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Systematic Review

Project-Based Learning (PBL) as an Experiential Pedagogical Methodology in Engineering Education: A Review of the Literature

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Abstract: This systematic literature review explores how the implementation of project-based-learning (PBL) as an experiential pedagogical methodology in engineering education contributes to the development of real-world skills among students. The methodology applied was the PRISMA protocol with searches in two databases in a 24 year timeframe. The research reviewed 54 pieces to explore the contribution of PBL to seven pillars of a holistic pedagogical model comprising the following categories: technology, an integrated curriculum, an international focus, sustainability, a multidisciplinary focus, simulation, and professional environments. Varied PBL developments across these pillars reveal challenges, including aligning with real-world complexities and promoting interdisciplinary integration. Despite obstacles, PBL in engineering shows promise for enhancing students' skills and channeling the added value of a holistic pedagogical model, despite significant differences in the number of experiences associated with each category. Limitations include restricted article access, emphasizing the need for open science promotion.

Keywords: PBL developments; engineering education; challenges; pedagogical framework; PBL systematic review

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1. Introduction

In the 21st century, in a globalized world, the education of future engineering professionals must train students in skills in line with the current reality, as well as in values and attitudes [1]. Active methodologies in which the student acquires a leading role in his or her own learning and the teacher adopts the role of guide of learning have been highlighted as an effective way to achieve this transversal training [2].

Targeting improvement of the academic achievement and transferable skills of students, Project-based learning (PBL) has been widely adopted in engineering education since the second part of the 20th century [3]. This type of teaching-learning methodology was first developed as problem-based learning in medical education as a response to the problems that simple memorization produced in students of the health sciences [4]. PBL not only helps to improve their academic performance [5] and maintain student attention and engagement [6] but also allows developing technical and non-technical skills that are key to becoming a successful professional [7]. In this context, we must also consider that Bloom's taxonomy is crucial for engineering education as it provides a structured framework for developing higher-order thinking skills, enabling students to not only understand and apply theoretical concepts but also analyze, evaluate, and create innovative solutions to complex engineering problems.

1.1. Literature Reviews in PBL

Benefiting from students' intrinsic motivation and ownership of the learning process [8,9], PBL implementation varies from practice to practice, depending on the context, resources, and curriculum design. Several decades of implementation in universities worldwide has resulted in an extensive research body concerning those experiences.

Similar but not equivalent literature reviews have been conducted in the field of PBL in higher education in recent years. Chen, Kolmos, and Du [10] created a review of the forms of implementation and challenges of PBL in engineering education, differentiating the practice of PBL, the culture, and the individual and institutional level challenges. In their "Systematic Literature Reviews in Engineering Education and Other Developing Interdisciplinary Fields" [11], Borrego, Foster, and Froyd aimed to introduce the systematic review method in engineering education as a way of informing researchers and pedagogues in a more efficient and complete way. In 2020, Guo, Saab, Post, and Admiraal [12] reviewed publications related to student outcomes and measures of problem-based learning experiences in higher education, analyzing the measuring tools that researchers used to assess students' outcomes.

However, if we differentiate between basic implementation of the methodology and more developed experiences in higher engineering education, the number of publications is significantly lower. This systematic literature review focuses on experiences that go beyond the canonical applications of the PBL methodology in universities. Also, it is important to differentiate between project-based learning and problem-based learning, with the latter falling out of the scope of the present review.

Guerra et al. [13], in the conference paper "Engineering grand challenges and the attributes of the global engineer: A literature review", focused on the global challenges that an engineer must face from student and industry perspectives. These challenges are technical, professional, personal, interpersonal, and cross-cultural. They proved the integrality and consequence of the learning environments, learning experiences, the student's active role in the process, and the curriculum constructions.

Savin-Baden et al. proposed the concept of categorizing PBL experiences to analyze their impact on students' skill acquisition, engagement, and learning outcomes in the form of constellations [14]. This framework illustrates nine types of PBL practices: PBL for knowledge management, PBL through activities, project-led PBL, PBL for practical capability, PBL for design-based learning, PBL for critical understanding, PBL for multimodal reasoning, collaborative distributed PBL, and PBL for transformation and social reform.

1.2. Pedagogical Model Framework

Recognizing the complexity and interconnected nature of engineering knowledge, it seems to be crucial to seek a holistic pedagogical model that prepares students for their field's challenges. This experiential model should promote a global and applied understanding of concepts, addressing the needs of higher education [15]. In this context, the project-based learning (PBL) methodology emerges as a promising strategy that allows developing the integration of theoretical knowledge with practical applications and fosters practical skills such as teamwork, problem solving, and innovation, which are essential for engineers in the 21st century [3]. The relationship between Bloom's taxonomy and project-based learning is inherently synergistic, as PBL effectively engages students at all levels of Bloom's cognitive hierarchy. Beginning at the basic levels, PBL requires students to remember and understand essential concepts and information relevant to their projects. As they progress, they apply this knowledge in real-world contexts, solving practical problems that require critical thinking. The iterative nature of PBL encourages students to analyze and evaluate their findings and processes, fostering deeper insight and refinement of their work. Ultimately, PBL culminates in the creation of a final product or solution, which represents the highest level of cognitive activity in Bloom's taxonomy. This global engagement not only reinforces knowledge acquisition but also fosters the development of higher-order thinking skills essential for lifelong learning and professional success. When, in addition, the project is developed from a holistic, experiential, pillar-based pedagogical model, it is possible to further deepen the higher levels of the taxonomy by making sense of them.

