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Special Issue Reprint

Problem-Based Learning in Science Education

Achievements, Pitfalls and Ways Forward

Edited by
Laurinda Leite and Luís Dourado

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Contents

About the Editors

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Preface

This reprint of the Special Issue "Problem-Based Learning in Science Education: Achievements, Pitfalls and Ways Forward" deals with problem-based learning (PBL) in science education.

Problem-based Learning (PBL) is a student-centered learning approach developed in the sixties within the scope of medical schools. Since then, PBL has been used in an ever-increasing diversity of areas, particularly in science education. The key feature of PBL is that it acknowledges problems (that should be real or seem to be real) as starting points for learning.

In science education, PBL should focus on real-world problems, which are interdisciplinary in nature. Hence, PBL may enable students to learn content and to develop their competencies in learning, as well as individual and social abilities that are relevant for 21st century citizens. Introducing PBL in science education requires teachers and students to change their own ways of learning, teaching, and assessing.

Being the first printed volume on PBL in science education, this Special Issue reprint aims at filling an existing gap in the specialized literature on science education and providing the reader with a set of systematic reviews and empirical papers that cover two broad dimensions of the topic: teaching and learning science through PBL, and educating teachers for promoting PBL in science education. The latter topic is relevant because PBL is an innovative and somehow demanding approach, and, therefore, it requires teachers to be trained to teach through PBL.

With science education researchers, post-graduate students, science teacher educators, and schoolteachers as its target audience, this reprint offers 10 papers written by authors from a variety of countries that adopted diverse research approaches and concentrated on different education levels and diverse learning contexts.

Considering the focus of this research, the papers may be organized into two sets: a set of seven papers that address teaching and learning, with three of them being heavily dependent on digital learning environments, and a set of three papers that deal with teacher education.

In the first group of papers, Behiye Akcay and İbrahim Benek's paper presents a systematic literature review of research that provides an overview of the key findings and trends in studies on problem-based learning within the context of Turkish science education. They noted that the most preferred research design was the quasi-experimental design, there was limited inclusion of final-year students, and researchers mainly preferred physics subjects for their studies.

Robyn M. Gillies conducted a review of the literature on the role of inquiry-based learning (a variation of PBL) when students work in cooperative groups. He concluded that the inquiry-based learning process requires students to engage with others, share their ideas, acknowledge the contributions others make, evaluate new information, and communicate logically their various understandings. It also requires teachers to play an active role in structuring inquiry-based experiences and engaging students in discussions that facilitate critical thinking and learning.

Joaquin Ayerbe-López and Francisco Javier Perales-Palacios report on the evaluation of a two-year-long environmental project designed under the PBL methodology to evaluate its implementation and didactic implications. These authors highlight the high levels of motivation, work, and participation among the students, as well as the didactic benefits of the enriching socialization of the project. They also identified some difficulties related to time management and cooperative group work, a lack of practice in the PBL methodology, and the use of ICT.

Jorge Pozuelo-Muñoz, Elena Calvo-Zueco, Ester Sánchez-Sánchez, and Esther Cascarosa-Salillas present a study involving 16-year-old students in Spain, using a problem-based learning approach as a pedagogical mode to develop science skills, to analyze the development of science skills through an inquiry process in class. They concluded that the PBL methodology followed facilitates the learning of science and the acquisition of scientific skills.

Clara Vasconcelos and Tânia Pinto report on a study that assessed whether teaching students about reducing pollution through nature-based solutions (NBSs) and a PBL approach based on digital tools could enhance their understanding and competencies in SDGs. These authors concluded that the students developed their knowledge about NBSs to improve air quality and showed a positive appreciation of PBL as an active methodology. Additionally, the study sheds light on the PBL facilitator's role and the challenges students face during PBL.

Stella A. Nicolaou and Ioanna Petrou analyzed how to redesign a face-to-face MSc centered around PBL for online implementation. The authors concluded that CiscoWebex is a suitable and user-friendly platform for synchronous online PBL; the students enjoyed both (face-to-face and online) formats and stated that online PBL is an effective teaching approach for promoting student learning. In regard to student interaction, the face-to-face mode was preferred, while online PBL was perceived as being more organized.

Chrissa Papasarantou, Rene Alimisi, and Dimitris Alimisis's paper introduces the virtual galleries method as a scaffold for applying PBL approaches in both physical and distance learning environments, within the field of STEM education. These authors argue that virtual galleries can facilitate PBL by serving as a conceptual framework for scaffolding the learning process, thus enabling the acquisition of new PBL-driven skills.

As far as the papers dealing with teacher education are concerned, Adewale Magaji, Michael Adjani, and Samuel Coombes conducted a systematic review of the literature in the field of PBL, with a focus on preservice science teachers' education. The authors concluded that PBL is not fully used in preservice science teachers' education, even though it is an effective pedagogical approach that enables preservice science teachers to engage in the process of learning by taking part in the PBL design process and experiencing it in the classroom to learn from the process.

Jorge Martín-García, María Eugenia Dies Álvarez, and Ana Sofia Afonso tried to find out whether teachers who coordinate science clubs in Portuguese schools promote activities that incorporate aspects of problem-based learning and project-based learning methodologies. Their results show that these teachers propose the implementation of projects and incorporate aspects of these strategies in the activities they conduct in science clubs, which offers an opportunity to develop PBL and PBL methodologies in a context free from the constraints of the classroom.

Finally, Benjamin Aidoo examined how the educators of teachers have integrated PBL in science teacher education and how they feel about that. The teacher educators perceived that the PBL approach enabled them to create collaborative learning activities to interact and communicate with students, which can lead to the development of conceptual knowledge. Nevertheless, the study also indicated challenges such as a lack of belief and competence, inadequate resources, and limited time allocated for school inquiry-based lessons.

As a concluding remark, it can be stated that the papers included in this Special Issue reprint indicate that PBL is a valuable approach to science teaching and learning, as well as being valuable for science teacher education. However, the authors point out some difficulties that may vanish if teacher education for PBL improves and the curricula of schools become more consistent with the spirit of PBL.

The editors are grateful to the papers' authors for their meaningful contribution to this Special Issue, to Kathy Zhao for providing the invitation and extending her trust to the editors, and to the reviewers and MDPI staff for their cooperation during the submission, review, and publishing processes. Finally, the editors would like to acknowledge the Research Centre on Education, Institute of Education, University of Minho, the FCT/MCTES-PT R&D Unit funded through projects UIDB/01661/2020 and UIDP/01661/2020, to which they belong.

Laurinda Leite and Luís Dourado
Editors

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Systematic Review

Problem-Based Learning in Türkiye: A Systematic Literature Review of Research in Science Education

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Abstract: This study aimed to conduct a systematic literature review of research to provide an overview of the key findings and trends in studies on problem-based learning within the context of science education in Türkiye. To achieve this goal, descriptive content analysis was used in this study. Articles and graduate theses conducted in Türkiye between 2000 and December 2023 were included in this study. The Turkish Academic Network and Information Center (TR Dizin) and National Thesis Center databases were used to access the articles and theses. The purposive sampling method known as the criterion sampling method was employed in this study, resulting in the inclusion of 133 studies, including 37 articles and 96 graduate theses. To facilitate data analysis, we developed a coding form. The results of this study showed that PBL had a positive impact on 34 different skills, and it had no impact on 11 different skills. Across all reviewed studies, the most preferred research design was the quasi-experimental design. There was limited inclusion of final-year students in the samples at various school levels, and researchers mainly preferred physics subjects for their studies.

Keywords: problem-based learning; science education; Türkiye

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1. Introduction

Problem-based learning (PBL) is a widely recognized pedagogical approach that has garnered substantial attention in education worldwide. Originating from medical education in the late 1960s, PBL has since evolved and been implemented across various educational contexts, including higher-education institutions [1]. According to Savery and Duffy [2], PBL is grounded in several key principles that shape its implementation, including using authentic, ill-structured problems as a starting point for learning, active engagement of students in problem-solving activities, collaborative learning within small groups, facilitator guidance rather than traditional teaching, and self-directed learning and reflection [2].

PBL has gained significant recognition and relevance in science education due to its effectiveness in promoting a deeper understanding of scientific concepts, enhancing students' problem-solving abilities, and fostering students' critical thinking skills as they analyze, evaluate, and synthesize information to solve problems [3]. Additionally, it helps prepare students for future careers in science-related fields by equipping them with skills, such as critical thinking, problem solving, teamwork, and adaptability, which are highly valued by employers. It is characterized by its student-centered, inquiry-driven, and collaborative nature. Students engage in a dynamic and collaborative inquiry process to explore and solve complex, authentic problems [4].

This approach emphasizes active learning, critical thinking, problem-solving skills, and the application of knowledge in practical contexts [5]. PBL engages students actively in the learning process, making science more interesting and relevant. They are motivated to seek out information, conduct research, and interact with peers to find solutions [6]. This hands-on approach encourages a deeper understanding of scientific concepts. PBL shifts the role of the teacher from a lecturer to a facilitator. Students take responsibility for their own learning, fostering self-directed learning skills and a sense of ownership over their education. The teacher guides and supports the learning process, providing resources and feedback when needed [7].

PBL typically begins with the presentation of scientific concepts and principles within the context of real-world problems or scenarios. It should be authentic, ill-structured, complex, and relevant to the content being studied in order to facilitate students to reach their own conclusions by doing open inquiry [8]. This serves as a trigger for learning. Students take ownership of their learning: they decide what information they need to acquire, how to acquire it, and how to apply it to solve the problem [6]. This contextualization helps students see the relevance of what they are learning and how it can be applied in practical situations. Students often work in groups, requiring effective teamwork, communication, and collaboration skills, essential in scientific research and professional settings. PBL often involves a cycle of research, discussion, and reflection. It encourages students to explore and understand the problem; identify relevant concepts and principles; generate hypotheses and solutions; and construct arguments to support their solutions [9]. Also, students are encouraged to reflect on their learning process, their understanding of the problem, and their solutions [10].

2. Theoretical Foundations

PBL is a pedagogical approach rooted in several well-established educational theories, each contributing to its effectiveness in science education. The theoretical underpinnings of PBL in science education, including constructivism, cognitive load theory, and situated learning, provide a strong foundation for understanding its effectiveness [1,2,10–12].

Constructivist learning theory posits that learners actively build their own understanding and knowledge through a process of constructing mental models based on their experiences and prior knowledge [13]. In the context of PBL in science education, this theory aligns with the idea that students construct scientific knowledge by engaging with authentic problems. In a PBL setting, students are presented with complex, real-world scientific problems that require them to draw upon their existing knowledge, engage in research, collaborate with peers, and synthesize information to generate solutions [2,12,14]. According to Leite, Dourado, and Morgado, teamwork and cooperative learning provide very effective learning environments for PBL [15]. This active engagement allows students to construct a deeper and more meaningful understanding of scientific concepts. By grappling with problems, they refine their mental models of scientific phenomena and develop problem-solving skills critical to scientific inquiry [2].

Cognitive load theory (CLT) explores how the cognitive load imposed on learners can impact their ability to process information and learn effectively [11,12,16]. PBL, when designed well, aligns with CLT principles by managing cognitive load in science education. In a PBL environment, the cognitive load is distributed over time, allowing students to build their understanding progressively. They start with a problem and incrementally acquire the necessary knowledge and skills to solve it. This "scaffolding" approach minimizes cognitive overload, ensuring that students can focus on meaningful learning experiences [17,18].

Situated learning theory [12,19,20] emphasizes the importance of learning in context. It argues that learning is most effective when it occurs within authentic, real-world situations. PBL in science education aligns with this theory by placing scientific knowledge and skills in relevant contexts. In PBL scenarios, students are immersed in situations that resemble the complexities and challenges faced by scientists in their research or practical work. This contextualization not only enhances the relevance of scientific content but also fosters the development of problem-solving skills that are transferable to real-world scientific endeavors [10].

These theories support the idea that PBL promotes active engagement, aligns with the cognitive processes of learners, and fosters the development of skills necessary for scientific inquiry. By integrating these theories into the design and implementation of PBL, educators can create a rich learning environment that enhances both scientific knowledge acquisition and problem-solving abilities among students [11].

3. Implementation of PBL in Türkiye

PBL was introduced to Turkish education by establishing medical faculties that adopted the curriculum of Maastricht University in the early 2000s [21]. Since then, PBL has gradually expanded to other disciplines and levels of education, including K-12, undergraduate, and graduate programs. PBL's implementation in Türkiye has been characterized by adapting international models to suit the local context [22].

The introduction of PBL in Turkish education has faced several challenges. Although the Turkish Ministry of National Education (MoNE) has restructured the curriculum according to constructivism since 2004, one of the main significant challenges is the traditional lecture-based teaching approach deeply ingrained in the educational system [23]. Resistance to change among educators and students has been a barrier to the widespread adoption of PBL. Language has also been challenging, particularly in disciplines with a substantial theoretical component. PBL often requires students to work in groups and communicate effectively in the target language, which may be a foreign language in some cases [21]. Another challenge is the need for well-trained faculty members who can facilitate PBL effectively. Training faculty members to transition from a didactic teaching style to a facilitative one that supports student-centered learning has been an ongoing process [23].

Despite these challenges, research in Türkiye has highlighted several benefits associated with PBL implementation. Studies have reported that PBL enhances students' critical thinking, problem-solving skills, and motivation for learning [24]. PBL has also been found to promote teamwork, communication skills, and a deeper understanding of the subject matter [21]. Furthermore, research suggests that PBL can contribute to developing lifelong learning skills and better prepare students for the demands of the modern workforce, aligning with Türkiye's goals of improving higher education and workforce readiness [24,25].

In Türkiye, PBL has made significant strides in higher education, with its implementation expanding beyond medical faculties to various disciplines. While challenges related to traditional teaching methods and faculty training persist, research indicates that PBL offers many benefits to students, including improved critical thinking, problem-solving skills, and subject matter comprehension [26]. As Türkiye continues to adapt and refine its approach to PBL, the potential for this student-centered pedagogy to positively impact Turkish education remains promising. Developing successful PBL should start with aligning PBL activities with the curriculum standards and learning objectives specified by the Turkish Ministry of National Education, ensuring that PBL projects address the key science concepts and skills that students are expected to learn. In accordance with the 2018 Primary Education Science Program issued by the Ministry of National Education, it is imperative to select science topics or problems that are both age-appropriate and relevant to students' daily lives. This approach is crucial for igniting curiosity, sustaining interest, and establishing connections to their own experiences, thereby facilitating meaningful learning [27].

In recent years, PBL has gained prominence in Türkiye as educators and policymakers seek innovative and effective teaching methods to enhance students' critical thinking, problem-solving abilities, and overall learning experiences. Türkiye, situated at the crossroads of Europe and Asia, boasts a diverse educational landscape that spans from primary schools to universities. As Turkish educators grapple with the challenges of preparing students for an increasingly complex and dynamic global environment, the adoption and implementation of PBL have emerged as a potential solution. This educational approach aligns with the broader goals of fostering autonomous learners equipped to navigate real-world challenges effectively [25].

The importance of conducting a descriptive content analysis of PBL studies in Türkiye becomes evident when considering the need to map the current state of PBL research, identify trends, and understand the contextual factors influencing its implementation. Such an analysis can offer valuable insights into the evolution of PBL within the Turkish educational system and highlight areas where further research and development may be necessary. This study aims to provide a comprehensive overview of the existing body of literature on PBL in Türkiye. Within the scope of this study, answers were sought to the following research questions:

1. What is the distribution of studies according to publication type?
2. What is the distribution of studies according to publication year?
3. What is the distribution of studies according to different research variables?
4. What is the distribution of studies according to the research methods used?
5. What is the distribution of studies according to level of education?
6. What is the sample distribution in the studies according to grade level?
7. What is the distribution of topics addressed in studies?
8. What is the distribution of studies according to the duration of the research?
9. What is the distribution of the results obtained from the studies related to PBL?
10. What is the distribution of studies according to science topics in the studies?

4. Materials and Methods

4.1. Research Design

In this study, the aim was to conduct a systematic literature review of research in science education related to PBL in science disciplines in Türkiye. To achieve this objective, a qualitative method known as descriptive content analysis was used in this study [28]. The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) protocol was used as a guide to conduct this study [29].

In the literature, meta-analysis, meta-synthesis, and descriptive content analysis approaches are used for content analysis. In meta-synthesis studies, which are expressed as a meta-analysis of quality [29,30], only the qualitative dimensions of qualitative or mixed studies conducted in a certain field are evaluated [29]. Meta-synthesis research involves a methodological approach that synthesizes the findings of each area of research included in the study in terms of theory, methods, and data [30]. A meta-analysis, on the other hand, is a method of determining the effect of an independent variable on a dependent variable by calculating the effect size of studies conducted on a particular subject, combining the results of the study and statistical analysis of the obtained research findings [31]. In descriptive content analysis, qualitative and quantitative studies on a particular subject are evaluated and analyzed [32]. Descriptive content analysis is a scientific method in which quantitative and qualitative data are systematically coded, synthesized, and analyzed within the framework of certain themes and patterns [20,32]. A flowchart illustrating the process of identifying pertinent publications for this systematic review is shown in Figure 1.

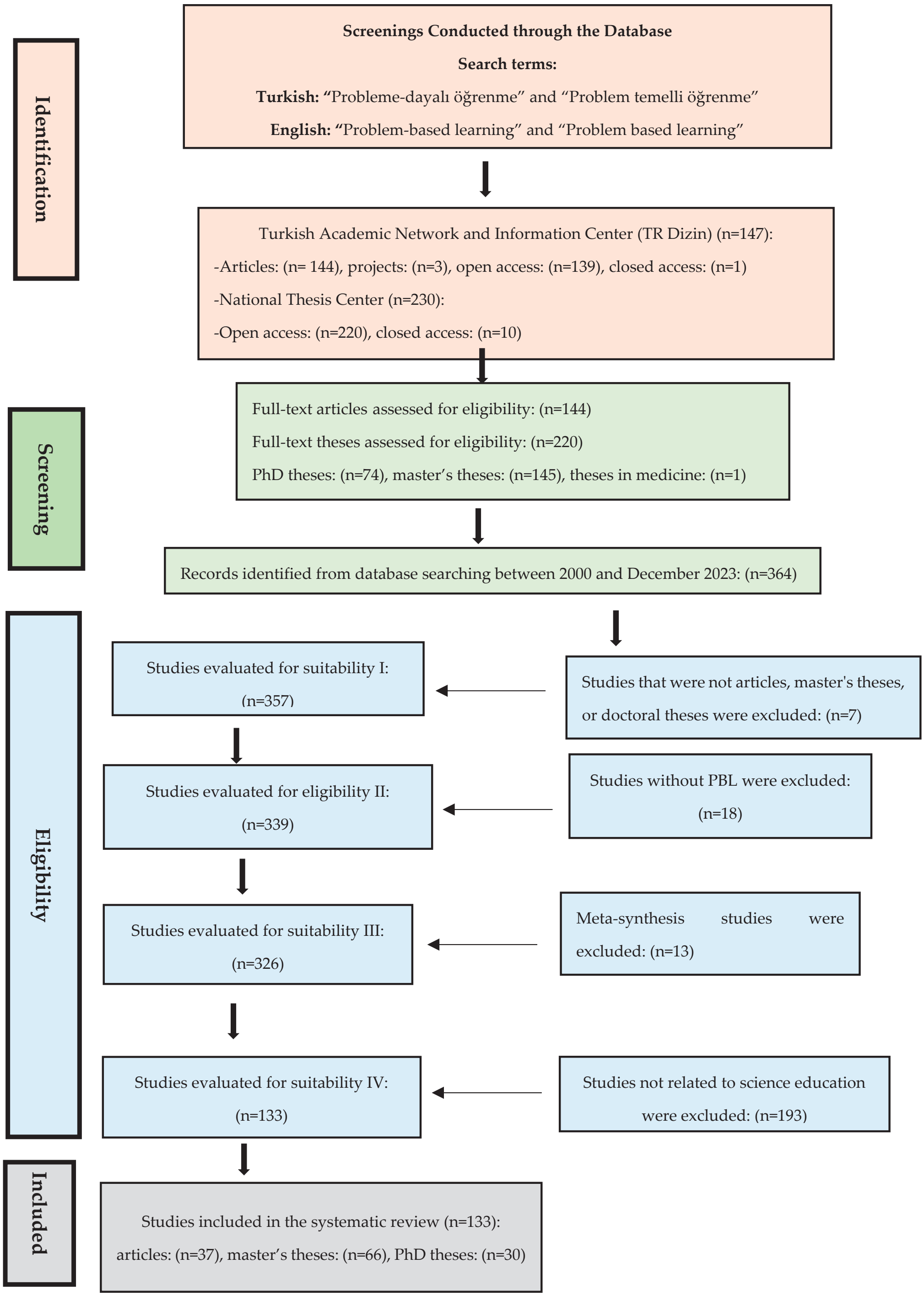

Figure 1. Flowchart illustrating the process of identifying pertinent publications for the systematic review.

