess students at the end of the PBL experience (N=129).

Focusing on research-based studies (n=52), we perceive a significant concern for researchers in developing skills related to sustainability (Figure 10) (Wiltshier & Edwards, 2014; Yusof et al., 2016; Cabedo et al.; 2018; Albareda-Tiana et al., 2019; Martin-Garin et al., 2021). PBL marks the theme of the studies after the implementation processes, its successes, and its failures are analyzed. However, as previously noted, these data do not mean that the studies are focused on the

integration between PBL and sustainability. In general, the discussion revolves around PBL as pedagogy, using the theme of sustainability, but any other theme could be used.

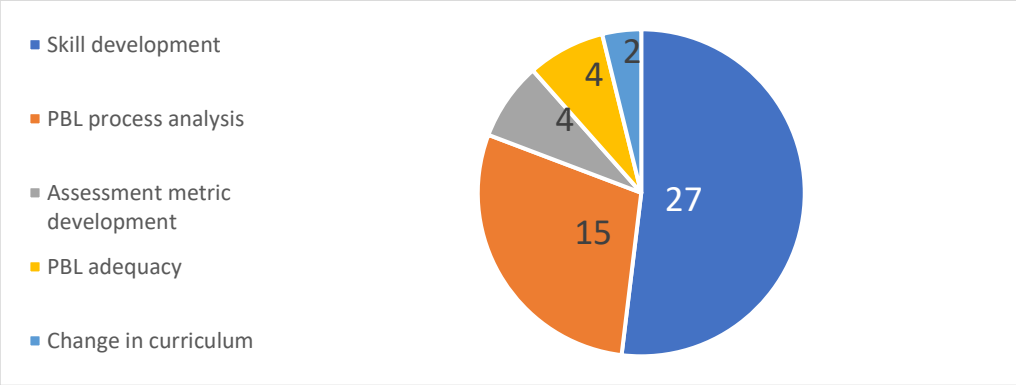


*Figure 10. Topics developed in research-based articles (n=52). The values marked on the chart indicate the number of articles for a given approach. Some papers demonstrate more than one approach.*

PBL was implemented to study sustainability in most cases of undergraduate university instruction, as shown in Figure 11, with most applications being in engineering-related courses, with 68 papers. Engineering plays an important role in the achievement of such goals through the development of innovative, sustainable solutions (ICEE, 2021), and the results show that to some extent.

This does not necessarily mean that PBL is not implemented at other levels, but rather that there is greater interest in research on the practice of PBL in universities (Chen, Kolmos & Du, 2021), where researchers are concentrated.

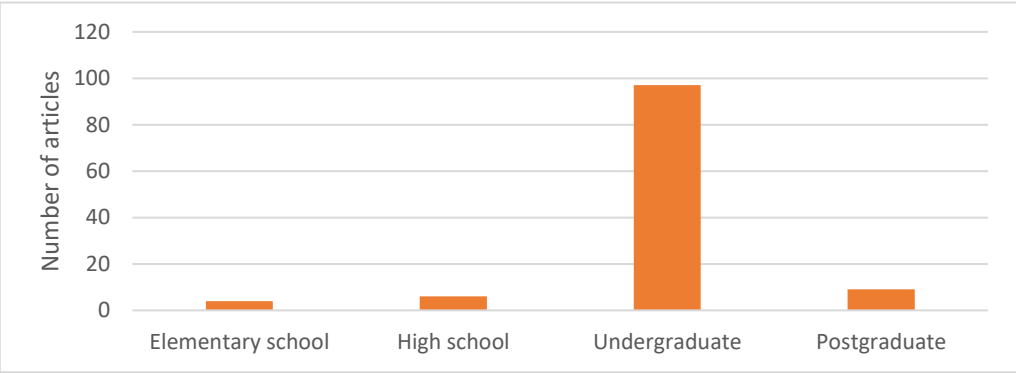


*Figure 11. Level of implementation (n=116).*

Regarding research trends on the topic, we concluded that most of the research design is a scholarly approach to teaching and learning. On the other hand, when we analyze research-based studies we notice that they do not discuss the integration of PBL with sustainability. We also observed that most of the studies are carried out in the undergraduate engineering course.