To address the educational needs of contemporary engineers [16], a holistic pedagogical model has been devised to align with recent educational trends, emphasizing experiential learning. This pedagogical approach prioritizes hands-on, real-world experiences where students actively apply theoretical knowledge to practical problems, fostering deeper understanding and skill development [17]. Current trends make us focus on training future engineers who are able to make complex decisions in a data-driven world, and thus digital skills and the use of artificial intelligence will be in high demand. Contemporary local and global challenges are becoming more intricate, necessitating an interdisciplinary approach. Innovative insights are often discovered at the confluence of various fields, requiring the integration of knowledge from various disciplines, and in a global and diverse world, there is a need to cultivate graduates who are not only competent but also respectful citizens. In this scenario, a holistic pedagogical model based on seven fundamental pillars is defined. This model consists of seven fundamental pillars, as seen in Figure 1.

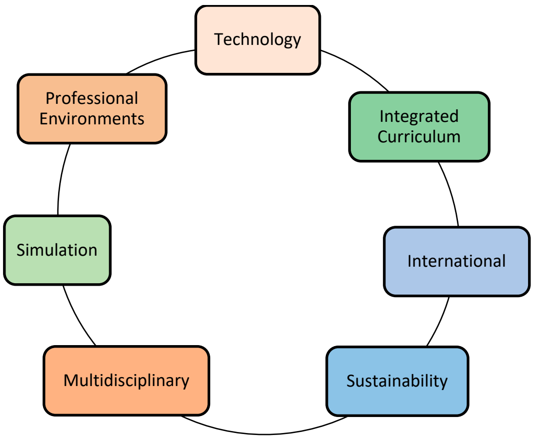

Figure 1. Seven pillars for a holistic pedagogical model.

Advancements in current technology allow the creation of complex scenarios, including those incorporating artificial intelligence (AI). Such learning environments have the potential to promote digital skills and facilitate data-driven decision making among students, thus defining the pillar of “technology”.

Aligned with the ABET engineering criteria of 2000 [16], contemporary advancements in engineering education have emphasized the need to develop a coherent and complete curriculum withing other crucial engineering practice skills (such as multidisciplinary teamwork, project management, communication, ethics, effective time management, and engineering economics). In order to establish a cohesive and all-encompassing educational framework, projects may demand students to apply and integrate knowledge from several subjects [18]. These experiential learning opportunities will be classified under the pillar of “integrated curriculum”.

Additionally, engineers are required to operate in a globalized world [19], and they should be prepared for this broadened context, which surpasses mere technical knowledge and skills. This imperative recognition of global interconnectivity gives rise to the emergence of multicultural and international learning environments, designated under the pillar of “international”. Furthermore, this global orientation may also focus training on sustainability to guide future engineers to be agents of innovation and social and economic development [20]. Therefore, another pillar arises from this trend: “sustainability”. Integration of knowledge and skills may occur among different degrees or disciplines involving students from diverse fields of study, which will define the pillar of “multidisciplinary”.

Engineering requires scenarios aimed at bringing learning closer to real-life situations in the professional environment and industry settings. Although many of these experiences may not occur within operating industries, they are designed to closely resemble real-life situations as much as possible, often through role-play or utilizing real or virtual laboratories. These experiences fall under the pillar of "simulation". Simulated environments allow us to create prototypes or experiment in laboratories and workshops in safe learning environments which recreate real professional environments in which to learn safely. Finally, "professional environments" bridge the gap between engineering education and the professional world [21]. In the development of projects, it is possible to have a company or institution that proposes the project to be developed and acts as a "client". This situation brings realism to the project, bringing the professional world closer to the classroom. At other times, PBL is a "good excuse" to work on entrepreneurship.

1.3. Research Question

Based on this framework, and with an increasing number of studies reporting their PBL practices in recent decades, to improve the application of PBL methodologies according to a holistic pedagogical model that cultivates fundamental student skills, we pose the following research question:

How does the implementation of project-based learning (PBL) as an experiential, pedagogical methodology in engineering education contribute to the development of real-world skills among students?

To address this question, the aim is to conduct a review that categorizes PBL experiences developed in engineering according to the pillars of the holistic pedagogical model described in Figure 1 and connect the theoretical framework of PBL types with various current PBL implementations. Furthermore, the objective is to help engineering faculty to refine their PBL curriculum design and improve the application of PBL methodologies according to a holistic pedagogical model that develops students' core skills.

In line with this, the PBL experiences will be categorized under each of the pillars of the pedagogical model shown in Figure 1, with each represented by one of the following seven categories, depending on the focus of PBL development:

- Technology when the project includes the use of an emerging or advanced technology, such as AI, by the students;
- Integrated curriculum when more than one subject or course of the same degree is involved;
- International when the experience is international or multicultural;
- Sustainability when the focus is on sustainable development or the Sustainable Development Goals (SDG) of the United Nations or it includes an NGO;
- Multidisciplinary when students of more than one degree or discipline participate;
- Simulation when this methodology is developed or advanced labs are used;
- Professional environments when a real company is involved or the project includes entrepreneurship skills from the students.

2. Methodology

The present systematic review article does not present meta-analysis, given that the papers reviewed did not consistently have a quantitative orientation. The research focuses on providing the spectrum of PBL developments in engineering degrees that have a holistic approach and provide added value to students beyond just technical and soft skills. Thus, the systematic review method was adopted to enable researchers to identify current reported PBL learning experiences.

The PRISMA protocol [22] was the frame for this systematic review, which included the following steps: (1) describe the rationale of the review and an explicit statement of the question to address; (2) set the eligibility criteria and information sources; (3) formulate a search strategy and selection process; (4) specify the methods used to collect data, the outcomes for which they were sought, and the methods for assessing risk; and (5) report the findings with a detailed description of the review procedures.

2.1. Developing the Research Protocol

The research question and the PBL model provided the criteria for search and inclusion in the databases: (1) All research needed to be conducted in the context of project-based learning and not the problem-based learning methodology. (2) Studies were conducted in the context of engineering education in colleges or universities. Middle school and high school education were excluded, as well as elementary school. (3) The practices had to be developed, and the implementation of the methodology or the perception of the stakeholders could not just be described. (4) The focus had to be experiential learning as a key part of the practice.