4.2. Sample

This study included a comprehensive search of The Turkish Academic Network and Information Center (TR Dizin) and National Thesis Center databases focusing on PBL in science education in Türkiye between 2000 and 2023. The purposive sampling method known as the criterion sampling method was employed in this study, resulting in the inclusion of a total of 133 studies, including 37 articles, 66 master's theses, and 30 doctoral theses (Appendix A. To identify relevant studies, searches were conducted using keywords, including problem-dayalı öğrenme (problem-based learning), problem temelli öğrenme (problem-based learning) in the search engines of TR Dizin and National Thesis Center databases. These keywords were searched in the titles, abstracts, and keywords of the articles and theses. During the search process, various combinations of these keywords in both Turkish and English were utilized.

Several criteria were considered when selecting articles and graduate theses for inclusion in the research. The selection criteria for the studies included:

- The studies had to be related to the problem-based learning (PBL) approach;
- The studies had to be related to science education;
- The studies had to be published in both Turkish and English;
- The studies had to have been conducted between 2000 and September 2023;
- Articles had to be published in journals indexed in The Turkish Academic Network and Information Center (TR Dizin);
- Graduate theses had to be accessible through the National Thesis Center database;
- The samples in the studies had to consist of pre-service and in-service teachers, including kindergarten, elementary, special education, science, biology, chemistry, and physics teachers;
- The samples in the studies had to consist of kindergarten, elementary, middle school, high school, undergraduate, and graduate students;
- The samples had to be located within the borders of Türkiye;
- The samples had to not be conference papers, projects, books, or reports.

Studies that did not meet the inclusion criteria were excluded from the research. As a result, 133 studies meeting these criteria were identified. These studies were compiled into a single-drive file, and each study was listed with the following information: sequence number, author(s), and publication year to facilitate easy access.

4.3. Data Collection Tools and Data Analysis

To facilitate the data analysis in a more accessible and understandable manner, we developed a coding form. Information regarding the articles and theses that met the research criteria was added to this form. The developed form is presented in Table 1.

The Coding Form included information about the author(s)' names, the year of the study, the index of the journal where the study was published, the dependent and independent variables of the study, the research design, the school level and grade level of the study, the qualitative and quantitative data collection tools used in the study, the duration of implementation, the unit/topic addressed in the study, and the results obtained from the study. The Journal Index column was applicable to articles and does not appear in the form of theses. To ensure coding reliability, two independent coders separately reviewed the studies and recorded the results in the coding form. The codings were compared, and the suitability of the codings was determined. The reliability between the coders was calculated as 94%.

Table 1. Article/thesis coding form.

Number	Author(s)	Publication Year	Journal Index	Variables		Research Design	School Level	Grade	Data Collection Tool		Content	Results
				Dependent Variable	Independent Variable				Qualitative	Quantitative		
1												
2												
3												

5. Results

5.1. Distribution of Studies According to Publication Type

When looking at the distribution of the studies related to PBL in science disciplines between 2000 and 2023 according to the publication type, it was determined that the studies were mostly conducted at the master's level (49.6%), while the number of studies at the article (27.8%) and doctoral (22.5%) levels was less (Figure 2).

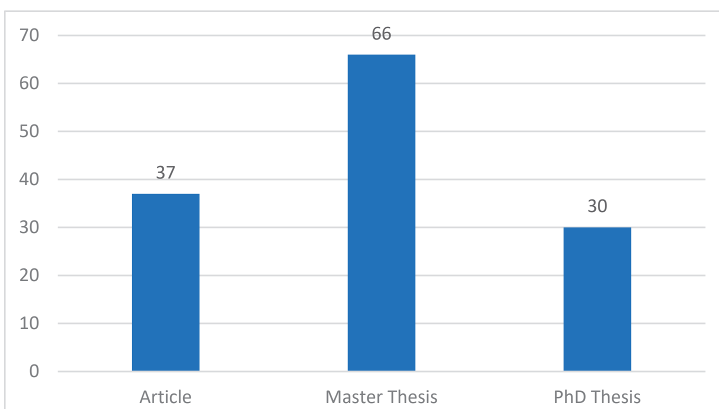

Figure 2. Distribution of studies according to publication type.

5.2. Distribution of Studies According to Publication Year

When Figure 3 is examined, it can be observed that there were no article studies related to PBL (presumably a specific subject or topic) between 2000 and 2004, or in 2006, 2007, 2011, 2016, and 2022. Similarly, no master's theses were conducted in 2000–2003 or in 2005, and no doctoral theses were conducted in 2000–2002, 2004–2007, and 2022–2023 about PBL. It was also evident that no studies related to PBL were conducted from 2000 to 2003. The first studies related to PBL in Türkiye appear to have started in 2003. It was found that the highest number of articles was produced in 2020 (six articles), the highest number of master's theses appeared in 2019 (seven theses), and the highest number of doctoral theses appeared in 2012 (five theses) and 2017 (five theses). Additionally, it was observed that the highest number of studies appeared in 2012 (14 studies) and 2017 (13 studies).

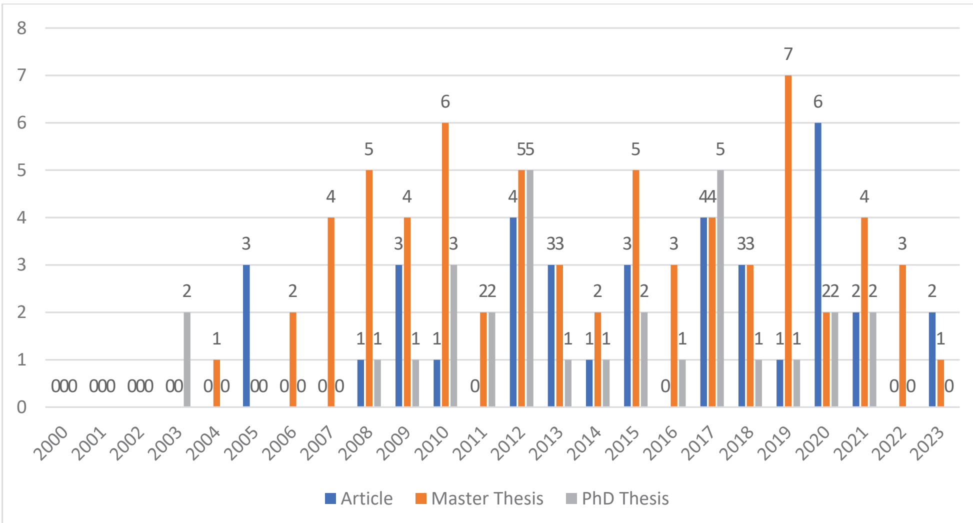

Figure 3. Distribution of studies by years.

5.3. Distribution of Studies According to Different Research Variables

When we analyzed the studies according to different research variables, it was seen that only two studies were conducted on PBL and these were theoretical/conceptual studies and one measurement tool development study. The remaining 130 studies had all been conducted in the context of examining the impact of PBL methods on different variables. These variables included problem-solving skills, self-efficacy beliefs, academic achievement, misconceptions, opinions, motivation, attitudes, metacognitive awareness, learning strategies, learning style, science process skills, cognitive processing skills, social skills, creative thinking skills, analytical thinking skills, persistence, conceptual understanding, scale development, the development of computer-integrated PBL materials, critical thinking, inquiry-based learning, pedagogical content knowledge (PCK), scientific reasoning ability, module creation and implementation, environmental education, self-directed learning, levels of conceptual structuring, the development and impact assessment of instructional materials, academic risk-taking, scientific literacy, metacognition, energy literacy, career interest, logical thinking, engineering and technology perception, reflective thinking skills for problem solving, digital literacy, reasoning skills, cognitive flexibility, cognitive skill level, the development of fundamental concepts related to heat and temperature, self-regulatory learning skills, and decision-making skills. A total of 69 dependent variables were examined in the studies. The 10 most studied dependent variables with the most impact are presented in Figure 4.

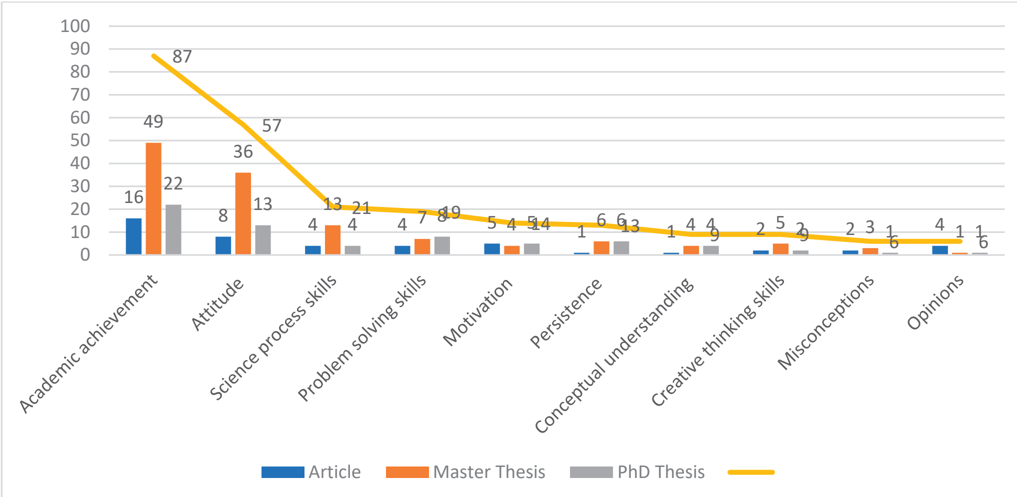

Figure 4. The most common dependent variables in the studies.

When Figure 4 is examined, it can be observed that the most frequently studied depended variable in the conducted research was the effect of the method on academic achievement (87). Following this, achievement, attitude (57), science process skills (21), and problem-solving skills (19) were examined, listed in order of their prevalence. Furthermore, when Figure 4 is examined, it is seen that there were fourteen studies on motivation, thirteen studies on persistence, nine studies on conceptual understanding, nine studies on creative thinking skills, six studies on misconceptions, and six studies on student opinions.

5.4. Distribution of Studies According to Research Methods Used

Findings regarding the distribution of studies according to the research methods used showed that both quantitative and qualitative methods were used in studies related to PBL. The methods used include "Full Experimental Design", "Semi-Experimental Design", "Weak Experimental Design", "Mixed method", "Case Study", "Action Research", and "Qualitative Research". The methods used in the studies are presented in Figure 5.

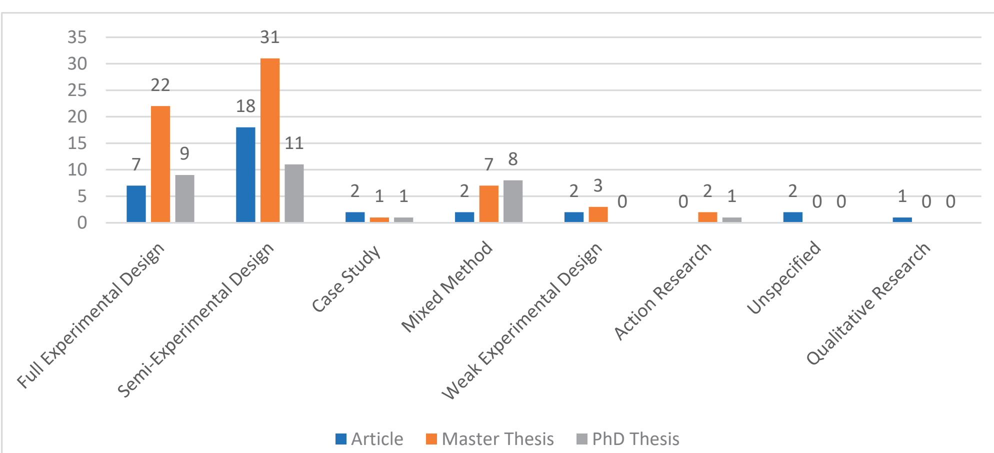

Figure 5. Methods used in the studies.

When Figure 5 is examined, it is observed that the most preferred method in these studies related to PBL was the semi-experimental design (60). This method was followed by the full experimental design (38), mixed-method (17), weak experimental design (5), case study (4), action research (3), and qualitative research (1) approaches. In two studies, the method was not clearly specified.

It was determined that the methods used in the studies had changed over the years. The evolution or clustering of the methods used in the studies over the years is presented in Figure 6.

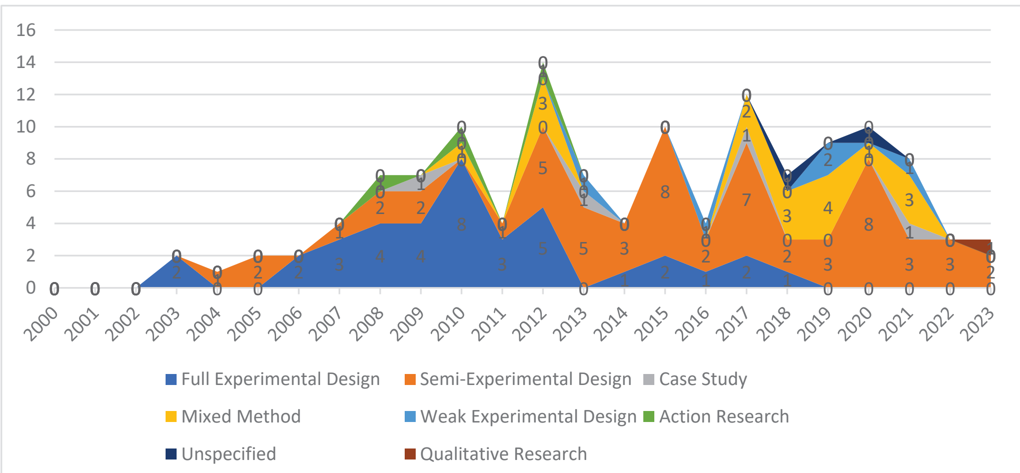

Figure 6. Stacked area graph of methods used in the studies.

When examining Figure 5, it is observed that the first studies related to PBL in Türkiye were full experimental studies. It was found that full experimental studies were most common between 2008 and 2012 (24 studies) and that their numbers have gradually decreased in recent years. On the other hand, semi-experimental studies have been on the rise since 2012. Approximately 85% (51) of the semi-experimental studies were conducted between 2012 and 2023. It was determined that the highest number of full experimental studies occurred in 2010 (eight studies), and the highest number of semi-experimental studies appeared in 2015 (eight studies) and 2020 (eight studies). The first qualitative study (action research) was conducted in 2008. It was observed that no mixed-method research was conducted until 2010, four mixed-method studies were conducted between 2010 and 2012, no mixed-method research was conducted between 2013 and 2016, and thirteen mixed-method studies were conducted after 2017. Based on this, it can be concluded that 76.47% (13) of the mixed-method research was conducted in recent years.

5.5. Distribution of Studies According to Level of Education

When the distribution of the studies was examined according to the level of education that was studied, it was determined that studies were conducted across all school levels, from kindergarten to university. It was seen that these studies were mostly conducted as master's theses studies (66 studies) (Figure 7).

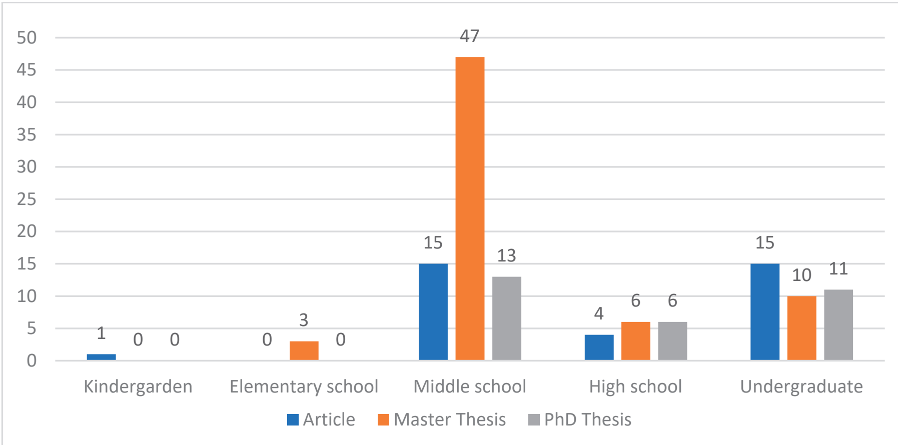

Figure 7. Clustered bar chart of research according to the studied level of education.

As shown in Figure 6, it can be observed that there was only 1 study related to PBL at the preschool level, 3 studies at the primary school level, 75 studies at the middle school level, 16 studies at the high school level, and 36 studies at the undergraduate level. Based on this, it can be concluded that more than half of the studies related to PBL are conducted at the middle school level.

5.6. Distribution of the Samples in the Studies According to Grade Levels

When the findings regarding the distribution of studies according to grade levels were examined, it was observed that most studies related to PBL were conducted with seventh-grade students. Following that, sixth-grade, fifth-grade, and junior students were the next most commonly selected as samples. In studies conducted at the undergraduate level, primarily junior students were chosen. Another noteworthy result observed when analyzing Figure 7 is the limited or almost non-existent selection of final-year students at the school levels as samples. It was seen that there were eleven studies related to 8th-grade students, three studies related to 4th-grade students, and one study related to senior students, but no studies related to 12th-grade students. Additionally, it is noted that three (3) of the conducted studies were carried out with students diagnosed with special abilities, two (2) undergraduate-level studies did not provide any information about the class level, and in two (2) undergraduate-level studies, more than one class level was selected as the sample. It was concluded that 80% of the studies investigating the effects of problem-based learning were conducted with seventh-grade, sixth-grade, fifth-grade, junior, eighth-grade, or freshman students (Figure 8).

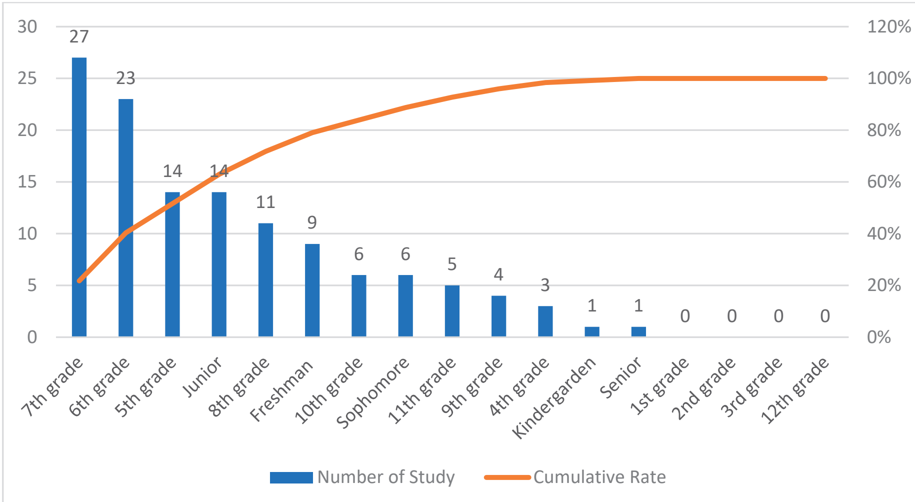

Figure 8. Pareto diagram of the samples according to the grade levels studied.

Findings regarding the discipline of the undergraduate samples (Figure 9) used in the research showed that 26 of the studies were conducted with pre-service science teachers (68.42%). Additionally, five studies were related to pre-service chemistry teachers, four studies involved pre-service elementary teachers, two studies involved pre-service physics teachers, and one study used pre-service mathematics teachers. These findings indicated that there were no studies conducted with pre-service biology teachers.