## Engineering education for sustainability in a PBL environment (RQ2): What and how has been researched so far? (n=12)

The main concern of the works observed here is based on the ecological dimension. Among the ecological problems addressed here, we note green chemistry, lighting, bee extinction, reuse of effluents, and solid waste, organic gardening, composting, climate change, and recycling. The remainder are environmental conservation and sustainability projects, and no approaches refer to the social or economic dimensions that, together with the environment, make up the tripod on which sustainability is based (Elkington, 1994).

Of the articles classified as studying reports (n=64), 48 are case studies, conceptual or editorial. Only 16 discuss PBL and sustainability in depth, integrating the two themes (Appendix 1), and of these, 12 were taken in engineering courses, demonstrating that research on sustainability education using PBL emerges more prominently and deeply in engineering courses.

Although the first article derived from our selection using the filters (N=129) was in 2003 (Figure 1), with regularity from 2007 onwards, the articles that make an in-depth discussion on the topics, integrating PBL and sustainability (n= 16) have become more common since 2011 (Appendix 1). Until then, articles were limited to reporting experiences without focusing on scientific research. This demonstrates a maturity in the topic, although small, as reflected by the scarce number of articles.

This demonstrates that the authors' focus has been on the product and not on the process. This appears to be counterintuitive, as product-oriented education emphasizes content, and progress is measured concerning the number of correct results, as in traditional disciplines. PBL, on the other hand, is based on pedagogy that emphasizes the use of procedures to enable students to achieve results on their own, transcending content knowledge (De Graaf & Kolmos, 2003). PBL has been applied, at least concerning education for sustainability, as a methodology that promises to depart from traditional approaches but in practice does not differ from them and is not as a pedagogy that seeks protagonism for the students.

The apparent increase in publications in 2021 is not relevant, first, due to the small sample size, which prevents a reliable analysis, and second, because not many publications of the type appeared until the middle of 2022, indicating that this year could also have low representativeness of the publications.

These evaluations are usually subjective or fail to represent the reality of the evaluation, based on summative assessments, adopting traditional methods, such as tests, questionnaires, and product reviews. In addition, these assessments do not serve to identify learning needs and adjust teaching

accordingly. The evaluation by rubrics, that is, evaluation related to the quality of the project, does not exist in quantity (six articles) being largely proposed by the group working on the EDINSOST project in the Spanish government (Albareda-Tiana et al., 2018; Baligar et al., 2018; Tejedor et al. 2019; Albareda-Tiana et al., 2019; Martin-Garin et al., 2021; Hsiao et al., 2022). This may be in line with the perception that most of the time, PBL and sustainability are not discussed, only suggested, disregarding theory on the subject, predominating, just the application of a methodology in practical terms. For this line of thought, the evaluation of results becomes something secondary.

We also observed that most of the time, the theme of interdisciplinarity is not discussed but only suggested, disregarding theory on the subject and thus leading to a dominance of articles that deal solely with the application of interdisciplinarity in practical terms. As PBL promotes interdisciplinary learning in which students identify and delimit problems, interdisciplinarity is a key area that deserves a deeper discussion (Jensen, Ravn, & Stentoft, 2019), especially regarding the topic of sustainability.

In this subsection we concluded that only 16 studies bring a discussion that integrates PBL with sustainability, this being a recent and intermittent approach, demonstrating that the theme is maturing. However, most of this work was carried out in engineering courses, demonstrating a greater concern in this area of concentration. Assessment is based on pre-post questionnaires, analyzed subjectively, without specific metrics. We also observed that the ecological dimension of sustainability is the most addressed and interdisciplinarity is not discussed clearly.

## Discussion, conclusion and recommendations

Higher education plays an important role in this context, as it prepares future professionals for sustainable competence and action. PBL methodology has been in use for over half a century in several universities around the world to develop specific skills in students (Kolmos & Fink, 2004). For this reason, it is not difficult to imagine PBL as a strategy for the development of sustainability-oriented skills.