The time frame selected included the year 2000 and expanded to the present, March 2024, to provide a review of the whole current 21st century. We conducted a scoping review to initially test preliminary sets of databases and search terms as well as to survey the breadth of the literature on PBL implementations in university settings for engineering studies with a focus on a holistic pedagogical model.

During this review, we iteratively refined the selected search terms and databases to eliminate sources that did not meet the inclusion criteria. Two databases were selected for their relevance in the field of education [23,24] and their worldwide reach as well as their allowing extracted data to be easily stored in CSV format, facilitating subsequent analysis: Web of Science and SCOPUS. Journal articles, book chapters, conference papers and proceedings, and reviews were included in the main database search. At this point, the only language restriction was that the title and abstract of the paper had to be in English due to the search words. However, no other restrictions were set in the filters. Table 1 condenses the inclusion and exclusion criteria. The application of these criteria was intended to substantially improve the homogeneity of the results analyzed.

Table 1. Final inclusion and exclusion criteria.

Inclusion Criteria	Exclusion Criteria
Published 2000–March 2024	Published before 2000
Abstract and title in English	Abstract or title not in English
Higher education	Not higher education
Project-based learning	Problem-based learning
Engineering education	Not engineering education
PBL developed	PBL not developed, mere implementation
Experiential	Not experiential
PBL experience with one or more of the pillars of the pedagogical model developed	PBL experience with none of the pillars of the pedagogical model developed

The possibility of applying the snowball technique to citation searching was considered to expand our review; that is, we reviewed the works cited by already-identified sources, as suggested by Borrego, Foster, and Froyd [11]. However, since our database searches yielded a satisfactory number of relevant studies, we did not deem it necessary to pursue this option to expand to more works.

2.2. Searching and Filtering

Different searches were conducted to define the final keywords and sets of Boolean operators that provided the most accurate and relevant results to analyze. The search took place until March 2024. The keywords, Boolean operators, and blocks related to the research question can be found in Table 2.

Table 2. Series of keywords for searching.

Block 1	TITLE ("project-based learning" OR "PBL")
Block 2	ABS ("PBL" OR "project-based learning") AND ABS (engineer *)
Block 3	AND ABS (develop *) AND ABS (experience *)
Block 4	AND NOT ABS ("middle school" OR "high school" OR "elementary school")
Block 5	AND PUBYEAR > 1999

An asterisk "*" is added to allow the search engine to include derivatives of the root word, such as "engineering", engineer".

The search provided 166 results in Web of Science and 304 results in SCOPUS. Once both sets of results were merged and duplicates were eliminated, the operating set included 344 pieces, with 104 articles, 9 book chapters, 88 proceeding papers, 141 conference papers, and 2 reviews.

The results were categorized and filtered according to the holistic pedagogical model described in the Introduction. Articles that did not belong to higher education [25] or were not about project-based learning but instead exclusively focused on problem-based learning [26] were excluded. These exclusion criteria were implemented to maintain consistency with the focus on project-based learning in higher education. A total of 11 pieces were excluded.

Twenty-two articles or papers were excluded because they described an experience focused on the assessment, grading, or feedback to the student [27] and not a holistic pedagogical model. Pieces describing a basic implementation of the canonical PBL methodology in a different context but also not containing any of the seven categories of the pedagogical model [28,29] were also discarded, totaling 203 works. Three reviews were also excluded because, again, the holistic pedagogical model was not considered [30]. Two of these reviews were categorized by the original authors as an article or conference paper and explained in the abstract. One article [31] generated a discussion by the reviewers, evaluating whether an eighth category called "research" was necessary for experiences where students had to develop research experiences and data-driven decision making. However, the piece did not sufficiently explore the competence acquisition of the students and as such did not merit a category, and no other pieces explained such a development. The article was discarded for being an implementation with no holistic pedagogical model features. Figure 2 shows the flow chart of the search and filtering process.

This systematic literary review did not have the budget to retrieve articles, conferences, proceeding papers, or book chapters that required payment. Therefore, the pieces that were not open access, a total of 50, were discarded.

The final number of selected pieces was 54, including 16 journal articles, 37 conference or proceedings papers, no book chapters, and 1 marked as a review which explained a PBL event. These were categorized according to the previously explained pillars of the holistic pedagogical model. The results were as follows: 4 technology, 6 integrated curriculum, 7 international, 7 sustainability, 4 multidisciplinary, 13 simulation, and 13 professional environments pieces. The proportion of articles belonging to each category was calculated, as presented in Figure 4.

Some of the pieces described experiences that could belong to more than one category. The learning outcomes or competencies developed may have belonged to both sustainability and simulation or to professional environments and multidisciplinary in a few cases. However, there was a dominant category in all of them, and this is what was applied in the categorization. Therefore, the chosen categorization agreed upon by the three reviewers involved in the process was deemed adequate and relevant to the holistic pedagogical model.