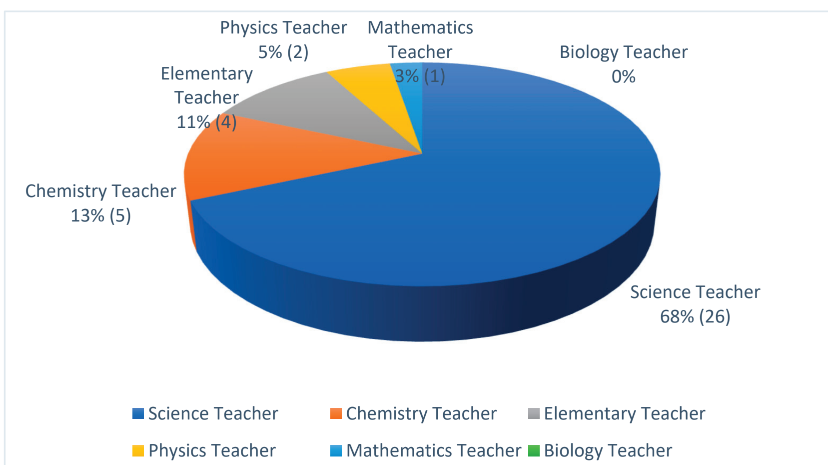

Figure 9. Pie chart of research based on the undergraduate samples.

5.7. Distribution of Topics Addressed in Studies by Subject

When we look at the distribution of the topics addressed in the studies in Figure 10, we see that the studies primarily focused on physics topics (64). In addition, there were 31 studies related to chemistry topics, 23 studies related to biology topics, 10 studies related to environmental topics, 2 studies related to laboratory science, and 1 study on mathematics topics.

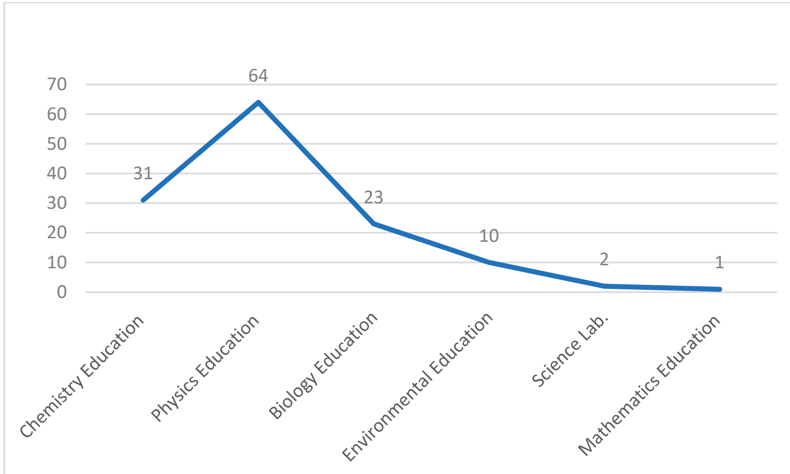

Figure 10. Distribution of topics addressed in the studies by subject.

5.8. Findings Regarding the Duration of the Research

Upon examining Figure 11, it can be observed that some studies provided information about the duration of their research in terms of weeks and class hours. In some studies, only information on the amount of weeks was given; in others, only information on the class hours was provided. In some studies, both week and class hour information was included, while one study lacked any information about the duration of its research. After the analysis, it was determined that 22 studies were conducted over five weeks, 21 studies lasted eight weeks, 16 studies lasted four weeks, 13 studies lasted nine weeks, 11 studies lasted six weeks, and 9 studies lasted three weeks. The study durations related to other elements can be examined from the decreasing Pareto diagram. Based on Figure 11, it was concluded that in 80% of the studies conducted to determine the effects of problem-based learning, the research was carried out over periods of 5, 8, 4, 9, 6, and 3 weeks.

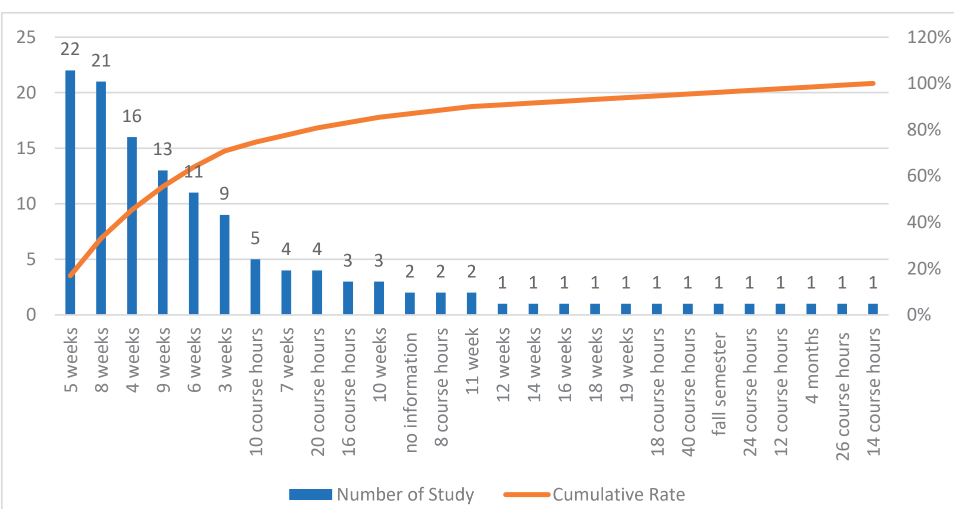

Figure 11. Pareto diagram of findings regarding the duration of the research.

5.9. Findings Regarding the Results of Reviewed Studies

When Figure 12 is examined, it can be determined that the PBL method had a positive effect on academic achievement (76), attitude (35), science process skills (17), students' opinions (18), conceptual understanding (14), problem-solving skills (12), motivation (12), creative thinking skills (9), knowledge retention (8), overcoming misconceptions (7), critical thinking skills (4), self-efficacy beliefs (3), and developing environmental awareness (3). In all of the conducted studies, PBL had a neutral effect, while in 47 studies conducted with these variables, including attitude (18), academic achievement (10), problem-solving skills (5), science process skills (4), motivation (3), knowledge retention (2), creative thinking skills (1), self-efficacy beliefs (1), inquiry learning skills (1), metacognition (1) and reflective thinking (1), it was found that it had no effect. In none of the examined studies was a negative effect of problem-based learning method detected.

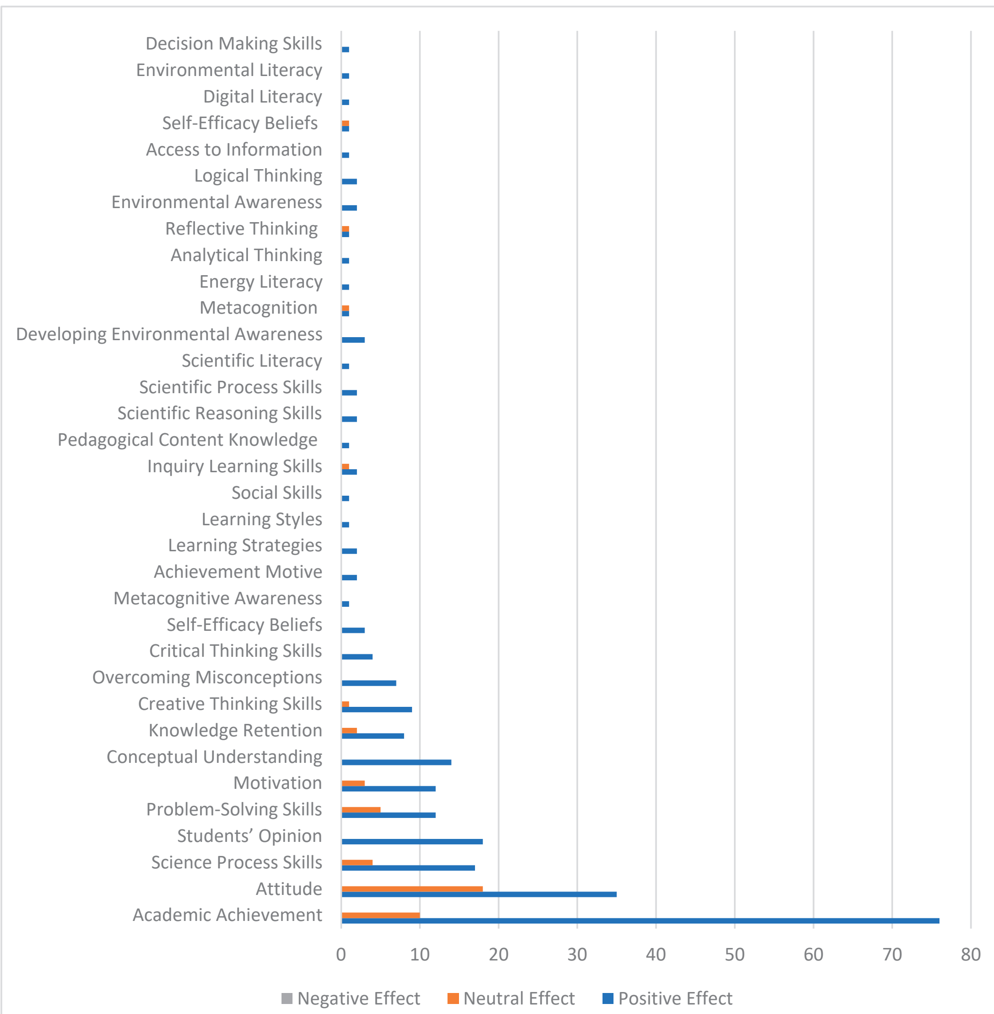

Figure 12. The findings of the reviewed studies' results.

5.10. Findings Regarding the Science Topics in the Examined Studies

When Table 2 is examined, it can be determined that research was conducted on topics related to physics, chemistry, biology, the environment, and astronomy. The effectiveness of the PBL method was mainly studied in physics, while there was a limited number of studies in the fields of the environment and astronomy. When all of the topics are considered, the most researched topics appear to be "Matter and Heat" (15), "Force and Motion" (14), "Electricity and Magnetism" (12), "Work-Energy" (9), "Acid-Base" (9), and "Systems in Our Body" (8).

Table 2. Distribution of science topics in the examined studies.

Discipline	Subjects	f
Physics	Matter and Heat	15
	Force and Motion	14
	Electricity and Magnetism	12
	Work–Energy	9
	Light and Sound	4
	Pressure	3
	States of Matter and Heat Fuels	2
	Light and Optics	2
Chemistry	Acid–Base	9
	Mixtures	6
	Particulate Structure of Matter	6
	Electrolysis and Batteries	6
	Chemical Properties of Solutions	3
	Physical and Chemical Changes	2
	Atomic and Periodic System	1
Biology	Systems in Our Body	8
	Heredity/Genetics	4
	Reproduction, Growth, and Development in Plants and Animals	4
	Matter Cycles	1
	Basic Structure of the Cell	1
	Natural Systems	1
	Viruses and Bacteria	1
	Bacteria and Archaea	1
Environment	Humans and the Environment	4
	Environmental Science	2
	Why do Ecosystems Change?	1
	Environmental Problems	1
	Energy Transformations	1
	Domestic Waste and Recycling	1
Astronomy	Astronomy and Renewable Energy	1
	Solar System and Eclipses	1

6. Discussion and Conclusions

In this study, research focusing on PBL in science education in Türkiye was examined using a descriptive content analysis method. The studies were scrutinized in detail, and by conducting a critical review of the data from these studies, general trends were identified. The studies conducted in Türkiye include meta-analyses, content analyses, descriptive content analyses, and systematic literature reviews related to PBL [6,22,24,25,33,34]. In some of these studies, "achievement" [33,35], "achievement and attitude" [36], and "achievement, attitude, motivation, and group dynamics" [34] were examined, while in others, the general outlines of PBL were explored [22,24,25]. In our study, we also examined the studies related to PBL in science education in a broad context.

As per the objective of this study, a total of 133 works related to PBL in science in Türkiye, comprising 96 graduate theses and 37 articles published between 2000 and 2023, have been examined. It was noted that there were three separate content analysis studies conducted on previous PBL research in science in Türkiye [24,25,35]. Additionally, six different content analysis studies were identified that examined PBL without limiting the scope to a specific field of science [22,33,34,36,37]. In their respective works, Alper et al. [22] examined 48 studies, Batdi [33] examined 26, Dagyar [37] examined 118, Ayaz [35] examined 24, Temel et al. [24] examined 58, Tosun and Yasar [25] examined 40, Mutlu and Aydogmuş [6] examined 40, Ozgul [36] examined 107, and Bati [34] examined 20 different studies. Therefore, it can be argued that our study is more comprehensive than previous similar studies.

In our study, when the distribution of the types of studies is examined, it is determined that 49.6% of the studies are master's theses, 27.8% are articles, and 22.5% are doctoral theses. When the studies are examined by publication year, it is observed that no studies were conducted between 2000 and 2003. The first studies related to PBL in science in Türkiye seem to have started in the year 2003. Additionally, it is noted that the highest number of studies were conducted in 2012 and 2017. It is found that 75,18% of the studies were conducted between 2010 and 2021. In 2022 and 2023, three studies were conducted each year, leading to the conclusion that the number of studies related to PBL in science has significantly decreased in recent years. Similarly, Mutlu and Aydogmuş [6] reported a significant decrease in studies related to PBL in Türkiye in recent years based on their examination of 40 theses conducted between 2014 and 2018.

Our results show that, in the conducted studies, 69 different dependent variables were examined. In studies related to PBL in science, the variable most frequently investigated was the impact of the method on achievement (64.61%). Additionally, attitude, scientific process skills, and problem-solving skills were the next most commonly examined variables, in that order.

Dagyar [37] conducted a meta-analysis of 118 studies in his doctoral thesis and examined the impact of the PBL approach on academic achievement. Similarly, Ozgul [36] conducted a meta-analysis study examining the effects of PBL on students' academic achievement and attitudes in 107 studies. Ozgul [36] found that in the studies he reviewed, the PBL approach had a positive impact on academic achievement in 73 cases and a negative impact in 4 cases. Furthermore, Batdi [33] in his study determined that online PBL had a positive effect on students' achievements, attitudes, and motivation. Based on this, it can be concluded that the use of PBL in classes has a positive impact on academic achievement. Additionally, Temel et al. [24] reported in their study that academic risk-taking, metacognitive awareness, logical thinking ability, learning strategies, the permanence of learned knowledge, problem-solving skills, creativity, motivation, and scientific process skills were also examined in research studies.

In this study, we also found that the PBL method had a positive impact on 34 different skills, and it had no impact on 11 different skills. Additionally, there was no evidence of the method having a negative impact on any skill. More than half of the studies (53.38%) identified a positive impact of the method on achievement. Furthermore, in 35 studies, the applied method had a positive effect on attitude, while in 18 studies, it had no effect on attitude. In 17 studies, the applied method had a positive impact on scientific process skills; in 18 studies, it had a positive impact on student opinions; in 14 studies, it had a positive impact on conceptual understanding; and in 12 studies, it had a positive impact on problem-solving skills.

Our results show that the most preferred research design was the quasi-experimental design in studies related to PBL in science. This was followed, in order, by the full experimental design, mixed-method design, weak experimental design, case study approach, action research approach, and weak experimental design. The analysis revealed that quantitative methods were more commonly used, with qualitative methods being less preferred. Additionally, it was observed that the earliest studies related to PBL in science in Türkiye were full experimental studies. The highest number of full experimental studies appeared in 2010, while the highest number of quasi-experimental studies occurred in 2017 and 2020.

The first qualitative action research study in science education was conducted in 2008. It was noted that no mixed-method research was conducted until 2010, but there have been 13 mixed-method research studies conducted since 2017. Consequently, it can be inferred that 76.47% of the mixed-method research studies were conducted in recent years. In their study, Mutlu and Aydogmuş [6] reported that experimental designs were predominantly preferred in the conducted studies.

When the studies related to PBL in science were examined according to the level of education that was studied, the findings showed that more than half of the studies (56.39%) were conducted at the middle school level. Following the middle school level, studies conducted at the undergraduate level had the next highest number (27.06%). The analysis revealed that there were sixteen studies conducted at the high school level, three studies conducted at the primary school level, and one study conducted at the preschool level. Furthermore, it was observed that the majority of the studies at the middle school level were conducted with seventh-grade students, followed by sixth-grade and fifth-grade students. When the studies conducted at the undergraduate level were examined, it was found that the sample predominantly consisted of third-year students.

Another noteworthy result obtained from this descriptive content analysis is the limited inclusion of final-year students in the samples at various school levels. This could be attributed to examination attempts such as the High School Transition System exam in the 8th grade, the Higher Education Institutions Examination in the 12th grade, and the Public Personnel Entrance Exam held in the senior year of undergraduate studies for students wishing to start a professional career. Mutlu and Aydogmuş [6] reported that in their examination of 40 theses related to PBL conducted between 2014 and 2018 in Türkiye, middle school students were predominantly selected as samples, and they did not come across any studies that included primary school students. Similarly, Tosun and Yasar [25] noted in their study that primary school students were selected as samples in research studies to a low extent, and there were no samples selected from preschool education.

As a result of this study, it was observed that 68.42% (26) of the studies conducted at the undergraduate level were related to prospective science teachers. Furthermore, the analysis revealed that in the research studies, 31 different topics from physics, chemistry, biology, environmental science, and astronomy were addressed, with 8 of them being related to physics, 7 to chemistry, 8 to biology, 6 to environmental science, and 2 to astronomy. When considering all of the topics covered in the studies, it was determined that the most frequently researched topics were, in order: "Matter and Heat", "Force and Motion", "Electricity and Magnetism", "Work-Energy", and "Acid-Base". In their study, Temel et al. [24] reported that 20 studies were conducted within the scope of middle school science courses, and 16 studies were conducted within the scope of undergraduate chemistry courses. Additionally, consistent with the findings obtained in the present study, Tosun and Yasar [25] found that the most preferred topic in their study was "force and motion", whereas in our study, the most preferred topics were "matter and heat" and "force and motion".

After the analysis, it was determined that 22 studies were conducted over five weeks, 21 studies lasted eight weeks, 16 studies lasted four weeks, 13 studies lasted nine weeks, 11 studies lasted six weeks, and 9 studies lasted three weeks.

This descriptive content analysis study underscores the growing interest in problem-based learning (PBL) within the context of science education in Türkiye. Despite challenges associated with resistance to change and faculty development, PBL in Türkiye has shown promise in improving students' critical thinking, problem-solving skills, and subject matter comprehension. As Türkiye continues to explore PBL, further research should focus on addressing these challenges and assessing the long-term effects of PBL on science education in the country.

While the articles reviewed here reflected on the challenges of PBL, they also pointed to future directions for PBL in science education in Türkiye. There was a consensus on the importance of faculty development programs to prepare educators for the transition to PBL.

Additionally, this research emphasized the need for further investigation into the long-term impact of PBL on students' learning outcomes and their preparedness for the workforce.

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Appendix A

Bibliographies of the studies in alphabetical order

Acikyildiz, M. (2004). *Investigation of effectiveness of problem-based learning at physical chemistry laboratory experiments* (Master's Thesis). Atatürk University, Erzurum.

Akbulut, H.H. (2010). *Implementation and evaluation of problem based learning on buoyant force and floating concepts* (Master thesis). Karadeniz Technical University, Trabzon.

Akcay, B. (2009). Problem-based learning in science education. *Journal of Turkish Science Education*, *6*(1), 28–38.

Akin, S. (2008). *Teaching environmental problems caused by stubble fires, ozon layer depletion and vehicles through problem-based learning* (Master thesis). Atatürk University, Erzurum.

Aksar B.G. (2022). *The effect of the problem based learning method applied in distance education on the academic achievement, conceptual understanding and attitude of the environment on the human and environment unit* (Master thesis). Marmara University, Istanbul.

Akti Aslan, S. (2019). *The effect of virtual learning environments designed according to problem-based learning approach to students' success, problem-solving skills, and motivations* (Doctoral dissertation). Inonu University, Malatya.

Alici, M. (2018). *Effect of STEM instruction on attitude career perception and career interest in a problem based learning environment and student opinions* (Master thesis). Kırıkkale University, Kırıkkale.

Alper, Y.A. (2003). *The Effect of cognitive flexibility on students achievement and attitudes in web mediated problem based learning* (Doctoral dissertation). Ankara University, Ankara.

Altuncekic, A. (2010). *The effect of web supported problem based learning medium upon cognitive and efffective learning products:* Gazi University Kastamonu Education Example (Doctoral dissertation). Gazi University, Ankara.

Arici, F. (2021). *Investigation of the effectiveness of problem based learning method of enhanced with augmented reality in the teaching of cell and divisions subject* (Doctoral dissertation). Atatürk University, Erzurum.

Arslan Turan B. (2014). *Effects of problem-based learning on achievement, self-regulated learning skills and academic self-concept* (Doctoral dissertation). Hacettepe University, Ankara.