Because PBL is a dynamic methodology, with a wide range of implementations (Chen, Kolmos & Du, 2020), in this systematic review, we seek to present an overview of the research trends that have been developed with PBL within sustainability education in the last 22 years.

PBL as a methodology for sustainability education is recent—the first article is dated 2003, but productivity has become constant since 2014. On the other hand, the subject does not present itself as an established line of research, as suggested by the low regularity of publications by the authors and the small rate of collaboration between them. This may be due to the 2005 beginning of the United Decade for Education for Sustainable Development, which sought to integrate sustainability concepts in all areas of education. However, half of the production is related to a scholarly approach to teaching and learning reports, as well as a few conceptual approaches. On the other hand, when we analyze research-based studies we notice that they do not discuss the integration of PBL with sustainability. This reflects the immaturity of the research area, which can be expected given the small time devoted to this line of study. Although PBL has acquired increasing numbers of adherents, there is still no consensus on its use.

To answer how PBL is being used to educate engineering students for sustainability, it was necessary to delve deeper into the articles that integrate PBL with the development of skills for sustainability. Of the 128 articles that dealt with the topic of sustainability and PBL together, only 16 brought a discussion that integrated PBL with sustainability (Appendix 1). This small number concerning a much larger universe of articles demonstrates that there has been little scientific research on the topic, so much so that articles are limited to reporting experiments. This corroborates our previous hypothesis that the use of PBL in education for sustainability is still in a maturation process.

Based on this data, we conclude that there are few concerns with research on education for sustainability using PBL. Possibly due to the need to achieve the goals of the 2030 Agenda, through the implementation of education for sustainability, teachers are developing PBL-type activities and choosing any SDG as a project/problem theme. Although the PBL methodology proposes an innovative form of education, its implementation has been carried out in traditional forms. No extensive concern is seen with the development of skills, or a form of assessment based on content. In short, our data indicate that the full potential of using the PBL environment is not being explored, and there is no trend toward PBL research in sustainability education, but rather a central concern with the classroom experience.

Our recommendations for future experiences are based on explicitly integrating sustainability competencies into PBL design, as well as considering assessment methods that capture the development of practical skills, sustainable attitudes, and the application of knowledge to solve real-world sustainability-related problems. This could involve creating training programs for teachers that address effective methods of implementing PBL for sustainability education, such as workshops, professional development courses, and resources to

support the integration of innovative practices. About research, we recommend that researchers seek to follow the experiments in more depth, taking the discussion to the level of integration of PBL with sustainability. This may involve greater collaboration between groups and research institutions or creating platforms for educators to share their experiences, best practices, and resources related to using PBL for sustainability.

We are aware of certain limitations of this work, such as the fact that several other indexing banks were not researched. On the other hand, we believe that this work can serve as a reference for expanding discussions on the use of PBL for education in sustainability by presenting the strengths and weaknesses of the use of the methodology.