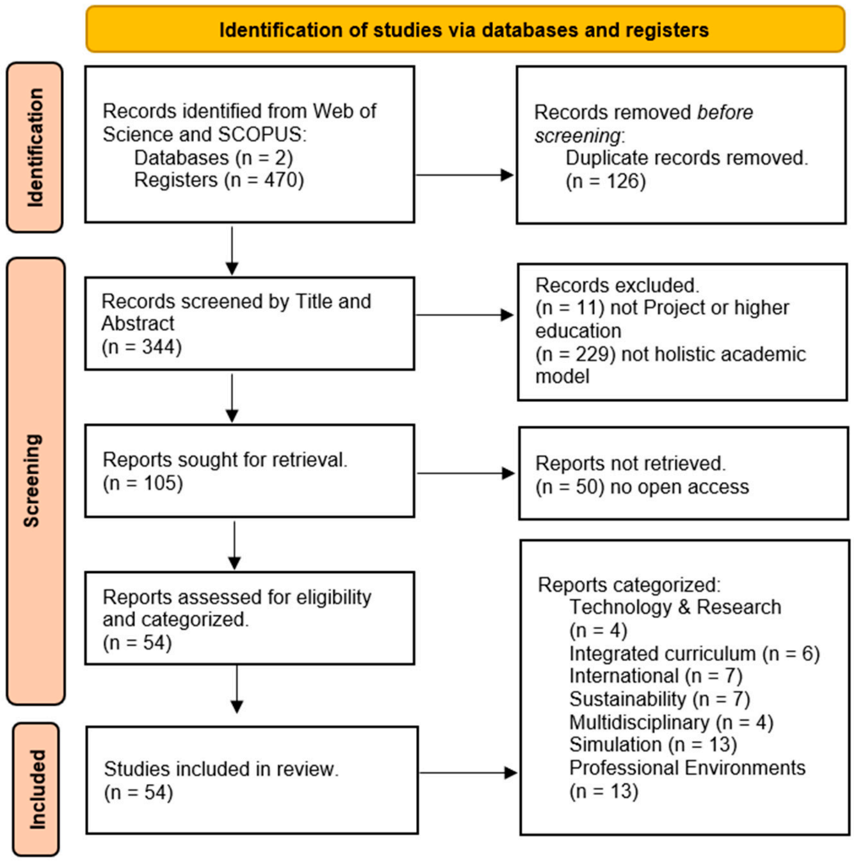

Figure 2. Flow chart of the search and filtering process.

2.3. Demographics of Selected Publications

To map the selected PBL experiences in engineering education, the publication year and editor were used to classify the pieces. Six of the selected pieces were published before 2010, with two more before 2015. Seven were published in 2015, and 13 were published between 2016 and 2019. There was a spike in 2020 with 12 published pieces. From then on, there were 6, 6, and 2 in 2021, 2022, and 2023, respectively, as can be seen in Figure 3.

In terms of publication source, there were conferences and journals, among which the following stood out in terms of number of pieces: the *ASEE Annual Conference* (13 pieces), *International Journal Of Engineering Education* (3), *International Symposium on Project Approaches in Engineering Education* (3), *Sustainability* (3), *International Research Symposium on PBL* (3), *IEEE Transactions On Education* (2), and proceedings from the *Frontiers in Education* (FIE) Conference (2).

Most of the pieces analyzed were written in English, which makes sense given that the search words and criteria were in this language. However, two pieces with titles and abstracts in English and bodies in Spanish [32,33] were included, as well as one partially described in Italian [34].

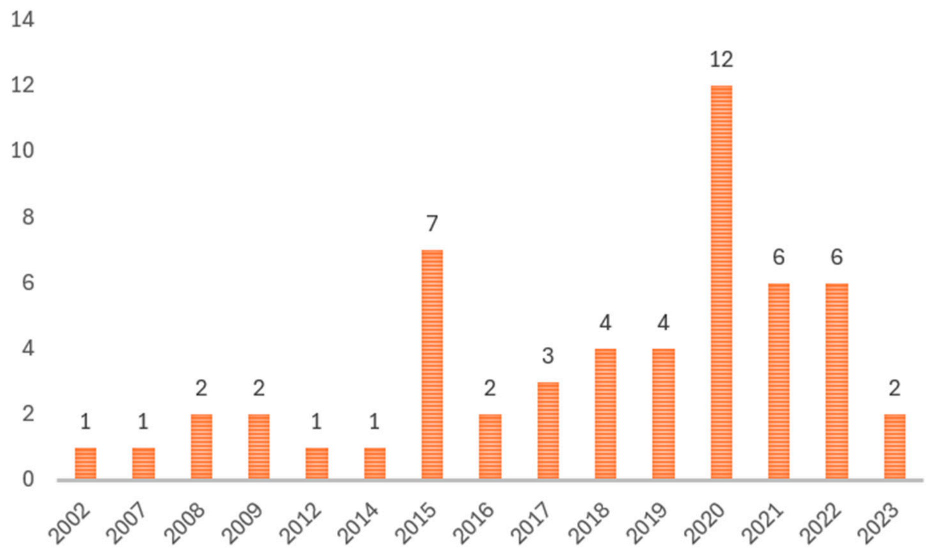

Figure 3. Publication years of selected pieces.

2.4. Tracking and Analysis

Since the intention was to provide an overview of various implementations of a pedagogical model based on PBL, discussions among the three researchers were initiated regarding the initial themes. Discrepancies were discussed, and the eligibility criteria were clarified. The aim was to guide the coding of the selected articles in the analysis processes, including the 7 pillars of the pedagogical model proposed for engineering education.

The process followed for validating the analysis conducted was as follows. The selected articles underwent multiple readings and were individually coded by the three researchers, incorporating their independent reflections. The articles were evaluated based on the eligibility criteria at three levels: title, abstract, and full text. During research group meetings, triangulation was employed to establish an initial consensus on the coding. The initial themes and codes underwent two rounds of modification and refinement through group discussions. Six of the final 54 articles or papers were determined to change category. Some examples of reclassified pieces included [35], which changed from multidisciplinary to simulation, or [36], which was determined to be sustainability and not simulation. In order to enhance the coder reliability, a researcher with qualitative research experience but unfamiliar with this specific study was invited to independently code eight articles using the established codebook. Following this step, a subsequent discussion led to further refinement of the coding results. Any remaining discrepancies between the researchers were thoroughly discussed before reaching a common consensus across all codes. Finally, an intentional sample of 21 articles was selected and provided to a second researcher experienced in qualitative research, along with the list of codes and their definitions, for the purpose of refining the categorization of those among the categories.

3. Results

This section includes the analysis of the seven categories of the pedagogical holistic model and the current challenges detected in PBL practice. The seven categories considered include 4 pieces for technology, 6 for integrated curriculum, 7 for international, 7 for sustainability, 4 for multidisciplinary, 13 for simulation, and 13 for professional environments, as shown in Figure 4. Complete tables with the total of pieces and references can be found in Appendix A.