Arslan, A. (2009). *The effect of learning style based on problem on the success of student in studying human and environment unit* (Master thesis). Sakarya University, Sakarya.

Ayaz, G. (2007). *The effect of problem-based learning on the elementary school students' achievement in genetics* (Master thesis). Middle East Technical Unıversity, Ankara.

Aydogdu, C. (2012). The effect of problem based learning strategy in electrolysis and battery subject teaching. *Hacettepe University Journal of Education*, *42*(42), 48–59.

Aysu, G. (2019). *An examination of the effects of problem-based learning STEM applications on students' academic achievements and permanence of learning* (Master thesis). Niğde Ömer Halisdemir University, Niğde.

Ayyildiz, Y. (2012). *Development, application and evaluation of an active learning material based on constructivist approach in the subject of chemical reactions and energy in the high school chemistry* (Doctoral dissertation). Dokuz Eylül University, Izmir.

Balim, A.G., Celiker, H.D., Turkoguz, S., Evrekli, E., & Ekici, D. İ. (2015). The effect of concept cartoons-assisted problem-based learning method on conceptual understanding levels and problem solving skill perceptions of students. *Journal of Turkish Science Education*, *12*(4), 53–76.

Balim, S. (2016). *The effects of using problem based learning method in science courses on talented students' levels of academic achievements, inquiry learning skill perceptions and attitudes towards science* (Master thesis). Dokuz Eylul University, Izmir.

Bayrak, B.K., & Bayram, H. (2012). The effect of problem-based learning in a web environment on the academic achievement of students with different learning styles. *Mustafa Kemal University Journal of Social Sciences Institute*, *9*(18), 479–497.

Bayram, A. (2010). *The effect of problem based learning on overcoming 5th grade students' misconceptions about "heat and temperature"* (Master thesis). Selcuk University, Konya

Bayram, F. (2023). *The effect of problem based learning approach to teaching the unit of the solar system and eclipses on academic achievement and problem solving skills* (Master thesis). Kocaeli University, Kocaeli.

Benli, E. (2010). *The research of the effects of problem based learning to the permanence of information, the academic success of science teacher candidates and their attitudes toward science* (Master thesis). Gazi University, Ankara.

Boncukcu, G. (2020). *The effect of problem based learning model on environmental literacy, problem solving and self-regulatory skills of 8th grade students in sustainable development* (Master thesis). Mersin University, Mersin.

Buyukdokumaci, H. (2012). *Effects of problem based learning on learning products in science and technology lesson for elementary 8th grade* (Master thesis). Pamukkale University, Denizli.

Can, I. (2021). *Determining of the Effects Problem-Based Science Learning Activities on Gifted Students* (Master thesis). Uşak University, Uşak.

Cayan, Y., & Karsli, F. (2015). The effects of the problem based teaching learning approach to overcome students' misconceptions on physical and chemical change. *Kastamonu Education Journal*, *23*(4), 1437–1452.

Celik, E. (2010). *The effect of problem based learning approach in science education on students? academic achievement, attitude, academic risk taking level and retention of knowledge* (Master thesis). Gazi University, Ankara.

Cakici, Y., Soyleyici, H., & Oguzhan Dincer, E. (2020). Investigation of the effect of problem based learning on the scientific process skills, attitudes and achievements of middle school students': unit light. *Trakya University Journal of Social Science*, *22*(1), 419–437.

Celik, E., Eroglu, B., & Selvi, M. (2012). The effect of problem based learning approach in science education on students' academic achievement, and attitudes toward science and technology course. *Kastamonu Education Journal*, *20*(1), 187–202.

Dadli, G. (2017). *The effect of learning activities based on authentic problems in the human and environmental relations unit on the reflective thinking skills, academic success, environmental attitude and awareness of 7th grade students* (Master thesis). Kahramanmaraş Sütçü İmam University, Kahramanmaraş.

Demirel, M., & Turan, B. (2010). The effects of problem based learning on achievement, attitude, metacognitive awareness and motivation. *Hacettepe University Journal of Education*, *38*, 55–66.

Demirel, O.E. (2014). *Effects of problem based learning and argumentation based learning on the students' chemistry achievement, their science process skills and science reasoning attitudes* (Master thesis). Mustafa Kemal University, Hatay.

Divarci, Ö. F. (2016). *The effects of the multimedia supported problem based learning on 8th grade students in relation to academic success, attitude and permanence: The subject of pressure* (Master thesis). Amasya University, Amasya.

Divarci, Ö. F., & Saltan, F. (2017). The effects of the multimedia supported problem based learning on academic success and attitude in science education. *Journal of Kırşehir Education Faculty*, *18*(3), 1–23.

Dursun, C. (2015). *The effect of problem-based learnıng method on students' attitude towards the environment and their environmental awareness* (7th Grade "Human and Environment" Unit Example) (Master thesis). Pamukkale University, Denizli.

Eceyurt Turk, G. (2017). *The effect of argumentation-supported problem based learning applications on the acid/bases and gases success of pre-service science teachers* (Doctoral dissertation). Gazi University, Ankara.

Elbistanli, A. (2012). *Investigation of the effect of problem based learning approach on the achievement, attitude and scientific process skills of 11. grade students through chemical equilibrium subject* (Master thesis). Mustafa Kemal University, Hatay.

Erden, S., & Yalcin, V. (2021). Investigation of the effect of preschool stem activities prepared according to the problem based learning approach on children's problem-solving skills. *Trakya Journal of Education*, *11*(3), 1239–1250.

Erdogan, E.M. (2022). *Investigation of problem-based learning method, enriched with the 5E learning model global warming and its effect on attitudes on climate change* (Master thesis). Kırıkkale University, Kırıkkale.

Eren, C.D. (2011). *The effect of problem based learning (PBL) on critical thinking disposition, concept learning and scientific creative thinking skill in science education* (Doctoral dissertation). Marmara University, Istanbul.

Eyceyurt Turk, G., & Kilic, Z. (2020). The effect of argumentation-supported problem based learning on the achievements of science teacher candidates regarding the subjects of gases and acids-bases. *Bartın University Journal of Faculty of Education*, *9*(2), 440–463.

Fettahlioglu, P. (2012). *The usage of argumentation-based and problem-based learning approaches intended for developing the environmental literacy of pre-service science teachers* (Doctoral dissertation). Gazi University, Ankara.

Fidan, M. (2018). *The impact of problem-based science teaching assisted with augmented reality applications on academic achievement, retention, attitude and belief of self-efficacy* (Doctoral dissertation). Bolu Abant İzzet Baysal University, Bolu.

Germi, N.T. (2020). *The effect of problem based learning 5th grade students' change of substance unit on achievements, creative thinking skills, comprehension levels of concepts and their motivations* (Doctoral dissertation). Ondokuz Mayıs University, Samsun.

Gocuk, A. (2015). *To improve the energy literacy for the 5th grades by using the approach of problem based learning* (Master thesis). Marmara University, Istanbul.

Gogus, R. (2013). *Problem based learning teaching science and its effect on students' academic achievement and attitudes* (Master thesis). Kırıkkale University, Kırıkkale.

Gokmen, S. İ. (2008). *Effects of problem based learning on students' environmental attitude through local vs. non local environmental problems* (Master thesis). Middle East Technical University, Ankara.

Gunter, T., & Alpat, S.K. (2018). Students' opinions about problem-based learning and scenario applied in teaching 'electrochemistry'. *Karaelmas Fen ve Mühendislik Dergisi*, *8*(1), 346–358.

Guzel, Z. (2018). *The effects of problem based approach practiced through self and peer assessment on students' achievements and attitudes in science teaching* (Master thesis). Necmettin Erbakan University, Konya.

Gül, Ş., & Konu, M. (2018). The effect of context- and problem-based learning activities on the students' achievements. *Education for Life*, *32*(1), 45–68.

Hiğde, E. & Aktamış, H. (2023). Students' views on problem-based blended learning during the Covid-19 pandemic process. *Trakya Journal of Education*, *13*(1), 260–279

Hun, F. (2017). *The effect of academic achievement and attitudes on the 7th grade students of problem based learning method and improved 5E learning model* (Master thesis). Giresun University, Giresun.

Hun, F., & Degirmencay, S.A. (2020). Effect of 5E teaching model supported by problem based learning on the achievement and attitude. *OPUS International Journal of Society Researches*, *16*(29), 1689–1717.

Ince Aka, E. (2012). *The effect of problem-based learning method used for teaching acids and bases on different variables and students? views on the method* (Doctoral dissertation). Gazi University, Ankara.

Inel, D. (2009). *The effects of the using of problem based learning method in science and technology course on students? the levels of constructing concepts, academic achievements and enquiry learning skill perceptions* (Master thesis). Dokuz Eylul University, Izmir.

Inel, D. (2012). *The effects of concept cartoons-assisted problem based learning on students? problem solving skills perceptions, motivation toward science learning and levels of conceptual understanding* (Doctoral dissertation). Dokuz Eylül University, Izmir.

İnaltekin, T., & Şahin, F. (2019). The effects of problem based learning on development of preservice science teachers' pedagogical content knowledge. *Ege Journal of Education*, *20*(1), 78–112.

Ince Aka, E. & Sarikaya, M. (2015). The effect of problem-based learning method on attitudes of preservice science teachers towards chemistry lesson. *GUJGEF*, *34*(3), 451–467.

Ince Aka, E., & Sarikaya, M. (2017). Developing attitude scale toward the problem based learning method. *Journal of Kırşehir Education Faculty*, *18*(2), 75–95.

Kacar, S. (2012). The *effects of problem based learning method integrated visual arts on students? academic achievements, scientific creativities and attitudes towards science teaching with art activities* (Master thesis). Dokuz Eylul university, Izmir.

Kacar, S., Ormanci, U., Ozcan, E., & Balim, A.G. (2020). Concept cartoon samples integrated into problem based learning in a science course. *Journal of Inquiry Based Activities*, *10*(2), 127–145.

Kan, S. (2013). *Evaluating project-based and problem-based instructional applications in physics instruction* (Doctoral dissertation). Karadeniz Technical University, Trabzon.

Kanar, A. (2017). *Examination of the effects of the using of problem based learning method in the teaching science and laboratory practice course on pre-service science teachers* (Master thesis). Uşak University, Uşak.

Kanar, A., & Inel Ekici, D. (2020). Problem-based science learning implementations integrated with designing activity with pre-service teachers. *Turkish Studies-Educational Sciences*, *15*(1), 549–570.

Kanli, E. (2008). *The effect of problem based learning in science & technology instruction on gifted and normal students' achievement, creative thinking and motivation levels* (Master thesis). Istanbul University, Istanbul.

Kanli, E., & Emir, S. (2013). The effect of problem based learning on gifted and normal students' achievement and creativity levels. *Necatibey Faculty of Education Electronic Journal of Science & Mathematics Education*, *7*(2), 18–45.

Karagoz, M.P. (2008). *The effect of teaching the unit of "power and motion" in primary school science course using the problem based learning approach on students science process skills, success and attitude* (Master thesis). Mugla University, Mugla.

Kartal Tasoglu, A. (2009). *The effect of problem based learning on students' achievements, scientific process skills and attitudes towards problem solving in physics education* (Master thesis). Dokuz Eylul University, Izmir.

Kartal Tasoglu, A. (2015). *Investigating the effects of the problem based learning approach on understanding the topics of magnetism* (Doctoral dissertation). Dokuz Eylül University, Izmir.

Keles, M. (2015). *The effect of problem-based learning method on student' recall level and success in the processing of science and technology course* (Master thesis). Necmettin Erbakan University, Konya.

Kilic, I., & Moralar, A. (2015). The effect of problem-based learning approach on academic success and motivation in science education. *Pegem Journal of Education and Instruction*, *5*(5), 625–636.

Kizilcik, h. S. (2012). *A case study on development of heat and temperature concepts in process of problem-based learning* (Doctoral dissertation). Gazi University, Ankara.

Kizilkaya, A. (2017). *The effect of problem based learning and jigsaw I technic in science teaching on students' academic achievement and knowledge permanence in steps of bloom taxonomy cognitive domain* (Doctoral dissertation). Atatürk University, Erzurum.

Kocakoglu, M. (2008). *The effect of problem based learning and motivational styles on students' academic success and attitudes towards biology course* (Doctoral dissertation). Gazi University, Ankara.

Konu, M. (2017). *The effect of context and problem based instruction on the students 'achievements, attitudes, motivations and problem solving skills in biology course* (Doctoral dissertation). Atatürk University, Erzurum.

Korucu, N.E. (2007). *Comparing with problem and cooperative based learning method applied in primary schools on the success of the students* (Master thesis). Selçuk University, Konya.

Kulekci, E. (1019). *Effects of concept cartoon assisted problem based Science, Technology, Engineering and Mathematics (STEM) activities on 5th grade science teaching* (Master thesis). Manisa Celal Bayar University, Manisa.

Kumas, A. (2008). *An assessment and implementation of problem based learning in cooperative learning groups in the unit of motion on the earth* (Master thesis). Karadeniz Technical University, Trabzon.

Kumbasar, T. (2019). *The effect of problem-based teaching intervention about acids and bases over the learning of students with different learning styles and multiple intelligence* (Master thesis). Marmara University, Istanbul.

Kurt, U. (2020). *Comparison of the effects of different active learning methods on the teaching of 'Cell and divisions' and 'Force and energy' units* (Doctoral dissertation). Atatürk University, Erzurum.

Kusdemir, M. (2010). *An analysis of the effect of problem based learning model on the students succes, attitude and motivations* (Master thesis). Mustafa Kemal University, Hatay.

Kusdemir, M., Ay, Y., & Tuysuz, C. (2013). An analysis of the effect of problem based learning model on the 10 th grade students' achievement, attitude and motivation in the unit of "mixtures". *Necatibey Faculty of Education Electronic Journal of Science & Mathematics Education*, *7*(2), 195–224.

Kuvac, M. (2014). *The effects of problem based learning on preservice Science Teachers' environmental consciousness and metacognitive awareness* (Master thesis). Istanbul University, Istanbul.

Kucuk Avci, S. (2017). *The effect of problem based learning in 3 dimensional virtual learning environments on conceptual understanding and learning performance based on problem solving* (Doctoral dissertation). Sakarya University, Sakarya.

Moralar, A. (2012). *The effect of problem-based learning approach on academic success, attitude and motivation in science education* (Master thesis). Trakya University, Edirne.

Nerse, B.N. (2021). *Study of the effect of the problem-based learning approach enriched wıth web 2.0 tools on the academic achievement, metacognitive awareness, self-directed learning with technology and digital literacy of students during online education process* (Master thesis). Kocaeli University, Kocaeli.

Olca, M. (2015). *The effects of problem based learning method on students' analytical thinking skills, conceptual understandings and attitudes toward science* (Master thesis). Dokuz Eylul University, Izmir.

Ozcan, E. (2013). *Effects of problem based learning on prospective science teachers' problem solving skills, academic achievements and attitudes* (Master thesis). Dokuz Eylul University, Izmir.

Ozcelik, C. (2021). *The impact of problem-based STEM applications on students' attitudes towards STEM, self-regulation skills and metacognitive abilities* (Doctoral dissertation). Bartın University, Bartın.

Ozdeniz, Y. (2021). *The effect of application of science module designed according to integrated curriculum model in blended learning environment on scientific reasoning and scientific process skills of gifted students* (Master thesis). Aydın Adnan Menderes University, Aydın.

Ozeken, O.F. (2011). *An investigation of effectiveness of problem based learning in teaching acid-base subject* (Doctoral dissertation). Atatürk University, Erzurum.

Ozkan, E. (2021). *Evaluation of the effectiveness of the problem based teaching model on the students' achievements and attitudes in high school chemistry courses* (Master thesis). Atatürk University, Erzurum.

Ozturk, Z.D. (2019). *The effect of problem based learning method on students' academic achievements and scientific process skills in a science course* (Master thesis). Pamukkale University, Denizli.

Ozturk, Z.D., & Ozel, M. (2021). The effect of problem based learning on students' scientific process skills. *The Journal of Buca Faculty of Education*, *51*, 1–31.

Saglam, O. (2022). *The effect of the argumentation-supported problem-based learning method on the teaching of the topic of 8th grade "simple machines"* (Master thesis). Sivas Cumhuriyet University, Sivas.

Sagir Ulucinar, Ş., Celik Yalcin, A., & Armagan Oner, F. (2009). The effect of problem based learning strategy in metalic activity subject teaching. *Hacettepe University Journal of Education*, *36*, 283–293.

Sahbaz, O. (2010). *The effects of different methods on students' science process skills, problem solving skills, academic achievements and retentions in primary school fifth grade science and technology lessons* (Doctoral dissertation). Dokuz Eylül University, Izmir.

Sahin, A. (2011). *To Analyze the effect of problem based learning (PBL) approach on academic success of students in teaching basic electrical circuits in general physics laboratory course* (Master thesis). Atatürk University, Erzurum.

Salgam, E. (2009). *The effect of problem based learning method on students' academic achievement and their attitude on physics education* (Master thesis). Dokuz Eylul University, Izmir.

Sarikaya, S.(2006). *Interactive teaching methods in environmental education* (Master's Thesis). Celal Bayar University, Manisa.

Sencan, D. (2013). *The effects of real-world problems on the 7th grade students' scientific process abilities, academic achievement and scientific literacy: Force and motion* (Master thesis). Marmara University, Istanbul.

Serin, G. (2009). *The effect of problem based learning instruction on 7th grade students' science achievement, attitude toward science and scientific process skills* (Doctoral dissertation). Middle East Technical University, Ankara.

Sifoglu, N. (2007). *The effects of constructivism and problem-based learning on students' success in the teaching the topic heritage" at the 8th grade* (Master thesis). Gazi University, Ankara.

Soyleyici, H. (2018). *Investigating the effect of problem-based learning on the scientific process skills, scientific attitudes, achievements and conceptual knowledge of middle school students': Unit light* (Master thesis). Trakya University, Edirne.

Senocak, E., & Taskeseligil, Y. (2005). Problem-Based Learning and its Applicability in Science Education. *Kastamonu Education Journal*, *13*(2), 359-366.

Tasoglu, A.K., & Bakac, M. (2023). The effect of problem based learning approach on students' academic achievement and critical thinking skills. *The Journal of National Education*, *52*(238), 855–884.

Tatar, E., Oktay, M., & Tuysuz, C. (2009). Advantages and disadvantages of problem based learning in chemistry education: A case study. *Journal of Education Faculty*, *11*(1), 95–110.

Tavukcu, K. (2006). *The effects on the learning outcomes of problem based learning in science instruction* (Master thesis). Zonguldak Karaelmas, Zonguldak.

Tekin, A.D. (2019). *Academic success of 7th grade students of problem based learning approach impact on process skills and motivations* (Master thesis). Marmara University, Istanbul.

Tosun, C. (2010). *The effect of problem based learning method on understanding of the solutions and its? physical properties* (Doctoral dissertation). Atatürk University, Erzurum.

Tosun, C., & Taskesenligil, Y. (2012). The effect of problem based learning on student motivation towards chemistry classes and on learning strategies. *Journal of Turkish Science Education*, *9*(1), 36–50.

Tosun, C., Senocak, E., & Ozeken, O.F. (2013). The effect of problem-based learning on undergraduate students' learning about solutions and their physical properties and scientific processing skills. *Chemistry Education Research and Practice*, *14*(1), 36–50.

Tunc, T. (2015). *The effect of problem based learning on students' academic achievements in the subject of Electrochemistry in Analytical Chemistry course* (Doctoral dissertation). Dokuz Eylül University, Izmir.

Tuysuz, C., & Demirel, O.E. (2020). *Examining the Effects of Problem Based and Argumentation Based Learning Methods on the "Mixtures" Unit. MSKU Journal of Education*, *7*(1), 43–61.

Ulukok, S. (2012). *The effect of computer assisted problem based learning method on the higher level thinking skills of prospective teachers* (Master thesis). Kırıkkale University, Kırıkkale.

Unal, S.Y. (2019). *The effect of problem based learning approach on teaching the subject 'the reproduction, growth and development of plant and animal'* (Master thesis). Uşak University, Uşak.

Vekli, G.S., & Cimer, A. (2017). Effect of problem-based computer-aided material (pbcam) on development of students' perceived problem solving skills. *Bayburt Faculty of Education Journal*, *12*(24), 809–830.

Yalcinyigit, C. (2016). *Research about critical thinking in problem based learning on biology* (Doctoral dissertation). Gazi University, Ankara.