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# Appendix 1

*Table 3. Articles that use PBL to educate for sustainability.*

| Year | Article | Authors | Type of research design | Approach | Type of research questions | PBL model and level of implementation | Level/type of sustainability learning |
|---|---|---|---|---|---|---|---|
| 2007 | Universities in Capacity Building in Sustainable Development: Focus on Solid Waste Management and Technology | Pariatamby, A., Hansen, J.A. | Research-based | Qualitative | Discussion on PBL methodology for education for sustainability | Interdisciplinarity<br><br>Postgraduate students | Environmental |
| 2011 | Problem-Oriented Project Based Learning (POPBL) in Promoting | Yasin, R.M., Rahman, S. | Conceptual | Qualitative | Discussion on PBL methodology for education for sustainability | Problem-Oriented Project Based Learning; interdisciplinarity Undergraduate course | General |
| 2012 | Creating sustainable development change agents through problem-based learning | Dobson, H.E., Tomkinson, C.B. | Conceptual | Qualitative | Discussion on PBL methodology for education for sustainability | interdisciplinarity | Environmental |
| 2012 | Problem-based learning and education for sustainable development: an overview in engineering education | Guerra, A. | Research-based | Qualitative | Curriculum development for sustainability using PBL | undergraduate engineering course | General |
| 2013 | Developing sustainability curricula using the PBL method in a Chinese context | Du, X., Su, L., Liu, J. | Research-based | Qualitative | Curriculum development for sustainability using PBL, considering cultural aspects | cross-courses model<br><br>undergraduate engineering course | Environmental |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2016 | Instilling Professional Skills and Sustainable Development through Problem-Based Learning (PBL) among First Year Engineering Students | Yousof, K.M., Sadikin, A.N., Phang, F.A., Aziz, A.A. | Research-based | 1st qualitative<br>2nd quantitative | Discussion on PBL methodology for education for sustainability | Cooperative Problem-based learning<br>undergraduate engineering course | Environmental |
| 2016 | Integration of sustainability in engineering education Why is PBL an answer? | Guerra, A. | Conceptual/ Research-based | Qualitative | Curriculum development for sustainability using PBL | undergraduate engineering course | General |
| 2018 | The ISA Lab workshop: a Project based learning initiative | Orozco-Messana, J., De la Poza, E. | Research-based | Qualitative | Discussion on PBL methodology for education for sustainability, considering cultural aspects | Interdisciplinarity<br>Master and undergraduate course<br>Engineering, law, and architecture | Environmental |
| 2020 | Integrating sustainability into higher education curriculum through a transdisciplinary perspective | Tasdemir, C., Gazo, R. | Research-based | Quantitative | Curriculum development for sustainability using PBL | Transdisciplinarity<br>Undergraduate course | Environmental |
| 2020 | Preparing Sustainable Engineers: A Project-Based Learning Experience in Logistics with Refugee Camps | Terrón-López, M.J., Velasco-Quintana, P.J., Lavado-Anguera, S., Espinosa-Elvira, M.C. | Research-based | Qualitative | Discussion on PBL methodology for education for sustainability | Interdisciplinarity<br>undergraduate engineering course | Social |
| 2021 | Developing Global Engineers Through Interdisciplinary PBL and Design Thinking | Poursharif, G., Doss, T.P., Broadbent, R., Knight, G. | Research-based | Qualitative/ quantitative | Discussion on PBL methodology for education for sustainability | Interdisciplinarity and design thinking<br>undergraduate engineering course | Environmental |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2021 | Educating engineers 2030 – PBL, social progress and sustainability | Guerra, A., Rodriguez, F. | Editorial | Qualitative | Discussion on PBL for education for sustainability | undergraduate engineering course | not applicable |
| 2021 | Pedagogical Approaches for Sustainable Development in Building in Higher Education | Martín-Garin, A., Millán-García, J.A., Leon, I., Oregi, X., Estevez, J., Marieta, C. | Research-based | Qualitative | Discussion on PBL methodology for education for sustainability | Multidisciplinary<br>Problem-based learning, research-based learning, computational thinking<br>undergraduate engineering and architecture course | Environmental |
| 2021 | Study of STEM for Sustainability in Design Education: Framework for Student Learning and Outcomes with Design for a Disaster Project | Chan, M., Nagatomo, D. | Research-based | 1st qualitative<br>2nd quantitative | Discussion on PBL methodology for education for sustainability | Multidisciplinarity<br>Innovation design undergraduate course | Social |
| 2021 | The Quest for Sustainable Teaching Praxis: Opportunities and Challenges of Multidisciplinary and Multicultural Teamwork | Doukanari, E., Ktoridou, D., Efthymiou, L., Epaminonda, E. | Research-based | 1st Quantitative<br>2nd qualitative | Discussion on PBL methodology for education for sustainability, considering cultural aspects | Case-based learning and PBL<br>Undergraduate Business School and Computer Science course | Social |
| 2022 | Sustainable Technologies Supported by Project-Based Learning in the Education of Engineers: A Case Study from Poland | Podgórska, M., Zdonek, I. | Research-based | Qualitative/ quantitative | Discussion on the use of SDGs in the PBL (which ones and who is interested in which) | Multidisciplinarity<br>undergraduate engineering course | General |