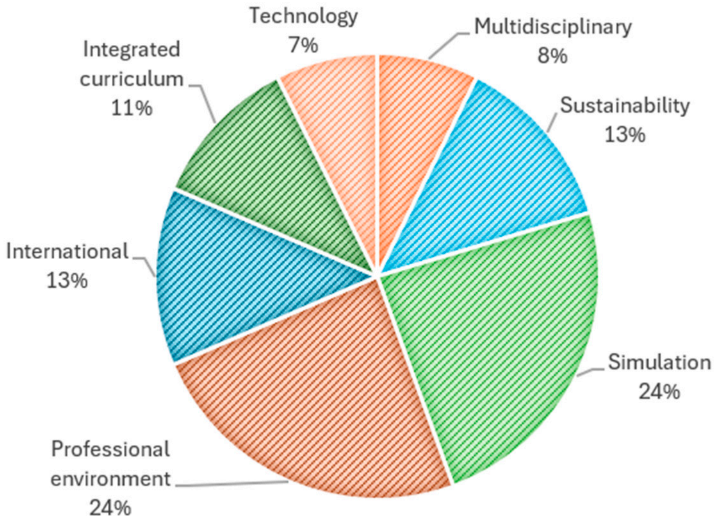

Figure 4. Proportion of pieces of each category.

3.1. PBL Developments with Technology Focus

This category included pieces that described PBL experiences with a high technological component. Four open-access PBL developments described this type of experience within the results: three conference papers and an article. Two of them supported the learning process with artificial intelligence [37,38], and two included complex technological developments by the students [39,40]. Three of the four pieces coincided in validating the PBL methodology for the students' acquisition of technical and generic professional skills, presenting them with real-world problems and current tools to find the solutions. The last piece [38] did not definitively state this because the development is still in its early stages, although it looks promising.

3.2. PBL Developments with Integrated Curriculum Focus

PBL-integrated curriculum experiences consist of a project that includes different courses or subjects of the same degree. Three articles [41–43] and three conference papers [44–46] matched this definition in the literature review. Five of these studies combined different subjects of the same sets of students and created a PBL project that benefitted from the learning outcomes of all of them, providing a learning environment with real-world-like challenges of an engineer. In particular, it allowed combining theory and practice, allowing students to apply, in real-world-like situations, the knowledge acquired. The last of them [42] presented what it called a hybrid project-based learning-flipped classroom design, which requires students to learn by themselves in advance what they are going to need for the project and also mixing theory and practice, even if it does not really belong to two separate subjects, and thus explaining it being included in this category.

3.3. PBL Developments with International Focus

To belong to this category, the pieces needed to have an international scope, including students from universities from different countries, or students from the same class that belonged to different contexts, providing a multicultural experience. Six experiences complied with the criteria to belong to this category; either the PBL experience was developed by international students, such as Russian and American students [47], Nepali and Bhutanese students [48], Malaysian and Japanese students [49], Portuguese, Thai, and Japanese students [50], and Indian and Swiss students [51], it was focused on integrating minority students into the teamwork [52], or it featured a multicultural class [53]. The research focused on motivation and student outcomes as well as the logistics necessary to perform these kinds of projects.

3.4. PBL Developments with Sustainability Focus

Seven pieces from the present review matched the sustainability category criteria. The aim of the project was, among others, to make the students aware of social or environmental causes and steer their solutions in sustainable ways. Three of the pieces [54–56] used real operating NGOs to participate as stakeholders for the students. The other four pieces [36,57–59] were centered on the environment and renewable energy, with all of them targeting the United Nations' Sustainable Development Goals.

3.5. PBL Developments with Multidisciplinary Focus

Pieces categorized as multidisciplinary in the present review described a PBL experience that included students from different degrees, including engineering as one of them, and developed a multi-disciplinary approach to the project solution. Only four of the experiences described in the articles and conference papers matched this category, though others suggested that students need to include skills and knowledge from other disciplines different from engineering to solve the problems. The projects included clusters of students from business or design [60], the arts [61], civil engineering and informatics [33], and communication and business [62]. This was the least populated category in the review.

3.6. PBL Developments with Simulation Focus

PBL experiences considered for the "simulation" category had a significant amount of lab work, prototypes, or the inclusion of virtual environments. The pieces that belonged to this category were [63–74]. The engineering areas where this category was more visible were electronics, robotics, and aerospace. It is worth mentioning that laboratory work is often oriented toward environmental improvement competencies, such as green energy. In addition, some prototypes presented in the experiences described prototypes with a high level of complexity, like a Formula Student racecar [67]. This was the most populated category in the review, tied with professional environments. This fact is not surprising, given that engineering is a traditionally hands-on discipline with laboratory practice present in most curricula worldwide.

3.7. PBL Developments with Professional Environments Focus

This category comprised PBL experiences that had an input, either in the design, development, or assessment of a real company or industry, or where the focus of the professor was to simulate as faithfully as possible a real-world professional environment or those experiences that promoted entrepreneurship skills in the students. This review had access to 13 of these pieces. All pieces insisted on the motivation of the students when exposed to real-world experiences. The ones that simulated a professional experience [34,75,76] reported an increase in the kill acquirement perception of the students and faculty. The ones that relied on a real business partner mainly involved in the assessment or the design [77–85] also disclosed the satisfaction of the industry partner. In some cases, the students' solutions led to innovations and even resulted in hires by the company. These published experiences [78,81,85] centered the aim of the article or paper on the relationship between industry and academia, describing extensively the framework in which the professional practices take place. However, those of them that did not [33,77] promoted the tools that students will master, such as CAD software or coding.