Yaman, S. (2003). *The effects on the learning outputs of problem based learning in science education* (Doctoral dissertation). Gazi University, Ankara.

Yaman, S., & Yalcin, N. (2005). Effectiveness of problem-based learning approach on development of problem solving and self-efficacy beliefs levels in science education. *Hacettepe University Journal of Education*, *29*(2005), 229–236.

Yaman, S., & Yalcin, N. (2005). Investigating of the effects on academic achievement and creativity thinking skills of prospective teachers' of problem based learning. *Bolu Abant Izzet Baysal University Journal of Faculty of Education*, *5*(2), 108–121.

Yildirim, C. (2017). *The effects of argumentation supported problem based learning on students' inquiry learning skills and problem solving skills and levels of conceptual understanding* (Doctoral dissertation). Pamukkale University, Denizli.

Yildirim, C., & Can, B. (2018). The effects of argumentation supported problem based learning on students' inquiry learning skill perceptions. *PAU Journal of Education*, *44*(44), 251–277.

Yildirim, H. (2011). *The effect of problem based and project based learning styles on primary school students? successes and attitude* (Master thesis). Selcuk University, Konya.

Yildiz, E., Simsek, U., & Yuksel, F. (2017). The effect of jigsaw-integrated problem based learning method on students' motivation towards science learning, social skills and attitude towards school. *Kastamonu Education Journal*, *25*(5), 1957–1978.

Yildiz, N. (2010). *The effect of experiment applications on the success, attitude and scientific process abilities of the students in the solution of the learning scenarıos based on problems in science education* (Master thesis). Marmara University, Istanbul.

Yildiz, S. (2019). *The investigation of the effect of problem based teaching approach on students' problem solving skills and academic achievements in science course* (Master thesis). Sakarya University, Sakarya.

Yildiz, T. (2017). *Investigation of the effectiveness of problem based teaching method in teaching the particulate structure of matter unit in primary science course* (Master thesis). Ağrı İbrahim Çeçen University, Ağrı.

Yilmaz, E. (2015). *The effect of teaching methods supported with online advance organizer concept teaching material to achievement, attitude and retention in force-motion unit* (Master thesis). Mehmet Akif Ersoy University, Burdur.

Yilmaz, T. (2016). *Problem based learning method's effect on teaching science education courses for secondary school 5. grade students' academic achievements and attitudes towards science education classes: Light and sound* (Master thesis). Bozok University, Yozgat.

Yilmazel, A. (2020). *The effect of the problem-based learning method in eliminating the misconception of heat and temperature of secondary school students* (Master thesis). Mersin University, Mersin.

Yurd, M. (2007). *The effect of know-want-sample-learn strategy, which is developed by using problem based learning and know-want-learn strategy, towards the 5th grade students' attitudes in science and technology lesson and towards to remove their misconceptions* (Master thesis). Mustafa Kemal University, Hatay.

Yurd, M., & Olgun, O.S. (2008). Effect of problem based learning and know-want-learn strategy to remove misconceptions. *Hacettepe University Journal of Education*, *35*, 386–396.

References

1. Allen, D.E.; Donham, R.S.; Bernhardt, S.A. Problem-based learning. *New Dir. Teach. Learn.* **2011**, *128*, 21–29. [CrossRef]
2. Savery, J.R.; Duffy, T.M. Problem-based learning: An instructional model and its constructivist framework. *Educ. Technol.* **1995**, *36*, 31–38.
3. Loyens, S.; Kirschner, P.A.; Paas, F. Problem-based learning. In *APA Educational Psychology Handbook*; Harris, K.R., Graham, S., Urdan, T., Bus, A.G., Major, S., Swanson, H.L., Eds.; American Psychological Association: Washington, DC, USA, 2012; Volume 3, pp. 405–423.
4. Savin-Baden, M.; Major, C.H. Foundations of Problem-Based Learning, 2004, MPG Books: Great Britain. New York. Available online: https://books.google.com.tr/books?hl=tr&lr=&id=EqhEBgAAQBAJ&oi=fnd&pg=PP1&dq=related:lggVOXhoBLEJ:scholar.google.com/&ots=kKbdV2Y6DI&sig=hq0XCFEUP5tc2FSBiPVsVc9MyTU&redir_esc=y#v=onepage&q&f=false (accessed on 18 August 2023).
5. Savery, J.R. Overview of problem-based Learning: Definitions and distinctions. *Interdiscip. J. Probl. Based Learn.* **2006**, *1*, 1–13. [CrossRef]
6. Mutlu, A.; Aydoğmuş, M. Problem-based learning studies: A content analysis. *Turk. Stud. Educ. Sci.* **2019**, *14*, 1615–1630.
7. Lenkauskaite, J.; Bubnys, R.; Masiliauskiene, E.; Malinauskiene, D. Participation in the assessment processes in problem-based learning: Experiences of the students of social sciences in Lithuania. *Educ. Sci.* **2021**, *11*, 678. [CrossRef]
8. Pozuelo-Muñoz, J.; Calvo-Zueco, E.; Sánchez-Sánchez, E.; Cascarosa-Salillas, E. Science skills development through problem-based learning in secondary education. *Educ. Sci.* **2023**, *13*, 1096. [CrossRef]
9. Himes, M.P.; Spires, H.A.; Krupa, E.E.; Borden, M.L.; Eagle, J.L. Project-Based Inquiry (PBI) global during a pandemic: A new learning ecology perspective. *Educ. Sci.* **2023**, *13*, 1099. [CrossRef]
10. Hmelo-Silver, C.E. Problem-based learning: What and how do students learn? *Educ. Psychol. Rev.* **2004**, *16*, 235–266. [CrossRef]
11. Hmelo-Silver, C.E.; Eberbach, C. Learning theories and problem-based learning. In *Researching Problem-Based Learning in Clinical Education: The Next Generation*; Bridges, S., McGrath, C., Whitehill, T., Eds.; Springer: New York, NY, USA, 2012; pp. 3–17.
12. Marra, R.; Jonassen, D.H.; Palmer, B.; Luft, S. Why problem-based learning works: Theoretical foundations. *J. Excell. Coll. Teach.* **2014**, *25*, 221–238.
13. Piaget, J. *To Understand Is to Invent: The Future of Education*; Grossman Publishers: New York, NY, USA, 1973.
14. Kemp, S. Constructivism and Problem-Based Learning. 2011. Available online: https://docplayer.net/38306946-Constructivism-and-problem-based-learning.html (accessed on 9 August 2023).
15. Leite, L.; Dourado, L.; Morgado, S. Sustainability on Earth Web Quests: Do they qualify as problem-based learning activities? *Res. Sci. Educ.* **2015**, *45*, 149–170. [CrossRef]
16. Sweller, J. Cognitive load during problem solving: Effects on learning. *Cogn. Sci.* **1988**, *12*, 257–285. [CrossRef]
17. Schmidt, H.G.; Rotgans, J.I.; Yew, E.H.J. The process of problem-based learning: What works and why. *Med. Educ.* **2011**, *45*, 792–806. [CrossRef] [PubMed]
18. Henderson, R. *Problem-Based Learning Perspectives, Methods and Challenges*; Nova Science Publishers Inc.: New York, NY, USA, 2016.
19. Oliver, R.; Herrington, J. Using situated learning as a design strategy for web-based learning. In *Instructional and Cognitive Impacts of Web-Based Education*; Abbey, B., Ed.; Idea Group Publishing: Hershey, PA, USA, 2000; pp. 178–191.
20. Lave, J.; Wenger, E. *Situated Learning: Legitimate Peripheral Participation*; Cambridge University Press: New York, NY, USA, 1991.
21. Kılınç, A. Problem based learning. *Kastamonu Educ. J.* **2007**, *15*, 561–578.
22. Alper, A.; Öztürk, S.; Akyol Altun, C. Problem based learning studies in Turkey. *Ank. Univ. J. Fac. Educ. Sci.* **2014**, *47*, 397–422.
23. Koçakoğlu, M. Problem based learning: The Epitome of constructivism. *Milli Eğitim Derg.* **2010**, *40*, 68–82.
24. Temel, S.; Şen, Ş.; Yilmaz, A. A content analysis related to the problem-based learning studies: The case of Turkey. *Kastamonu Educ. J.* **2015**, *23*, 565–580.
25. Tosun, C.; Yaşar, M.D. Descriptive content analysis of problem-based learning researches in science education in Turkey. *Kastamonu Educ. J.* **2015**, *23*, 293–310.

26. Ersoy, E.; Başer, N. The effects of problem-based learning method in higher education on creative thinking. *Procedia Soc. Behav. Sci.* **2014**, *116*, 3494–3498. [CrossRef]
27. Ministry of National Education (MoNE). Fen Bilimleri Dersi Öğretim Programı [Science Curriculum]. 2018. Available online: https://mufredat.meb.gov.tr/Dosyalar/201812312311937-FEN%20B%C4%B0L%C4%B0MLER%C4%B0%20%C3%96%C4%9ERET%C4%B0M%20PROGRAMI2018.pdf (accessed on 21 June 2023).
28. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLoS Med.* **2021**, *18*, e1003583.
29. Dincer, S. Content analysis in for educational science research: Meta-Analysis, Meta-Synthesis, and Descriptive Content Analysis. *Bartın Univ. J. Educ.* **2018**, *7*, 176–190.
30. Çalık, M.; Sözbilir, M. İçerik analizinin parametreleri Parameters of content analysis. *Eğitim Bilim Educ. Sci.* **2014**, *39*, 33–38.
31. Akgöz, S.; Ercan, İ.; Kan, İ. Meta-analizi. *Uludağ Üniversitesi Tıp Fakültesi Derg.* **2004**, *30*, 107–112.
32. Polat, S.; Ay, O. Meta-synthesis: A Conceptual Analysis. *J. Qual. Res. Educ.* **2016**, *4*, 52–64. [CrossRef]
33. Batdi, V. A meta-analysis study comparing problem based learning with traditional instruction. *Electron. J. Soc. Sci.* **2014**, *13*, 346–364. [CrossRef]
34. Batı, K.A.A.N. Investigation of the effect of online problem-based learning on achievement, attitude, motivation, and group dynamics: A systematic literature review. *Hacet. Univ. J. Fac. Educ.* **2022**, *38*, 314–343. [CrossRef]
35. Ayaz, M.F. The effect of the problem-based learning approach on the academic achievements of the students in science lesson: A study of meta-analysis. *Turk. Stud.* **2015**, *10*, 139–160.
36. Ozgul, B. Effectiveness of the Problem-Based Learning Approach: A Meta-Analysis Study. Master's Thesis, Mehmet Akif Ersoy University, Burdur, Turkey, 2021.
37. Dagyar, M. The Effects of Problem Based Learning on Academic Achievement: A Meta-Analysis Study. Ph.D. Thesis, Hacettepe University, Ankara, Turkey, 2014.

education sciences

Review

Using Cooperative Learning to Enhance Students' Learning and Engagement during Inquiry-Based Science

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Abstract: Much attention over the last two decades has been given to inquiry-based learning in science as a way of capturing students' interest and participation in learning. However, while the research on inquiry-based learning consistently demonstrates that students do attain higher learning outcomes than peers who are taught by traditional transmission approaches, little research has been attached to researching the key elements of this approach that contribute to its success. This review focuses on the role of inquiry-based learning where students work in cooperative groups to investigate topics that challenge their curiosity, encouraging them to ask questions to clarify their understandings, evaluate evidence that may help to explain phenomena, and predict potential solutions to the problems at hand. The key role teachers play in inducting students into ways of thinking and reasoning and providing opportunities for them to work with others in the context of inquiry-based learning will also be discussed.

Keywords: inquiry-based science; cooperative learning; dialogic teaching and learning

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1. Introduction

Over the past two decades there has been a concerted effort to teach science using an inquiry-based approach as a way of galvanizing students' curiosity and motivation to actively participate in learning science. Learning through inquiry encourages students to actively participate in learning science so they ask questions about the topics that challenge their thinking, test out potential solutions to problems, and consider alternative possibilities as they learn to reconcile their developing understandings with previous knowledge and experience [1]. "Inquiry refers to a variety of processes and ways of thinking that support the development of new knowledge in science" ([2], p. 19). Inquiry teaching requires teachers to not only teach the content but also help students to understand the approaches and processes scientists use as they conduct their investigations.

Understanding how science works is critically important to understanding the processes involved in scientific inquiry. Science is a set of processes that are interconnected, and students, like scientists, learn to ask questions about the world in which they live as they investigate different phenomena [3]. In essence, students learn science by actively engaging in the practices of science. These practices involve learning to ask and answer questions and compare answers with what is currently known, collect and analyse data, formulate and test their suppositions, and work collaboratively with others to resolve issues with the intention of sharing the results of their investigations [4]. Being able to collaborate with others often involves students working together on problem-based learning activities involving real-world contexts that are topical and of interest to students; for example, issues on climate change where the goal is to solve a challenging problem. In this sense, students have opportunities to collaborate with others on topics that are of socio-scientific interest and likely to generate student discussion, motivation, and learning [1].

However, many teachers appear to experience difficulties embedding inquiry-based science approaches into their science curricula, possibly because enacting inquiry requires teachers to situate learning in authentic problems that often require them to guide and scaffold students' investigations in the context of classrooms where they are expected to not only teach the content but also simultaneously manage a variety of roles. In fact, Duschl and Duncan [5] reported that it takes approximately 20 days of professional learning across a period of two to three years for elementary teachers to feel skilled and competent in teaching using an inquiry-based approach. This, Crawford [3] maintains, is why this type of teaching is often not evident.

This paper provides a review of the role of inquiry-based learning in science where students work in cooperative groups to investigate topics that challenge their curiosity, encouraging them to ask questions to clarify their understandings, and evaluate possible solutions to the problems they are confronting. Implementing inquiry-based science instruction involves extensive changes in classroom management practices with learning situated in authentic problems that often require teachers to guide and scaffold students' investigations. In this respect, teachers have a key role in inducting students into different ways of thinking and reasoning and providing opportunities for them to discuss their ideas with others. This type of teaching is referred to as dialogic teaching, where students learn to engage in talk to promote thinking by exchanging ideas, negotiating meaning, and reconciling their understandings with previous knowledge and experience. Finally, this paper discusses these developments in the context of current research.

2. Inquiry-Based Teaching in Science

Given the importance attached to teaching science using an inquiry-based approach, this section reviews current meta-analyses that report on the effects of inquiry-based teaching on students' academic outcomes in primary and secondary schools. It also reviews the research on teachers actively guiding or structuring the learning tasks in contrast to more open-inquiry situations where guidance is less evident or traditional transmission approaches to teaching science.

Implementing and managing inquiry-based science instruction involves extensive changes in classroom management practices [6]. The National Research Council [1], in a report on teaching and learning science in K–8 classrooms, emphasise that if students are to become proficient in science, they need to be able to: "know, use, and interpret scientific explanations; generate and evaluate scientific evidence and explanations; understand the nature and development of scientific evidence, and participate productively in scientific practices and discourse" ([1], p. 36).

These proficiencies, the NRC [1] argues, are interrelated and connected and represent ways of thinking about scientific ideas where conceptual understandings of natural systems are linked to the ability to develop explanations of different phenomena and conduct empirical investigations to evaluate knowledge claims. However, if students are to engage productively in science, they need to understand how to participate in scientific discussions where they are able to listen to others, share their thinking, and be willing to ask questions to clarify their understandings or challenge others' perspectives. Such ways of thinking, though, only develop when teachers actively induct students into these ways of thinking and reasoning and provide opportunities for them to interact with others in the context of inquiry-based learning.

Furtak, Seidel, Iverson, and Briggs [7], in a meta-analysis of 37 empirical studies of inquiry-based science published between 1996 and 2006, reported that inquiry-based teaching contributed to improved student achievements with an overall mean effect size of 0.50. Furthermore, this result was greater than previous meta-analyses reviewed by the authors (see p. 303). Furtak, Seidel, Iverson, and Briggs [7] also found that studies that contrasted epistemic (E) activities (e.g., nature of science, conclusions based on evidence, or generating and revising new theoretical perspectives) and the combination of procedural, epistemic, and social (PES) activities had the highest mean effect sizes, with mean effect sizes of 0.75 (epistemic) and 0.72 (PES). Moreover, studies that involved activities that were led by teachers had mean effect sizes that were about 0.40 larger than those which were led by students, indicating that students achieved higher learning outcomes when teachers actively guided the learning tasks.

Firman, Ertikanto, and Abdurrahman [8] conducted a meta-analysis across 15 articles that reported on the use of inquiry-based learning in science education in primary and secondary schools. The results showed that 10 of the studies recorded median to large effect sizes with the overall effect size being 0.45 (median effect). Of the five studies with low effect sizes, none of them recorded negative effect sizes. The authors argued that the results demonstrate that inquiry-based learning had a positive impact on students' learning in science in comparison to students who learn via traditional teacher-centred approaches. Interestingly, the effect sizes were higher when students were involved in structured-inquiry or guided-inquiry where the teacher actively guided the activities in contrast to more open-inquiry situations where guidance was less evident.

Similar results were reported by Heindl [9], who investigated the efficacy of inquiry-based learning to improve students' academic performance in comparison to students who learn by traditional teaching approaches. Thirteen studies met the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria for inclusion in this meta-analysis. Eight studies were conducted in secondary schools with an effect size of 0.81, and five were conducted in primary schools with an effect size of 0.67. The results showed that inquiry-based learning is an effective teaching approach that can be used in primary and secondary schools leading to higher academic outcomes for students learning science. Moreover, Heindl [9] argued that inquiry-based learning is more effective when teachers and students are well prepared for inquiry-learning through practice-coaching or training.

In summary, meta-analyses by Furtak, Seidel, Iverson, and Briggs [7], Firman, Ertikanto, and Abdurrahman [8], and Heindl [9] demonstrate that inquiry-based learning in science has a positive impact on students' academic learning in science in comparison to peers who learn via traditional transmission approaches. Furthermore, inquiry-learning is more likely to have a greater impact when teachers actively guide the inquiry process.

3. Promoting Scientific Thinking and Reasoning

It is critically important that teachers induct students into different ways of thinking and reasoning by explicitly teaching and modelling how to express ideas, ask for assistance, challenge alternative perspectives, and reason logically. It is well known that learning occurs when students have opportunities to discuss ideas with others, and emphasis in recent years has been on encouraging teachers to engage students in class discussions where they are able to interact with their teachers and peers on problem-based topics that challenge their curiosity and understandings [10]. This type of teaching is known as dialogic teaching, and it is designed to encourage students to be more active in their learning by expressing their thoughts and understandings and asking questions to clarify topics they do not understand. Interactions between teachers and students not only enable students to demonstrate what they know but they also enable teachers to gain an understanding of any misconceptions that students may hold. This allows teachers to adjust their teaching so any misunderstandings can be discussed and clarified.

Alexander [10] maintained that dialogic teaching is predicated on teachers and students addressing learning tasks together; listening to each other, sharing ideas, and considering alternative perspectives; encouraging students to share their ideas without feeling self-conscious or embarrassed; and building on each other's ideas in order to develop rational and logical solutions. During this process, the teacher needs to guide classroom discussions with the purpose of achieving specific educational goals.

When this occurs, Alexander [10] maintained, a number of changes occur in how talk is enacted in the classroom, with more talk occurring among students and between students and teachers. Student and teacher exchanges tend to be longer, with teachers building on student responses to prompt and facilitate students' thinking. Students, in turn, begin to build on each other's ideas as they seek to extend others' ideas or clarify misunderstandings. Their responses become more diverse as they learn to provide more explanations, justifications, and suppositions on topics they are discussing. In short, students are initiating more talk as they speculate, think aloud, and help each other as they realise that they can be active in their own learning. There is also more participation by children who are less academically able, as the chance to talk provides them with the opportunity to express their opinions and demonstrate competence. This, in turn, Alexander notes, leads to "the interactive culture in these classrooms is becoming more inclusive" ([10], p. 108).

In a comprehensive account of the Dialogic Teaching Project, Alexander [11] discusses the development and randomised control trial that was funded by the UK Education Endowment Fund (EEF) between 2014 and 2017. The purpose of the intervention was to invigorate classroom talk to promote student engagement, learning, and attainment in the context of social and educational disadvantage. The intervention's professional development for teachers included a full day's induction program where they were introduced to dialogic teaching and the professional development program that would be implemented across the following 20 school weeks. This included mentoring from experienced teachers in the schools, guided planning and target setting with the mentees, reflections by teachers on lesson video recordings of classroom talk, reading materials, and mentoring from the Dialogic Project Team. Data were collected from 76 schools across three United Kingdom cities that met the criteria of having at least 25% of their students eligible for free school midday meals (a marker for social disadvantage).

Alexander [11] reported that the children in the Dialogic Teaching Schools gained two additional months' progress in English and Science and one additional month's progress in mathematics in comparison to children in the non-intervention schools. Furthermore, the children who were eligible for a free school lunch (marker of disadvantage) made a further two months' progress on standardised assessments in English, Science, and Mathematics compared to their peers in the non-intervention schools. Interestingly, independent analysis of the video-recorded lesson episodes showed that classroom talk in the intervention classrooms began to become more dialogic early in the intervention, with marked differences between the intervention and the non-intervention classrooms. Differences in talk were evident in both teacher and student talk by week 19, with talk becoming more dialogic as teachers and students spent more time listening to each other and incorporating each other's ideas into their discussions. Additionally, the principals, mentors, and teachers reported that the Dialogic Teaching approach had a positive effect on students' self-confidence and participation in learning.

While meaningful gains were recorded in the children's progress in the intervention schools in comparison to their peers in the non-intervention schools, feedback from the teachers in the intervention schools felt it would take longer than 20 weeks to fully embed the Dialogic Teaching approach in their curricula and suggested that the study should be scaled up to a longer period of time to see the full effects. The outcomes achieved by the Dialogic Teaching Project led Alexander [12] to acclaim that "evidence shows that well-founded classroom dialogue improves student engagement and learning" ([12], p. 1).

The results obtained from the Dialogic Teaching Project [11] led to Alexander [13] developing a framework on eight dialogic teaching repertoires designed to help teachers to engage with the different forms of classroom talk between and among teachers and students including the key areas of: questioning, extending talk to open up students' thinking, discussing, deliberating and arguing, and finally, argumentation, where students learn to advance reasons and evidence and challenge and refute claims to solve a problem or address an identified question. (NB: Repertoires 1 and 2, involving Interactive Culture [how talk should be managed] and Interactive Settings [ways students are grouped], will be discussed in the section on Cooperative Learning).

Dialogic teaching, Alexander [13] argues, is a talk pedagogy that utilises the influence of talk to excite and extend students' thinking and learning to enable them to discuss, reason, and argue as they participate in discussions with their teachers and other students.

This includes engaging in talk to promote thinking where students learn to talk and exchange ideas with others, which promotes a better understanding of different issues under discussion. It also includes recognising that talk is very much a social process, and in classrooms, talk engages students' attention and motivations as they interact to communicate in everyday transactions where they exchange and negotiate meaning.

When teachers engage in dialogic teaching with their students, Alexander [13] notes, there is more talk about how the participants will interact with each other as well as the procedures they will follow. Teachers, in turn, often ask more open questions that encourage students to participate in the discussion, enabling students to feel more welcome and able to contribute in ways that are more mutually beneficial to the discussants. Boyd and Markarian [14] also noted that dialogic teaching is apparent when teachers engage in conversations with students where they actively listen to what students have to say, encourage them to share their thinking, or they ask questions to clarify issues. In dialogic classrooms, students are encouraged to consider alternative propositions, make their thinking explicit, and support each other so both students and teachers build on each other's ideas as they develop "coherent lines of thinking and enquiry" ([15], p. 8). The following section on Dialogic Teaching in Classrooms discusses the way dialogic teaching is enacted in classrooms by teachers and students and the evidence that supports this approach to teaching and learning.

4. Dialogic Teaching in Classrooms

Teaching and learning in the dialogic classroom, Reznitskaya [16] argues, is characterized by authority over the content and form of discourse shared among participating group members, where students accept responsibilities for turn taking, asking questions, reflecting on each other's answers, and suggesting new topics. Teachers challenge students' answers, ask for justifications, and provide meaningful feedback to help students negotiate and construct new meanings. These types of dialogic discussions promote meta-level reflections that challenge students to seek clarification and connect ideas across contexts. In so doing, they learn to elaborate on their thinking as they collaborate with others to construct new understandings and mutually agreed-upon knowledge.

Garcia-Carrion, Aguileta, Padros, and Ramis-Salas [17], in a review of the social impact of dialogic teaching and learning, noted that there is a large volume of evidence from small- and large-scale studies that dialogic teaching contributes to academic achievement and social cohesion, resulting in classrooms that are more inclusive as students are invited to take an active and meaningful role in discussions. In effect, it transforms classroom relationships as students realise their contributions are valued as they cooperate to reach a common agreement, enabling them to complete tasks.

Others who have investigated the role of different types of talk in classrooms are Scott and Mortimer [18], who developed a framework for analysing the different ways discussions are undertaken in science classrooms in secondary schools and the functions they serve. One type of interaction that they highlighted is the interactive and dialogic approach. This involves the teacher listening to students' ideas, probing their thinking on a particular topic, and working together to explore different ideas and suggestions. This type of interaction tends to be characterized by high levels of interaction as teachers and students participate in animated discussions with each other.

A second form of interaction is the interactive and authoritative approach, where the teacher focuses mainly on one specific point of view and leads students through a series of questions with the aim of helping them to gain a clearer understanding of the topic. In this type of interaction, the teacher is active in guiding the discussion with the students to help them develop an understanding of the specific goals of the lesson [19]. Scott, Mortimer, and Aguiar [20] argued that changes between these styles of interaction are an unavoidable part of teaching science as the interactive and authoritative approach is often used to introduce new information and ideas while the dialogic and interactive approach provides opportunities to investigate the information presented in more detail.

There is no doubt that successful inquiry-based learning experiences are predicated on teachers creating learning environments where students are not only amazed and challenged by the experiences they have, but also are able to interact with their teacher and peers to ask questions, seek clarification, offer explanations, justify their positions, and build on the ideas of others: in short, dialogue with others [21]. This type of interaction, Lehesvouri, Ramnarain, and Viiri [22] argue, improves students' willingness to engage in dialogic exchanges during inquiry-based learning activities. Moreover, it is through teacher interactions that students learn how to engage in appropriate ways of interacting in different classroom settings [23].

Rojas-Drummond, Littleton, and Velez [24] report on a study that investigated dialogic literacy, essentially the interplay between talking, reading, and writing, among 120 Grade 6 students in two primary schools as they collaborated in small groups on a literacy task involving reading and writing. The study utilized an intervention program called Learning Together which uses collaborative learning to enhance the development of children's oracy and literacy skills. One school implemented the intervention program (experimental condition), while the other continued with its regular literacy program (control condition).

Collaborative learning is critically important for helping students to understand the guidelines that they need to follow if they are to explore topics together. The ground rules that were proposed to help students to understand how they were to collaborate as they worked together were adopted from Mercer, Wegerif, and Dawes [25] and included:

(a) All relevant information needs to be shared.
(b) Group members need to reach agreement on all topics under discussion.
(c) Members need to accept responsibility for group decisions.
(d) Members need to provide reasons for positions adopted.
(e) Members need to accept challenges from others both within and outside the group.
(f) Alternative propositions need to be considered before the group makes a decision.
(g) All group members are encouraged to participate in the discussion.

Concurrently to establishing the guidelines for collaborate discussions, Rojas-Drummond, Littleton, and Velez [24] reported that the teachers played a key role in encouraging students to share their thoughts, outline their reasons for adopting a particular position, and explicitly state what they know about a topic and share this information with the class. They also modelled ways of using language that children could adopt for themselves, in peer group discussions and other settings, and they provided opportunities for students to make extended contributions to the discussion, enabling them to express their current understandings or communicate their difficulties [26].

The Learning Together program involved 18 sessions of 90 min each across a seven-month period in which the students in the experimental condition worked together on a variety of oral and written communication tasks [24]. Data on the written summaries produced by the students in both conditions were analysed using the Test of Textual Integration (TTI). The results indicated that the students in the experimental condition scored significantly higher on the quality of the text they produced and on each of the partial scores: title (comprehensive, informative, and concise), main ideas (six main ideas), organization of ideas (coherence of ideas), and level of expression (sophisticated expression).

Follow-up micro-analysis of the discussions and co-regulatory processes of four student triads (two experimental and two control triads) in the Rojas-Drummond, Littleton, and Velez [24] study while solving the group version of the Test of Textual Production (TTP) is reported in Rojas-Drummond, Omedo, Cruz, and Espinosa [27]. The purpose was to identify how the interactive, communicative, and co-regulatory processes emerged in each group, as well as how these processes might give way to the utilization of these processes in the written composition in the Learning Together groups (experimental groups). The results showed that the experimental student triads (in comparison to their control peers) gradually learned to adopt a more collaborative, dialogic, and strategic way of working together. The results highlighted the key role dialogic discussions and co-regulatory processes play in facilitating the development of written text in primary students.

Given that the knowledge-building practices of scientists are essentially social and collaborative, cooperative small group learning provides opportunities for students to investigate different observable trends, discuss potential solutions and research questions, identify the data to be collected and analysed, and communicate their understandings to others in ways that are seen as logical and well-thought through. However, many teachers experience difficulties in establishing cooperative learning experiences where students have opportunities to share, critique, and evaluate possible explanations for the phenomena under investigation. The following section will discuss some of the perceived difficulties teachers face.

5. Cooperative Learning: Creating an Interactive Culture and Setting

Inquiry-based science requires students to cooperate to investigate problems, ask questions, challenge each other's conceptions or misconceptions, and negotiate acceptable solutions to the problem at hand. When students cooperate, they learn to listen to what others have to say and reflect on their points of view, share their thinking on issues, challenge and rebut misconceptions, and engage in the practices of building new understandings and knowledge that promote learning. However, creating cooperative groups where students are able to discuss tasks in a meaningful way can be quite challenging unless students have a clear understanding of how they are expected to cooperate and what they are expected to achieve [28].

Productive classroom talk, Alexander [12] argues, requires developing a shared understanding of the way talk should be managed, often requiring that some explicit ground rules are established. These rules may eventually become part of the classroom routine, so students understand that these are the accepted norms for communicating, as occurs when an interactive culture is promoted. Alexander also maintained that talk is affected by the way students are grouped. Interaction is facilitated when students work in small groups (often three to four students) where they can see and hear each other as they work on a designated task.

In a review of five studies where teachers explicitly structured cooperative small group learning, Gillies [29] reported that students demonstrated higher levels of cooperation, group interaction, and learning than peers who learnt in unstructured small groups. Furthermore, "the benefits of cooperative learning are enhanced when groups do not exceed four members, are gender-balanced and of mixed-ability, instruction is designed to meet the groups' needs, and teachers have been trained in how to implement this pedagogical strategy" ([29], p. 47). These results were consistent across both primary and high school settings.

While cooperative learning is well established as a pedagogical approach that can be implemented in science classrooms to promote students' engagement and learning [30], establishing the conditions for it to be employed effectively can be a challenge both for the teachers and the students involved. Teachers are often reluctant to embrace cooperative learning possibly because of the challenge it poses to their control of the instructional process, where teaching tends to be more teacher-centred rather than learner-centred. Furthermore, the changes that teachers need to make to accommodate this organisational change to how they teach and the personal commitment they need to make to sustain their efforts are often regarded as further impositions on their role as teachers. It may also be due to a lack understanding of how to embed cooperative learning pedagogy into their classroom curricula to foster open communication and engagement between teachers and students to create learning environments where students feel supported and emotionally safe and secure.

6. Conditions Needed for Successful Cooperative Learning

Placing students in groups and expecting them to work together does not ensure that they will cooperate, as some students will often defer to more able students who may assume the important roles and tasks for themselves, leaving the less able students to undertake more diminished roles. One way to ensure that all students have opportunities to participate in groups is to structure the group, so students understand that they are linked interdependently around the task. When this structure is in place, students know how they are expected to work together, what they are expected to achieve, and how they are expected to behave [28, 29].

Research has identified five key components that need to be embedded in groups for members to cooperate [30]. These components are:

1. Positive interdependence exists when group members perceive that they are linked together in such a way that in order to achieve their goals, they must assist others to do so as well. Positive interdependence can be structured in a group so that each member has to complete part of the group's task, for example, a group project where each member works on one part of the larger task. Members then share their contributions with other group members so the larger task can be completed. Johnson and Johnson [31] found that when positive interdependence is established in a group, two important psychological processes occur. The first involves members allowing one member's actions to substitute for the actions of another. This occurs when one member undertakes an action that other members of the group accept as an action they see as important to the group. The second psychological process involves being open to the influence of others and willing to accept their ideas as valuable. When these two processes are evident, the group members become psychologically interdependent, with members realising they need to work together, be open to assisting others, and contribute their ideas to ensure the group completes its task or achieves its goal/s.
2. Promotive interaction enables group members to discuss topics with others and think about issues in ways that they may never have considered previously. In so doing, the information and ideas exchanged are transformed so they become part of their new ways of knowing and doing. In fact, when this occurs in science classrooms, Ford and Forman [32] found that the interactions that the students had with each other encouraged them to work together to collaboratively construct and critique different ideas and points of view. This participation in talk where students learn to give and take in their discussions, Ford and Forman believe, is essential if productive scientific talk is to occur. Moreover, it is these dialogic interactions that, in turn, support changes to students' reasoning and ways of thinking in science.
3. Interpersonal and small-group social skills are critically important if students are to work successfully together. However, these skills do not develop automatically, and teachers need to ensure that students understand how to interact respectfully and appropriately with others. Gillies [33] reported that when students were trained in how to use these skills, they demonstrated more cooperative behaviour, provided more help to each other, and used more inclusive language or language that invited others to participate than peers who had not been taught these skills. This may have been because when students learned to interact appropriately with other group members, they felt more supported by their group and were more willing to reciprocate in kind. There is no doubt that social support tends to increase group cohesion and sense of purpose, which, in turn, affect pressure to be a productive group member.
4. Individual accountability is evident when students accept responsibility for completing their part of the group task. When individual accountability or personal responsibility is evident, group members realise that they are also contributing to the group's goals. This responsibility, in turn, helps create a sense of group cohesion and motivation to cooperate as members realise the importance of their contributions to the group's goals. Johnson and Johnson [30] found that that individual accountability or personal responsibility increases the effectiveness of a group and the work each member completes. By supporting each other as they work together, students learn that they can not only achieve the group's goal, but their own performances also improve.

5. Group processing and reflecting are processes that are critically important for students' learning, as they allow students to discuss how well the group is working to achieve its goals and maintaining effective working relationships [30]. Johnson and Johnson [34] argue that this includes making decisions about what behaviours to continue or change; discussing how to streamline the learning process so all group members understand what they need to do; reviewing the group's progress as they complete specific tasks; and evaluating how they are working together as a team.

7. Inquiry-Based Science and Cooperative Learning

Successful implementation of an inquiry-based science approach in classrooms is very dependent on students working cooperatively together to investigate problems, search for possible solutions, make observations, ask questions, consider different perspectives on the issue, think innovatively, and use their intuition. Given the emphasis attached to the importance of students being actively involved in their own learning, as inquiry-based investigations enable them to do, questions naturally arise about the effectiveness of this approach to learning in the context of cooperative learning. Howe et al. [35] reported on a study of twenty-four classrooms across twelve schools where students worked in small cooperative groups on inquiry-based science tasks (intervention condition), while the three classrooms in the control schools participated in their regular classroom science program. The results showed that the students in the intervention condition achieved significantly higher scores on their inquiry-based science tasks than students in the control condition. Furthermore, the students in the intervention condition obtained significantly higher scores in their dialogic interactions (proposition, disagreement, explanations, and questions) than students in the control condition. Howe et al. [35] attributed the success of the students' progress in science to their cooperative group experiences.

Thurston et al. [36] reported on a two-year longitudinal study of the effects of cooperative learning on science attainment, attitudes towards science, and the social connectedness of 204 students involved in the Howe et al. study [35]. The study investigated whether the gains recorded in the Howe et al. study in science understanding, attitudes, and social relationships transferred and persisted even though the students were now in high school in comparison to students in the control condition. The study found that attainment gains that were recorded during the original study persisted over time and were maintained in the intervention condition 18 months after the original cooperative learning project. Furthermore, the social relationships that were developed by students before the transition were significantly related to higher post-transition attainment. In short, the use of cooperative learning during inquiry-based science may allow the transfer of knowledge and skills acquired to new learning environments.

Gillies, Nichols, and Burgh [37] reported on a study that involved thirty-five groups of sixth grade students in eighteen classrooms from nine elementary schools who worked on two inquiry-based units of science in three conditions: the cognitive questioning condition, the philosophy for children condition, and the regular classroom (comparison) condition. Teachers from all three conditions participated in four professional development days that provided them with background information on the inquiry-science units and the cooperative learning strategies they were to implement. Each inquiry-science unit ran for 6–10 weeks and required students to work together in small cooperative groups to investigate topics, test out ideas, evaluate their conceptions, and build new working theories or understandings in a continuous cycle of inquiry, the outcomes of which were shared with the wider class.

While the children in the cognitive questioning condition and the philosophy for children condition were taught specific ways of asking questions to prompt discussion and think carefully about issues that emerged, the results showed that the children in all conditions demonstrated more helpful discourses or discourses known to mediate learning. This outcome was encouraging because it is the way the students were taught to help each other by providing explanations, elaborating on points, and providing reasons for their thinking that promoted follow-up learning. In effect, it was the opportunities that the students had to participate in the inquiry-based science units where they were taught how to cooperate that promoted the dialogic interactions that occurred.

Ting et al. [38] reported on a meta-analysis of the effects of active learning (i.e., collaborative learning, discovery learning, experiential learning, group inquiry-based learning, problem-based learning, and activity-based learning) on Asian students' performance in science, technology, engineering, and mathematics (STEM) subjects. A main criterion for inclusion was Asian students' experience with an active learning experience in comparison to traditional, didactic lecture-based pedagogy. All the active learning approaches were defined as "any instructional method that engages learners in their own learning process through their active involvement in class" ([38], p. 381). Forty-four studies met the criteria for inclusion in the meta-analysis. The results showed that a moderately large effect of 0.66 was detected, indicating a positive effect of active learning on Asian students' academic performance. Moreover, the effect sizes for active learning pedagogies in the different STEM disciplines were similar, and there were no significant differences between different countries or regions in Asia.

Ting et. al. [38] concluded that by changing traditional learning to active, learner-centred, inquiry-based, and collaborative approaches, Asian students became fully engaged and found learning more relevant to their needs. "The deep learning process that results from this active learning instructional approach as opposed to the passive and rote learning approach, ultimately leads to higher order learning, meaningful learning outcomes and enhanced academic performance" ([38], p. 389).

Nugroho, Suranto, and Masykuri [39] reported on a meta-analysis of the effectiveness of inquiry learning in science on the development of argumentation skills: skills needed to make claims, explain reasons, justify decisions, and provide evidence for decisions taken. Seventeen inquiry learning studies that had focused on developing argumentation skills met the criteria for inclusion in the meta-analysis. All studies investigated the effectiveness of inquiry learning on the development of argument in biology, physics, chemistry, and integrated natural science in secondary schools and colleges. The results showed that argumentation skills had a positive impact on the quality of students' written and oral arguments, with effect sizes ranging from 0.41 (moderate effect size) to 2.00 (very large effect size). The authors concluded that "scientific activities in inquiry provide opportunities for students to discuss and debate arguments, do their assignments to make valid conclusions, and are supported by original evidence" ([39], p. 100011-4).

8. Conclusions

The research by Howe et al. [35], Thurston et al. [36], Gillies, Nichols, and Burgh [37], Ting et al. [38], and Nugroho, Suranto, and Masykuri [39] highlight the academic and dialogic benefits that students achieve when they have opportunities to participate in inquiry-based tasks in science in comparison to peers who learn through traditional transmission approaches.

Inquiry-based learning emphases the importance of students investigating problems, making observations, asking questions, testing out ideas, challenging the ideas of others, and thinking creatively as they work cooperatively on solutions to the problem at hand. There is no doubt that the inquiry process is complex, as it requires students to be adept at engaging with others, sharing their ideas, acknowledging the contributions others make, evaluating new information, and communicating their various understandings in ways that are logical and well-reasoned. In such situations, teachers need to play an active role in not only structuring inquiry-based experiences that will help students to develop an understanding of the content, but also the dialogic practices that will help them to engage in well-reasoned discussions that facilitate critical thinking and learning.