4. Discussion

In this systematic review, we aimed to categorize PBL experiences developed in engineering according to the pillars of the holistic pedagogical model described in Figure 1 and connect the theoretical framework of PBL types with various current PBL implementations. Following this, the results were interpreted for each category (pillar), answering the research question. In the following sections, we will describe and discuss some limitations identified, organized by category, and the limitations of the review methodology and propose possible lines of future work.

4.1. Interpretation by Category

In the category "technology", we presented those works in which the use of a project-based learning methodology aimed to introduce students to researching and promoting "research interest", a challenge which they perceived as difficult in the early stages but which allowed them to develop professional skills. The conclusions analyzed affirmed that the availability of resources and the preparation of curricula are major obstacles to the success of these learning experiences. In those cases where the objective was the use of a specific technology such that, through the PBL methodology, the aim was to develop digital competences, the difficulties focused on the adequate allocation of resources for preparation and required an adequate alignment of the whole course's organization with the chosen methodology.

The "integrated curriculum approach" aims to bring together knowledge from different subjects and apply it to the project. This approach makes students more responsible for their learning process and provides in-depth understanding of the subjects involved. Teamwork is favored when more theory-oriented students are mixed with other more practice-oriented ones for integrating the curriculum. Assessment must be congruent with the project, and demands and tasks must be distributed accordingly while minding the workload and timescales, allowing students to role-play their future engineering performance. Furthermore, coordination among the subjects involved is key to the success of the experience and requires greater involvement from the faculty staff.

The "international focus" orientation of the PBL project [86] not only mimics real-world experiences in the engineering sector but also allows building communities and exposing students to different realities and cultures. The capability of solving global issues became one of learning objectives, and students faced greater team diversity because they needed to work with people with various cultural backgrounds and subject backgrounds [87]. Challenges for the faculty arise from the design and coordination of these projects as well as sustaining the motivation of the students for collaboration. Team leadership and structures vary from culture to culture, as well as students' relationship with the faculty, particularly in environments where teachers are the traditional authority of knowledge. The themes selected to develop the project can also be a handicap as they must be meaningful and relevant for all the contexts. Not only are technical skills developed but also soft skills such as teamwork and adaptability, in addition to sensitivity and understanding of different cultures.

The "sustainability" PBL experiences present two benefits. Students not only acquire technical and soft skills through the project-based learning approach but also propose sustainable solutions to real-world problems, many of which have been implemented or fully developed. Overall, students feel more motivated and encouraged to do a good job, driven by the recognition of the social or environmental impact of their work. The ethical values perceived contribute to the learning experience. Institutional support, whether it be financial or increased teacher resources, is usually needed to develop this kind of project, which presents a challenge when having to coordinate with external agents such as NGOs.

The "multidisciplinary focus" experiences emphasize the development of collaborative skills among students from different degree programs, along with the perception of achieving better outcomes and taking responsibility for their own learning. These experiences highlight the creativity that emerges from the process and underscore the importance of leadership in coordinating the team and managing the contributions made from each discipline. Compared with other projects, the parallel with real-world work environments for engineers is higher, as they interact with professionals from various fields. Additionally, more complex problems or challenges may arise. Therefore, clear guidelines and coordination in assessment by all the involved teachers are essential.

Engineering is a discipline in which traditionally laboratories have always been part of the curriculum. The "simulation" category gathers experiences that involve a significant amount of lab work, prototypes, or virtual environments. These developments represent hands-on learning experiences from the students and show that they valued the application of theory to practice. However, the increased workload for the faculty and students, along with challenges related to the availability of materials and resources, emerged as notable concerns in some cases.

When experiences belonged to "professional environments", the industrial partners often reported the importance of communication with the students. Students benefitted from continuous interaction with stakeholders and clients, finding their feedback more relevant than that provided by the faculty. Moreover, interdisciplinary student groups collaborating with various departments within enterprises resulted in positive experiences, offering them insights into real-world business operations and, in some cases, promoting their entrepreneurial ambition.

4.2. Review Limitations

Some of the articles were excluded from our review because they were not openly accessible. This lack of access to full-text versions prevented the inclusion of 50 pieces identified during the systematic literature review, despite meeting the inclusion criteria based on titles and abstracts. A significant budget allocation in future research projects could facilitate a more comprehensive analysis. This highlights the compelling need for promoting open science and ensuring global access to scholarly articles, conference proceedings, and book chapters for the academic community.

This restriction of access to many pieces of information meant that the most populated type of document analyzed was conference papers instead of journal articles, which have higher reliability because of the peer review process. Even when 28 original articles were considered in the screening of the search results, after only open-access pieces could be read in full, only 16 articles were categorized and analyzed. Given that the aim of the investigation was to quantify the number of experiences that related to each category, there were no specific assessments of risk of bias for each included study.

Finally, by restricting the search to engineering-related studies, valuable insights and alternative approaches from other fields may have been overlooked. This narrow scope may have limited the comprehensiveness and applicability of the findings, as solutions and innovations from diverse disciplines may offer unique and interdisciplinary perspectives that can enhance the understanding and effectiveness of interventions within engineering education.

4.3. Conclussions and Future Directions

Based on the findings of this systematic literature review, it is evident that project-based learning (PBL) serves as a suitable methodology for implementing a holistic pedagogical model within engineering education. However, there remains ample opportunity for further growth and exploration, particularly in categories such as "professional environments" and "simulation", which exhibited robust evidence of effectiveness.

Nevertheless, it is imperative to delve deeper into pillars such as "multidisciplinary" and "technology". Existing experiences underscore the acquisition of competencies in these areas, suggesting their relevance to engineering studies in higher education.

Moving forward, this review highlights several avenues for future research in engineering education. Recommendations are provided for engineering faculty to refine their PBL curriculum design and enhance the application of PBL methodologies within a holistic pedagogical framework aimed at fostering students' core skills. This includes exploring innovative approaches to multidisciplinary collaboration and leveraging technology and research opportunities within PBL contexts.

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Appendix A

Table A1. Technology pieces reviewed.

Technology: Title	Reference	Authors	Criteria
Enhance project-based learning experience for undergraduate students with wireless sensor network	[39]	Wang, Y.; Cui, S.	Complex technological developments
A Project Based Learning Approach for Teaching Artificial Intelligence to Undergraduate Students	[37]	Vargas, M.; Nuñez, T.; Alfaro, M.; Fuertes, G.; Gutierrez, S.; Ternero, R.; Sabattin, J.; Banguera, L.; Duran, C.; Peralta, M.A.	Artificial intelligence
Systematic integration of project-based learning in an undergraduate human-computer interaction course: A case study	[40]	Ribu, K.; Patel, T.	Complex technological developments
The online PBL (project-based learning) education system using AI (artificial intelligence)	[38]	Ito, T.; Tanaka, M.S.; Shin, M.; Miyazaki, K.	Artificial intelligence

Table A2. Integrated curriculum pieces reviewed.

Integrated Curriculum: Title	Reference	Authors	Criteria
Enhancing entrepreneurship education in a master's degree in computer engineering: A project-based learning approach	[43]	Arias, E.; Barba-Sánchez, V.; Carrión, C.; Casado, R.	Different subjects of the same sets of students
3-Phase multi subject project based learning as a didactical method in automotive engineering studies	[44]	Bratschitsch, E.; Casey, A.; Bischof, G.; Rubesa, D.	Different subjects of the same sets of students
Research projects as a part of a 3-phase multi subject project based learning in vehicle engineering studies	[46]	Bratschitsch, E.; Casey, A.; Trzesniowski, M.	Different subjects of the same sets of students
Collaborative project-based learning capstone for engineering and engineering technology students	[45]	Ritenour, A.P.; Ferguson, C.W.; Gardner, P.; Banther, B.R.; Ray, J.L.	Different subjects of the same sets of students
Multi-Role Project (MRP): A New Project-Based Learning Method for STEM	[41]	Warin, B.; Talbi, O.; Kolski, C.; Hoogstoel, F.	Different subjects of the same sets of students
The hybrid Project-Based Learning-Flipped Classroom: A design project module redesigned to foster learning and engagement	[42]	Chua, K.J.; Islam, M.R.	Project-based learning-flipped classroom

Table A3. International pieces reviewed.

International: Title	Reference	Authors	Criteria
AC 2012-4638: an experiment in project-based learning: a comparison of attitudes between Russia and America	[47]	Sanger, P.A.; Ziyatdinova, J.; Ivanov, V.G.	Russian and American
A Case Study: How Collaborative PBL Affects Learning of Minority Students in Engineering Courses at Senior Level	[52]	Dong, J.Y.; Chen, P.	Minority students' integration

Table A3. *Cont.*

International: Title	Reference	Authors	Criteria
An evaluation of boundary-crossing skill development in a project-based learning course	[51]	Ryser, T.; Ulbrich, S.; Dey, C.; Ganesh, M.P.	Indian and Swiss
Engineering Students Learning Experience through a Unique Global Project-Based Learning	[49]	Ghazali N.E.; Yusof, K.M.; Phang, F.A.; Arsat, R.; Ahmad, N.A.; Morino, H.	Malaysian and Japanese
The role of teamwork on students' engineering professional identity development in the AAU pbl model: From the perspectives of international engineering students	[53]	Chen, J.; Kolmos, A.; Du, X.	Multicultural class
Global PBL: Cross-cultural educational project for engineering students	[50]	Navas, H.V.G.; Hasegawa, H.; Watanabe, D.; Khantachawana, A.; Alves, A.C.	Thai and Japanese
Design Thinking as a Strategy to Inculcate Problem-Based Learning (PBL) in Undergraduate Education Across South Asian Universities	[48]	Acharya, S.; Bhatt, A.N.; Chakrabarti, A.; Delhi, V.S.K.; Diehl, J.C.; Mota, N.; Jurelionis, A.; Subra, R.	Nepali and Bhutanese

Table A4. Sustainability pieces reviewed.

Sustainability: Title	Reference	Authors	Criteria
Multidiscipline team teaching approach to enhance project-based learning of sustainable design	[36]	Burian, S.; Johnson, W.; Montague, F.; Holt, A.; Nielson, J.; David R.	Environment and renewable energy
Making practical experience: Teaching thermodynamics, ethics and sustainable development with PBL at a bioenergy plant	[59]	Del Carmen Ramirez, D.; Ramírez, P.M.	Environment and renewable energy
A Project Based Learning Experience Using NGO Projects and A Volunteer Program Abroad	[54]	Terron-Lopez, M.J.; Archilla, Y.B.; Velasco-Quintana, P.J.	With real operating NGOs
A research program about a short-term PBL approach based on the SDG	[53]	Braga, M.; d'Escoffier, L.; Guerra, A.	With real operating NGOs
Case Study to Analyze the Impact of Multi-Course Project-Based Learning Approach on Education for Sustainable Development	[57]	Khandakar, A; Chowdhury, M.E.H.; Gonzales, A.S.P.; Touati, F.; Al Emadi, N.; Ayari, M.A.	Environment and renewable energy
Preparing Sustainable Engineers: A Project-Based Learning Experience in Logistics with Refugee Camps	[56]	Terrón-López, M.J.; Velasco-Quintana, P.J.; Lavado-Anguera, S.; Espinosa-Elvira, M.D.	With real operating NGOs
Bringing Project-Based Learning into Renewable and Sustainable Energy Education: A Case Study on the Development of the Electric Vehicle EOLO	[58]	Ariza, J.A.; Olatunde-Aiyedun, T.G.	Environment and renewable energy

Table A5. Multidisciplinary pieces reviewed.