When teachers dialogue with students, they not only model and scaffold different ways of talking, but also provide feedback to help students develop clearer understandings of their learning. These types of dialogic discussions promote meta-level reflections that help students to connect ideas across contexts, promoting higher order thinking that leads to learning that is more meaningful and enhanced academic outcomes. In short, student learning and engagement is promoted when they have opportunities to work cooperatively together on inquiry-based science tasks that have been well-structured.

Limitations and Recommendations for Future Research

There are three limitations to the research reported in this paper. Firstly, the focus is on inquiry-based teaching in science where students work in cooperative groups to investigate challenging problems. This requirement automatically limits the number of studies that have addressed these issues. Secondly, while meta-analyses are used to describe the impact of inquiry-based learning on students' achievements, no information is provided on how teachers can implement inquiry-based teaching in science in their classrooms; this is a clear indication of the limitations of meta-analyses. Finally, the paper focuses specifically on academic achievement and does not address student motivation to learn during inquiry-based science activities. Future research will need to address these limitations if inquiry-based teaching in science is to be fully embedded in science curricula.

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References

1. National Research Council (NRC). *Taking Science to School: Learning and Teaching Science in Grades K-8*; National Academy of Sciences: Washington, DC, USA, 2007; 387p.
2. Llewellyn, D. *Inquire Within: Implementing Inquiry and Argument-Based Science Standards in Grades 3–8*; Corwin: Thousand Oaks, CA, USA, 2014.
3. Crawford, B. Learning to teach science as inquiry in the rough and tumble of practice. *J. Res. Sci. Teach.* **2007**, *44*, 613–642. [CrossRef]
4. Metz, K. Children's understanding of scientific inquiry: Their conceptualization of uncertainty in investigations of their own design. *Cogn. Instr.* **2004**, *22*, 219–290. [CrossRef]
5. Duschl, R.; Duncan, R. Beyond the fringe: Building and evaluating scientific knowledge systems. In *Constructivist Instruction: Success of Failure?* Tobias, S., Duffy, T., Eds.; Routledge: London, UK, 2009; pp. 311–332.
6. Harris, C.; Rooks, D. Managing inquiry-based science: Challenges in enacting complex science instruction in elementary and middle school classrooms. *J. Sci. Teach. Educ.* **2010**, *21*, 227–240. [CrossRef]
7. Furtak, E.; Seidel, T.; Iverson, H.; Briggs, D. Experimental and quasi-Experimental studies of inquiry-based science teaching: A meta-analysis. *Rev. Educ. Res.* **2012**, *82*, 300–329. [CrossRef]
8. Firman, M.; Ertikanto, C.; Abdurrahman, A. Description of meta-analysis of inquiry-based learning of science in improving students' inquiry skills. *J. Phys. Conf. Ser.* **2019**, *1157*, 022018. [CrossRef]
9. Heindl, M. Inquiry-based learning and the pre-requisite for its use in science at school: A meta-analysis. *J. Pedagog. Res.* **2019**, *3*, 52–61. [CrossRef]
10. Alexander, R. Culture, dialogue and learning: Notes on an emerging pedagogy. In *Exploring Talk in School*; Mercer, N., Hodgkinson, S., Eds.; Sage: Thousand Oaks, CA, USA, 2008; pp. 91–114.
11. Alexander, R. Developing dialogic teaching: Genesis, process, trial. *Res. Pap. Educ.* **2018**, *33*, 561–598. [CrossRef]
12. Alexander, R. Whose discourse? Dialogic pedagogy for a post-truth world. *J. Dialogic Pedagog. Int. J.* **2019**, *7*, 1–19. [CrossRef]
13. Alexander, R. *A Dialogic Teaching Companion*; Routledge: London, UK, 2020; 246p.
14. Boyd, M.; Markarian, W. Dialogic teaching: Talk in service of a dialogic stance. *Lang. Educ.* **2011**, *6*, 515–534. [CrossRef]
15. Wolfe, S.; Alexander, R. Argumentation and Dialogic Teaching: Alternative Pedagogies for a Changing World. 2008. Available online: http://www.robinalexander.org.uk/index.php/publications/ (accessed on 15 December 2013).
16. Reznitskaya, A. Dialogic teaching: Rethinking language during literature discussions. *Read. Teach.* **2012**, *65*, 446–456. [CrossRef]
17. Garcia-Carrion, R.; Aguileta, G.; Padros, M.; Ramis-Salas, M. Implications of social impact of dialogic teaching and learning. *Front. Psychol.* **2020**, *11*, 140. [CrossRef] [PubMed]

18. Scott, P.; Mortimer, E. Meaning Making in high school science: A framework for analysing meaning making interactions. In *Research and the Quality of Science Education*; Boersman, M., Goedhart, M., de Jong, O., Eikelhof, H., Eds.; Springer: Dordrecht, The Netherlands, 2005; pp. 395–406.
19. Aguiar, O.G.; Mortimer, E.F.; Scott, P. Learning from responding to students' questions: The authoritative and dialogic tension. *J. Res. Sci. Teach.* **2010**, *47*, 174–193. [CrossRef]
20. Scott, P.; Mortimer, E.; Aguiar, O. The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Sci. Educ.* **2006**, *90*, 605–631. [CrossRef]
21. Scott, P. Talking a way to understanding in science classrooms. In *Exploring Talk in School*; Mercer, N., Hodgkinson, S., Eds.; Sage: Thousand Oaks, CA, USA, 2008; pp. 17–36.
22. Lehesvouri, S.; Ramnarain, U.; Viiri, J. Challenging transmission modes of Teaching in science classrooms: Enhancing learner-centredness through dialogicity. *Res. Sci. Educ.* **2018**, *48*, 1049–1069. [CrossRef]
23. Webb, N. The teacher's role in promoting collaborative dialogue in the classroom. *Br. J. Educ. Psychol.* **2009**, *79*, 1–28. [CrossRef]
24. Rojas-Drummond, S.; Littleton, K.; Velez, M. Developing reading Comprehension through collaborative learning. *J. Res. Reading* **2014**, *37*, 138–158. [CrossRef]
25. Mercer, N.; Wegerif, R.; Dawes, L. Children's talk and the development of reasoning in the classroom. *Br. Educ. Res. J.* **1999**, *25*, 95–111. [CrossRef]
26. Rojas-Drummond, S.; Mercer, N. Scaffolding the development of effective collaboration and learning. *Int. J. Educ. Res.* **2003**, *39*, 99–111. [CrossRef]
27. Rojas-Drummond, S.; Omedo, M.; Cruz, I.; Espinosa, M. Dialogic interactions, co-regulation and the appropriation of text composition abilities in primary school children. *Learn. Cult. Soc. Interact.* **2020**, *24*, 1–13. [CrossRef]
28. Gillies, R.; Ashman, A. Behavior and interactions of children in cooperative Groups in lower and middle elementary grades. *J. Educ. Psychol.* **1998**, *90*, 746–757. [CrossRef]
29. Gillies, R. Structuring cooperative group work in classrooms. *Int. J. Educ. Res.* **2003**, *39*, 35–49. [CrossRef]
30. Johnson, D.; Johnson, R. Learning together and alone: Overview and meta-analysis. *Asia Pac. J. Educ.* **2002**, *22*, 95–105. [CrossRef]
31. Johnson, D.; Johnson, R. An educational psychology success story: Social interdependence theory and cooperative learning. *Educ. Res.* **2009**, *38*, 365–379. [CrossRef]
32. Ford, M.J.; Forman, E.A. Uncertainty and scientific progress in classroom dialogue. In *Socializing Intelligence through Academic Talk and Dialogue*; Resnick, L.B., Asterhan, C.S.C., Clarke, S.N., Eds.; AERA: Washington, DC, USA, 2015; pp. 143–156.
33. Gillies, R.M. *Cooperative Learning: Integrating Theory and Practice*; Sage: Thousand Oaks, CA, USA, 2007.
34. Johnson, D.; Johnson, R. Cooperative learning in 21st century. *An. De Psicol.* **2014**, *30*, 841–851. [CrossRef]
35. Howe, C.; Tolmie, A.; Thurston, A.; Topping, K.; Christie, D.; Livingston, K.; Jessiman, E.; Donaldson, C. Group work in elementary science: Towards organisational principles for supporting pupil learning . *Learn. Instr.* **2007**, *17*, 549–563.
36. Thurston, A.; Topping, K.; Tolmie, A.; Christie, D.; Karagiannidou, E.; Murray, P. Cooperative learning in science: Follow-up from primary to high school. *Int. J. Sci. Educ.* **2010**, *32*, 501–522. [CrossRef]
37. Gillies, R.; Nichols, K.; Burgh, G. Promoting problem-solving and reasoning During cooperative inquiry science. *Teach. Educ.* **2011**, *22*, 429–445. [CrossRef]
38. Ting, F.; Shroff, R.; Lam, W.; Garcia, R.; Chan, C.; Tsang, W.; Ezeamuzie, N. A meta-analysis of the effects of active learning on Asian students' performance in science, technology, engineering, and mathematics (STEM) subjects. *Asia Pac. Educ. Res.* **2023**, *32*, 379–400. [CrossRef]
39. Nugroho, A.; Suranto, S.; Masykuri, M. A meta-analysis of the effectiveness ofinquiry learning towards scientific argumentation skills. *AIP Conf. Proc.* **2023**, *2619*, 100011.

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Evaluating a Secondary Education Urban Ecology Project within the Framework of a Problem-Based Learning Methodology

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Abstract: As a reaction to the current situation of local and global environmental deterioration, recent decades have seen the emergence of multiple educational strategies and methodologies within Environmental Education (EE) with the aim of promoting pro-environmental attitudes among young people. One of these strategies is Problem-Based Learning (PBL), and it is necessary to analyze the didactic implications of this methodology in the field of EE in order to maximize its effectiveness. This study evaluates the implementation and didactic implications of an environmental project designed under the PBL methodology. The project was carried out over consecutive years of compulsory secondary education (Grades 9 and 10) in two secondary schools in the province of Granada, Spain. The data collection instruments used included the researcher's diary, self-assessment and reflection questionnaires for the participating students, and questionnaires and rubrics completed by the audience during the presentation of the final product. The study employed a qualitative interpretative approach, using response categorization and SWOT analyses, the results of which revealed multiple conclusions, highlighting the high level of motivation, work and participation of the students, as well as the didactic benefits of the enriching socialization of the project. Difficulties, such as time management and cooperative group work, lack of practice in the methodology used and challenges related to the use of information and communication technologies (ICT), were also identified. Finally, recommendations are provided for the application of this methodology in other educational contexts.

Keywords: problem-based learning; environmental education; environmental problems; cooperative work; SWOT analysis; secondary education

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1. Introduction

Well into the 21st century, we can confidently assert that we are facing unprecedented anthropogenic environmental deterioration [1–3]. Some of the most important parameters indicating the various current environmental issues include climate change, biodiversity loss, disruptions in the global nitrogen and phosphorus cycles, ozone depletion, ocean acidification, global freshwater consumption, land use changes, chemical pollution, and atmospheric aerosol concentration [4]. It is evident that the solution to this array of problems is complex and multifactorial. However, as educators, we have an important role to play through Environmental Education (EE) in trying to improve this situation to the best of our abilities, particularly in terms of empowering individuals to take action [5]. In this sense, Ref. [6] points out that effective environmental education goes beyond a unidirectional transfer of information. Instead, it develops and enhances environmental attitudes, values, and knowledge while building skills that prepare individuals and communities to collaboratively undertake positive environmental action. In fact, there is now a general social consensus on the importance of EE as a key element for creating awareness in citizens of the need to maintain the environmental conditions of our surroundings within acceptable margins [7].

In any case, the challenges are also numerous, with the feeling that we are always trailing behind issues that surpass the objectives and possibilities of EE. Some of these challenges are as follows:

- The paradox that even though we have more environmental information available, especially through the media, it has not resulted in a social transformation towards more sustainable lifestyles. These lifestyles often clash with immediate beliefs and interests that encourage consumerism and tend to overlook individual responsibility in the global situation.
- Formal EE is practically anecdotal despite recognizing certain advances in curriculum designs and materials. However, the conditions of the teaching staff also do not contribute to greater involvement.
- Pure activism [8], or in other words, taking pro-environmental actions without undertaking appropriate reflection on what we do, why we do it, and for what purpose, prevents us from interpreting what is happening and being able to undertake future actions based on well-founded reasons.

In recent years, alternative teaching and learning strategies have emerged in the field of science education in general, and EE in particular, as a reaction to conventional methods and in line with constructivist principles [9]. According to [10], there is already sufficient evidence of the effectiveness of various inquiry-based methods of instruction, including project-based learning, inquiry-based learning, guided discovery, and others, which have all provide opportunities for developing explanations and seeking solutions of a different nature. One such methodology is Problem-Based Learning (PBL). As Ref. [9] indicates, PBL approaches develop students' abilities to tackle complex, unstructured problems that resemble situations they are likely to encounter in the future. Therefore, PBL seems to align with the educational needs of EE, which frequently involve finding solutions to diverse environmental problems [11,12]. Moreover, this methodology offers noteworthy didactic potential, manifested in the improvement of knowledge and skill integration, avoidance of fragmented learning, development of creative and critical thinking, interdisciplinary and autonomous learning, teamwork, and enhanced problem-solving [13–16]. Hence, the aforementioned supports the presumed suitability of PBL in EE development. However, few studies have analyzed the relationship between the two and the potential deficiencies and challenges that may arise in their implementation.

The aim of this work is to describe in the form of a case study the functioning, performance, problems addressed, and didactic implications of the methodology in question when applied to the field of EE, as well as to specify recommendations for future implementations. In order to achieve this objective, a qualitative interpretative investigation was carried out, consisting of a detailed analysis of the development of this methodology in two Spanish secondary schools over two consecutive academic years with students in the ninth and tenth grades of secondary education. For this purpose, an evaluation was performed using three instruments to collect formative evidence in the development of the PBL methodology, namely an analysis of Strengths, Weaknesses, Opportunities and Threats (SWOT) of the diary of the researcher who applied the PBL methodology, self-evaluation and reflection questionnaires of the participating students, and questionnaires and rubric of the audience present on the day of the exposition of the final product obtained by the students. Some of the conclusions following the analysis of the aforementioned instruments and their subsequent triangulation, as well as the comparison between the two years of intervention, were as follows: the high level of motivation, work and participation, the positive didactic implications of the rich socialization of the project, the problems in time management and cooperative group work, the lack of practice in the methodology under study (PBL) and the problems with the use of ICT.

2. Theoretical Framework

In recent years, various didactic and methodological strategies have been used in EE, such as service learning, problem-based learning, project-oriented learning, simulation games and case studies [17]. Project-based learning (PjBL), together with problem-based learning (PBL), are teaching approaches that are emerging as authentic alternatives to traditional methods. Through previous work using bibliographic analysis [9], we established a comparison between both of them and also with Inquiry-Based Learning (IBL) and Cooperative Learning (CL), establishing a spatial relationship through the conceptual map shown in Figure 1.

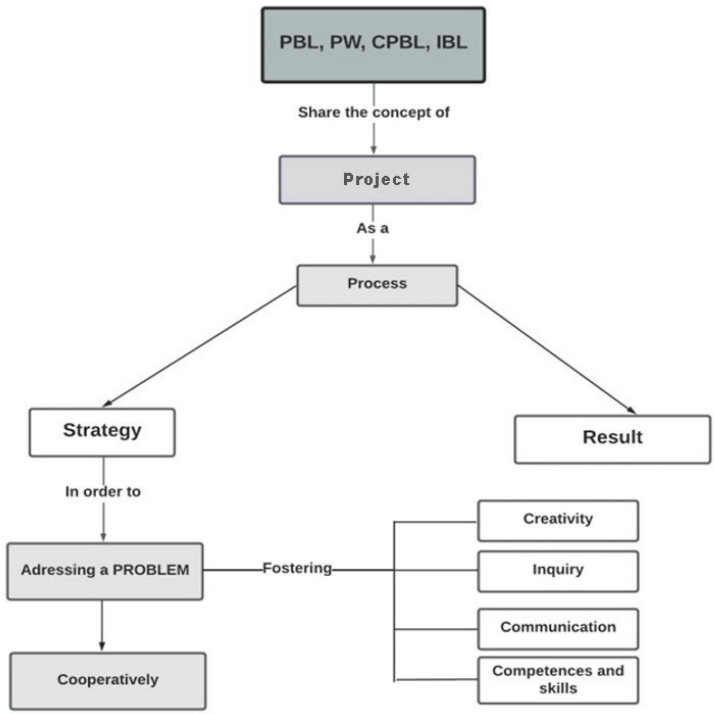

Figure 1. Conceptual map relating Problem-based Learning (PBL), Project Work (PW), Cooperative Project-Based Learning (CPBL), and Inquiry-Based Learning (IBL).

One of the conclusions we reached was that the project, in terms of its denomination and internal relationships, can be considered as the overarching concept, with PBL, CPBL, and IBL as subconcepts, with the latter being seen as a consequence of Project-Based Learning (PjBL). It was found to stimulate creativity, inquiry, communication, and diverse learning.

Despite its adaptability to different types of knowledge, Environmental Problems (EPs) are an ideal target on which to focus PBL due to the disciplines involved in their resolution, their diversity and their magnitude, which is leading us to a state of "planetary emergency". The 2030 Agenda of the United Nations and the periodic meetings on Climate Change (those of the IPPC, for example) are good proof of this.

Among other characteristics, EPs [18,19] possess the following features:

- Due to their complex and ever-changing nature, they do not have a single solution (referred to as open-ended problems in educational jargon [20].
- Their resolution requires reflection and creative investigation, drawing upon interdisciplinary scientific knowledge as well as everyday and traditional knowledge.
- They should be useful and applicable to everyday life.
- They can be used as a didactic end (learning problem-solving skills) or as a means (learning environmental content).

These same characteristics mean that there are also difficulties in dealing with them, some of which are as follows:

- In the school curriculum, content is often not presented as problematic or integrated across different subjects.
- They may not emerge from students' interests and everyday experiences.
- Their complexity is often overlooked, presenting them as simple and linear cause–effect relationships.
- The responsibility for solving environmental problems is often attributed to higher authorities, neglecting individual and collective citizen responsibility.

Relationship between EE and PBL

Several studies have been carried out in recent years using PBL/PjBL as a strategy for EE on various topics and research designs. These have focused on water management [21], river dredging [22], ocean water [23,24], school projects [25,26], ecological farming [27], ecological gardens [28], knowledge and attitudes [29–31], the development of cross-domain and domain-specific components of experimental problem-solving ability [32], open problem-solving [33], use of smartphones and outdoor education [34]. The research designs used by the mentioned authors vary from quasi-experimental to single-group designs.

In an attempt to summarize the results from this diverse range of previous research, the following accomplishments of PBL in EE for its users can be mentioned: a favorable attitude to its use in the classroom is perceived, environmental awareness is increased, improvement in skills and problem-solving abilities is observed, integrated use of knowledge and knowledge sharing in collaborative group work occur, creativity and research are enhanced, as well as evidence-based argumentation, critical thinking, global thinking, and scientific competence. These findings have been corroborated by other studies [35–39].

On the other hand, in the literature review we conducted earlier, some difficulties or weaknesses for students in the application of PBL have been identified, which seem to contradict some of the previous results, at least partially. These include a lack of improvement in learning outcomes or critical thinking compared to traditional methods, a lack of practice in this methodology, inherent workload overload, challenges associated with group work, a lack of autonomy in approaching the proposed activities, as well as feelings of confusion, uncertainty, and insecurity, especially in the early stages of the strategy [40].

From the teachers' perspective, [41,42] include the difficulty of evaluation as a negative aspect, and [42] points out that the implementation of PBL in the classroom is less comfortable for teachers, with increased noise and movement among students, as well as uncertainty compared to more traditional methodologies.

These last disadvantages can surely be totally or partially overcome as this way of working in the classroom is consolidated over time and the majority of the school where it is carried out join in.

3. Methodology

3.1. Research Methodology and Design

The research methodology employed in this study was qualitative, with data processing following a qualitative-interpretive approach [43]. To achieve the research objectives, the same teacher implemented a project in two different secondary schools over consecutive academic years. By replicating the interventions, the aim was to analyze the functioning of the methodology in question in two different contexts, allowing for the comparison and triangulation of the results obtained in both educational settings and enhancing their validity, which was further increased by employing three data collection instruments focused on the same instructional process (the methodology under study), which were triangulated and compared for this purpose.