Multidiciplinary: Title	Reference	Authors	Criteria
STEM-oriented alliance for research (SOAR): An educational model for interdisciplinary project-based learning	[62]	Murray, J.; Paxson, L.C.; Seo, S.; Beattie, M.	Communication and business
Project-Based Learning versus Cooperative Learning courses in Engineering Students	[33]	Fuertes, G.; Vargas, M.; Soto, I.; Witker, K.; Peralta, M.; Sabattin, J.	Civil engineering and informatics
A blended learning experience applying project-based learning in an interdisciplinary classroom	[60]	de Medeiros, F.P.A.; Júnior, P.; Bender, M.; Menegussi, L.R.; Curcher, M.	Business or design
A practice of collaborative project-based learning for mutual edification between programming skill and artistic craftsmanship	[61]	Nitta, N.; Takemura, Y.; Kume, I.	Arts

Table A6. Simulation pieces reviewed.

Simulation: Title	Reference	Authors	Criteria
Problem- and Project-Based Learning in Engineering: A Focus on Electrical Vehicles	[71]	Gonzalez-Rubio, R.; Khoumsi, A.; Dubois, M.; Trovao, J.P.	Significant laboratory work or prototypes
Design on Project-Based Learning for Analog Circuits	[70]	Kataria, D.; Sanchez, G.	Significant laboratory work or prototypes
VIDAR Lab: A Virtual Network Environment for Project-Based Learning of Undergraduate Students	[74]	Karal, L.; Rathke, B.; Reichwein, W.	Significant laboratory work or prototypes
Project-based learning with implementation of virtual reality for green energy manufacturing education	[72]	Chiou, R.; Fegade, T.; Wu, Y.-C.; Tseng, T.-L.B.; Mauk, M.G.; Husanu, I.N.C.	Significant laboratory work or prototypes
Space engineering—Project based learning by working real space programs	[73]	Twiggs, R.	Significant laboratory work or prototypes
Collaborative Graphic Simulation Experience Through Project-Based Learning to Develop Spatial Abilities	[68]	López-Chao, V.; Saorín, J.L.; De La Torre-Cantero, J.; Melián-Díaz, D.	Significant laboratory work or prototypes
Blending problem- and project-based learning in internet of things education: Case greenhouse maintenance	[65]	Mäenpää, H.; Tarkoma, S.; Varjonen, S.; Vihavainen, A.	Significant laboratory work or prototypes
A Multidisciplinary PBL Approach for Teaching Industrial Informatics and Robotics in Engineering	[35]	Calvo, I.; Cabanes, I.; Quesada, J.; Barambones, O.	Significant laboratory work or prototypes
Building Small Prototypes in a PBL Intervention for Learning Automatic Control Systems	[66]	Fernández-Samacá, L.; Higuera-Martínez, O.I.; Sanabria-Totaitive, C.A.	Significant laboratory work or prototypes
Design and practical experience in power electronics project based learning approach at UKM	[69]	Yusof, Y.; Za'im, R.	Significant laboratory work or prototypes
Application of project based learning in an environmental engineering program	[64]	Yang, H.	Significant laboratory work or prototypes

Table A6. *Cont.*

Simulation: Title	Reference	Authors	Criteria
An experience of project based learning in aerospace engineering	[63]	Castaldi, P.; Mimmo, N.	Significant laboratory work or prototypes
Challenges in implementing PBL: Chalmers formula student as a case	[67]	Kjellberg, M.; Adawi, T.; Brolin, K.	Significant laboratory work or prototypes

Table A7. Professional environment pieces reviewed.

Professional Environment: Title	Reference	Authors	Criteria
Achieving Scalability in Project Based Learning through a Low-Code platform	[77]	Fernandes, J.P.; Araujo, R.; Zenha-Rela, M.	Real business partner or industry
Utilizing Transdisciplinary Project-Based Learning in Undergraduate Engineering Education	[84]	Davis, L.M.; Caldwell, B.S.	Real business partner or industry
Developing successful industrial interactions in support of project based learning, an organic model	[85]	Walsh, D.	Real business partner or industry
Developing real-life problem-based learning (PBL) activities through partnership with industry	[78]	Mativo, J.M.; Sochacka, N.W.; Youngblood, K.M.; Brouillard, D.; Walther, J.	Real business partner or industry
The PBL Projects: Where we've been and where we are going	[82]	Donnelly, J.F.; Massa, N.M.	Real business partner or industry
Employability competences through short-term intensive PBL-events in higher education	[79]	Wyke, S; Jensen, A.A.; Krogh, L.; Ravn, O.; Svidt, K.	Real business partner or industry
Project-based learning of advanced CAD/CAE tools in engineering education	[33]	Berselli, G.; Bilancia, P.; Luzi, L.	Faculty simulated professional environment
Pbl to foster integration of company projects in engineering curricula—a case example	[81]	Garmendia, M.; Alberro, G.; Guerra, A.	Real business partner or industry
PBL and society: University-industry collaborative learning; [PBL y sociedad: Aprendizaje colaborativo universidad-industria]	[32]	Sandoval-Carvajal, M.-M.; Madriz, F.L.; Piedra, E.P.; Cortés, R.C.	Real business partner or industry
PBL in a University-Business cooperation in Engineering and Operations Management Master: challenges and opportunities	[80]	Alves, A.C.; Costa, N.; Nunes, M.L.; Sousa, R.; Lima, R.M.; Carvalho, D.	Real business partner or industry
Development of ecosystem and learning spaces in effective implementation of pbl in vishwaniketan campus	[76]	Deshapande, S.S.; Kate, S.	Faculty simulated professional environment
Understanding First-year Engineering Students' Perceptions of Working with Real Stakeholders on a Design Project: A PBL Approach	[83]	Murzi, H.; Fielding, L.; Huerta, M.; Alvarez, J.O.; James, M.; Katz, A.; Grohs, J.	Real business partner or industry
A PBL experience to simulate a business environment in a discipline of chemical engineering course	[75]	Giordani, D.S.; Moraes, E.J.C.	Faculty simulated professional environment

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