3.2. Contextualisation and Description of the Sample

Both interventions were carried out in the province of Granada (Spain) in two public secondary schools. The teaching researcher was the same in both courses and had no experience in using PBL as a teaching methodology. The first year of the intervention was carried out in a grade 10 group with 26 students (14 boys and 12 girls) in a school in the provincial capital, which receives students from a medium socio-economic level and with academic results above the average for the area. However, the second intervention was carried out in a grade 9 group with 31 pupils (14 boys and 17 girls) from a secondary school in a village near the capital with a medium-low socio-economic level and with lower academic results than the former. This guaranteed the possibility of analyzing the development of the methodology under study in two different educational scenarios.

3.3. Description of the Project and Problem Posed

The project, which is detailed in Ref. [40], began with a driving question: "Is Granada a liveable city?", generating, together with the analysis of news and evidence of the situation of environmental parameters, a starting debate that laid the foundations for the development of the project. Likewise, the problem situation the students were required to face was: "How can we improve the urban environment of your city/town?". In order to answer these questions, the students were divided into cooperative groups (with specific roles assigned). Each group focused their research on a specific environmental parameter of the urban environment: noise pollution, air pollution by gases, the situation of rivers passing through the city, the surface area of urban parks and their condition. The groups analyzed the situation of each of the parameters and looked for possible solutions to the problems found in each of them. To this end, the tasks carried out by the students were diverse: preparation of a glossary of basic ecological and environmental terms; elaboration of a portfolio (with all the information related to the study carried out); creation of a learning diary on the project; diagnosis of the environmental situation in their locality (diversified in the parameters mentioned above: measurement of noise levels, determination of pollutants in river water, analysis of the diversity of parks and gardens, processing of information and elaboration of graphs and tables), the design of a plan of action for the improvement of the environment (this was the proposed solution to the problem posed) and preparation of a presentation and exposition to an audience outside the school. The evaluation was diversified, and rubrics were applied. The total duration of the intervention comprised 24 sessions (Table 1) in both academic years and was carried out within the subject of biology and geology, although language, geography and history teachers also participated.

Table 1. Phases and duration of the interventions.

Phase	Sessions
Beginning event and problem presentation	2
Learning of concepts	4
Chat with experts (Council)	1
Urban environment diagnosis	4
Urban environment trip	1 morning
Chat with experts (Ecologists)	1
Processing of information and determination of environmental state	2
Solving the problem: Creation of urban environmental improvement plan.	5
Preparation of presentation for showing to audience	4
Showing of presentation	1

3.4. Data Collection Instruments

As mentioned above, three instruments were used to obtain the required information to achieve the research objectives: the researcher's diary, a self-assessment and reflection questionnaire (completed by the participating students) and a questionnaire and evaluation rubric on the presentation of the final product by the students (completed by the audience present).

The researcher's diary is an extremely useful tool for collecting and/or storing information during the course of a research project [44]. At the end of each day, the diary was filled out, in which the researcher (and teacher) systematically noted down (including the title and date for each entry) reflections, points of view, preliminary conclusions, initial hypotheses, doubts, etc. These notes were structured into five descriptors: observations and description, problems or difficulties, positive aspects or progress, reflections or conclusions and possible improvements. The self-assessment and reflection questionnaire (which was anonymous) had three objectives. Firstly, the students' level of awareness of the development and structure of the project developed was determined by asking them what the key question of the project was and what the main steps or stages of the project were. Secondly, the personal implications were uncovered by answering the following questions: What was the most important thing you learned from this project? What would you have liked to spend more time on or what would you have done differently? What part did you work on best? Finally, we wanted to know what the strengths and weaknesses of the project were from the students' point of view, as well as suggestions for improvement; for this purpose, we asked the following questions: What was the most enjoyable part of this project? What was the part you liked the least? How should your teacher modify this project to make it better next time? The questionnaire was taken and adapted from Larmer et al. and administered following the end of the educational intervention [45]. Finally, the audience questionnaire and rubric were used to collect data to obtain relevant information after the students' execution of the final product exposition. On the one hand, a questionnaire, completed voluntarily and anonymously by the audience, asked five questions about the content and execution of the final product presentation: What did you learn from this presentation, or what did it make you think about? What were the strengths of this presentation? How could this presentation be improved? Any other comments about this presentation? The audience was also asked to fill in a rubric for the students' presentation (overall). The sections of the rubric were as follows: clear speech, volume, vocabulary, comprehension, content, body posture and eye contact. In both interventions, the audience to whom the final product was presented comprised undergraduates from the Faculty of Education Sciences of the University of Granada (Spain) in the first year of the Social Education degree and the second year of the Teaching degree, respectively. Both the questionnaire and the rubric were taken and adapted from Ref. [45].

4. Data Analysis

4.1. Researcher's Diary

In this section of the investigation, a Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis was carried out on the researcher's diary entries. As Mc Dermott points out [46], it is not sufficient to assess the impressions included in the researcher's diary; rather, it is necessary to systematize, through the SWOT analysis, the evaluation of the teaching–learning process that occurred, classifying and objectifying their assessments. To do this, each of the entries in the diary was divided into the ideas, impressions or descriptions of which it was composed, and each of them was assigned to one of the categories (Weaknesses, Threats, Strengths and Opportunities). The process for the treatment of said analysis was as follows [47–49]:

- Comparison and graphic representation of the frequency of positive (strengths-opportunities, S-O) and negative (weaknesses-threats, W-T) statements in order to determine the general perception (positive or negative) of the teaching–learning process.

- Comparison and graphic representation of the frequencies of the strengths against the weaknesses of each diary entry.
- Inductive determination, from the entries in the researcher's diary, of categories [43], grouping by similarity the weaknesses, threats, strengths and opportunities, obtaining the absolute frequencies in each one of them. A radial graph was subsequently generated to present this result.

4.2. Self-Assessment and Reflection Questionnaire

Once the student responses to the questionnaire were obtained, they were transcribed into a database and processed depending on the type of question. In the case of the first example, the number of students who knew the key question or project guide was simply counted, compared to those who did not (relative frequencies). For the second question, a scale of gradation of knowledge of the steps followed in the project was made as follows, obtaining the relative frequencies for each level of the scale: Excellent: details the steps of the project precisely; Satisfactory: lists most of the steps; Unsatisfactory: only specifies some disorderly steps; and Poor: does not specify the steps. For the remaining questions in the questionnaire, categories were obtained emergently, grouping the responses of the students to each question in the questionnaire by similarity [43]. The categories were formed when there were two or more assumable answers in the same category; otherwise, they were included in "others". The number of responses per category was quantified, and the relative frequencies of the responses were calculated (which were tabulated), allowing for analysis in terms of satisfaction, deficiencies, improvements, etc.

4.3. Audience Opinion Questionnaire and Rubric

The responses were obtained and then transcribed into a database and processed as in the previous section using a qualitative interpretative methodology for grouping the open responses into emerging categories and with quantifiable elements. (relative frequencies), subsequently producing an analysis of them for each of the questions in the questionnaire [43]. Regarding the rubrics, the absolute and relative frequency of the assessment of each of the sections considered was determined.

In all three cases, the software used to process the data and to prepare the frequency tables and the generated graphs was Microsoft Excel 2016.

5. Results

In another study [44], we report other results obtained in the two educational interventions in terms of environmental awareness, lexical richness and abundance, and perception of the state of the environment.

5.1. Researcher's Diary SWOT Analysis

Table 2 shows the absolute frequencies of each of the categories of the SWOT analysis implemented for each entry that was made in both years of intervention. In the first year, the number of strengths exceeded the number of weaknesses (37 versus 32); likewise, the opportunities and threats were balanced (8 in both cases). In the second year of the intervention, the number of strengths was again higher than the number of weaknesses (40 versus 37), while the opportunities presented a lower frequency (6) than the threats (10).

Table 2. Absolute frequencies of the SWOT analysis in both interventions.

First Intervention					Second Intervention				
Entries	**S**	**W**	**O**	**T**	**Entries**	**S**	**W**	**O**	**T**
16	37	32	8	8	21	40	37	6	10

On the other hand, in Figures 2 and 3, a greater weight is observed in the number of statements that are located in the upper part of the graph, which corresponds to the strengths, compared to the lower part, which corresponds to the weaknesses. This occurs in both interventions, although with a more positive trend for the first year of the implementation of the project.

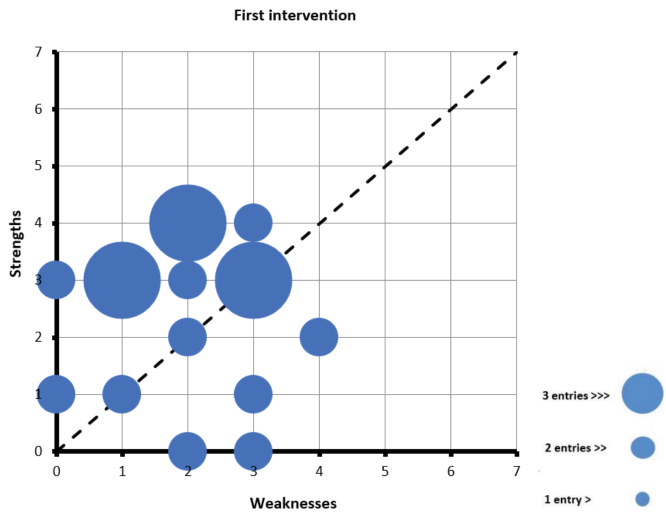

Figure 2. Number of strengths and weaknesses per entry in the researcher's diary in first intervention.

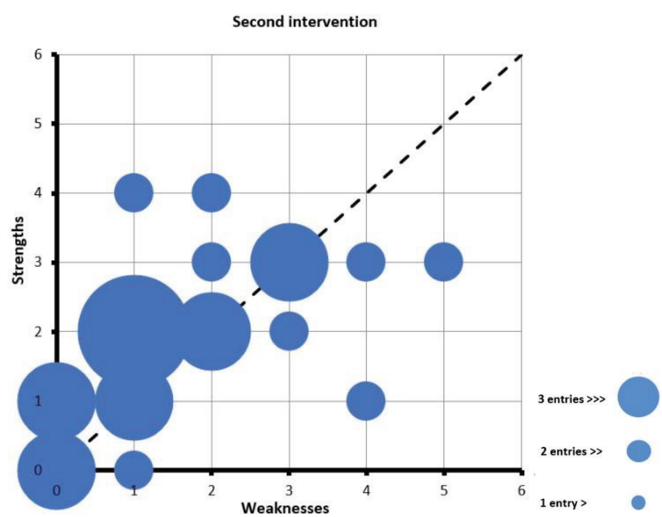

Figure 3. Number of strengths and weaknesses per entry in the researcher's diary in second intervention.

The number of statements collected from the researcher's diary with a positive connotation (strengths and opportunities) as opposed to those with a negative connotation (weaknesses and threats) were 45 and 40, respectively, in the first intervention (Table 3), with the sum of strengths and opportunities being slightly higher. In the second intervention, there were 46 (statements with a positive connotation) compared to 45 (negative connotation), giving a nearly balanced situation between the two (Figures 4 and 5).

Table 3. Total positive and negative statements (absolute and relative frequency) and overall perception of the SWOT analysis in both interventions.

Intervention		Negative Statements			Positive Statements			
	Entries	Weaknesses	Threats	Total	Strengths	Opportunities	Total	Perception
1st year	16	32	8	40/0.47	37	8	45/0.53	Positive
2nd year	21	37	10	47/0.51	40	6	46/0.49	Balanced

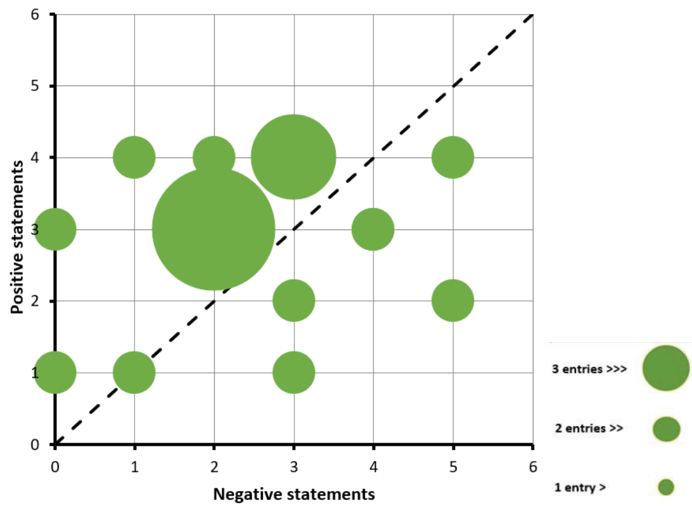

Figure 4. Set of positive versus negative statements collected in the researcher's diary in first intervention.

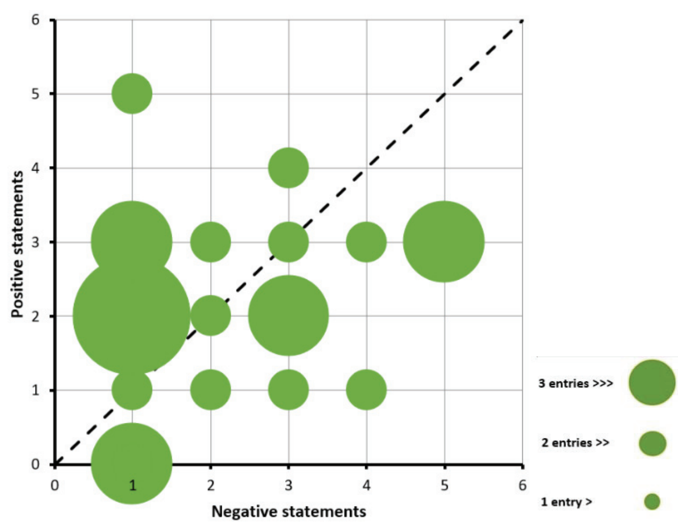

Figure 5. Set of positive versus negative statements collected in the researcher's diary in second intervention.

As for the process of categorizing the statements collected in the learning diary, Table 4 shows the different categories that emerged (12 in the first intervention and 10 in the second) and their frequency. The categories Information Search and Environmental Awareness did not appear in the second year. In the first intervention, Motivation, Performance and Attitude and Awareness stand out as strengths; weaknesses include Performance and Cooperative Groups; among the opportunities, rich socialization is noteworthy, whereas, among the threats, Time Management was the most frequent category. In the second intervention, the results are very similar except for the weaknesses, where Time Management stood out, and the threats, where ICT was prominent. These results can be easily seen visually in the radial graphs (Figures 6 and 7).

Table 4. Results of the categorization and frequency of the entries in the researcher's diary in both years of intervention.

	First Intervention				Second Intervention			
Category	**S**	**W**	**O**	**T**	**S**	**W**	**O**	**T**
Motivation	7	1	0	0	9	0	0	0
PBL Knowledge	0	3	0	0	1	4	0	0
Performance	7	6	0	0	8	8	0	1
Work	5	3	0	0	6	3	0	1
Attitude	9	4	0	0	10	2	0	1
ICT	1	2	0	2	1	6	0	4
Presentation	3	2	1	1	2	4	0	0
Collaborative groups	2	5	0	0	2	6	0	2
Rich socialization	0	3	5	1	1	0	6	1
Time management	1	2	0	3	0	4	0	0
Environmental awareness	1	1	1	1				
Information search	1	0	1	0				

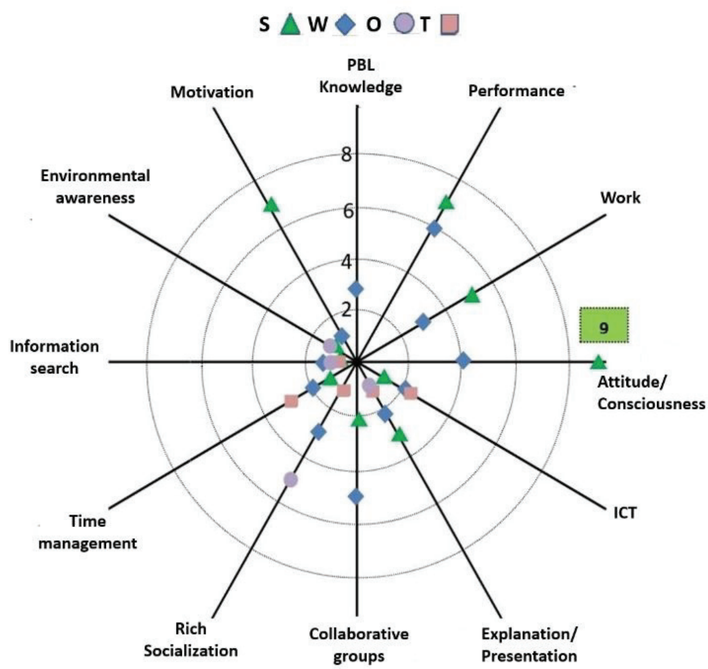

Figure 6. Radial graphs of frequency of appearance of the categories obtained in the SWOT analysis in first intervention.

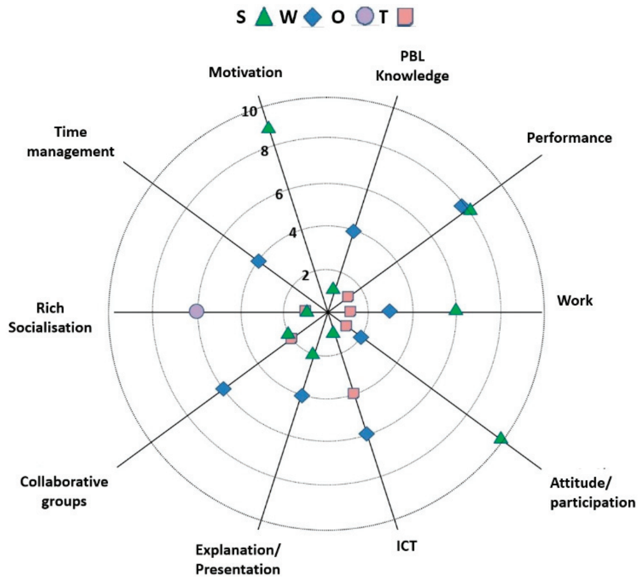

Figure 7. Radial graphs of frequency of appearance of the categories obtained in the SWOT analysis in second intervention.

5.2. Self-Assessment and Reflection Questionnaire

The total number of completed questionnaires was 26 in the first year and 31 in the second. Regarding the percentage of students who knew the driving question ("Is Granada a liveable city?") of the project, in the first intervention it stood at 92% (24 of 26 students), while in the second year, the percentage was 47% (15 of 31 students).

Regarding the question of what steps had been followed in the project, more than 80% of the students in the first year of the intervention carried out an excellent or satisfactory description of the different steps implemented, with this percentage dropping to slightly over 30% in the second year (Table 5).

Table 5. Degree of precision (absolute and relative frequency) in the description by the students of the different parts of the project in both interventions.

	1st Intervention		2nd Intervention	
Descriptor	**N**	**%**	**N**	**%**
Excellent: details the steps of the project precisely	10	38	1	3
Satisfactory: lists most of the steps	12	46	9	29
Unsatisfactory: only specifies some disorderly steps	4	15	14	45
Poor: does not specify the steps	0	0	7	23

Table 6 shows the different categories obtained after processing the rest of the questions in the questionnaire; in some cases, the same answer could be considered in more than one category. These largely coincided in both intervention years, with slight adjustments. Furthermore, the absolute and relative frequencies by category are presented. Of the two most frequent categories of each issue, for all questions, at least one category coincides between both interventions, with questions where the coincidence amounts to 2 or 3 categories. It is considered that there is a high degree of similarity in the answers in both years of study.

Table 6. Categories, absolute and relative frequencies obtained after processing the responses to the questionnaire by the students in both interventions.

		1st Intervention		2nd Intervention	
Question	**Category**	**N**	**%**	**N**	**%**
What was the most important thing you learned from this project?	Detect and be aware of environmental problems	20	64	20	53
	Ecology	5	16	12	32
	Teamwork	3	10	4	10
	Lose stage fright	2	6	2	5
	Others	1	3	-	-
What would you have liked to spend more time on or what would you have done differently?	Make more observations (in situ)	3	11	7	21
	More time to take surveys	3	11	6	18
	More time to complete all the tasks	14	50	11	32
	In nothing. It was right	-	-	5	15
	Another way of making improvement and diagnosis plans	6	20	-	-
	Others	2	7	5	15
What part did you work on best?	In data processing	2	6	6	16
	In search of information	4	13	3	8
	In the preparation of the presentation and/or exposition	3	10	4	11
	In conducting surveys	2	6	11	30
	In carrying out tasks for final products	20	64	8	22
	In the taking of samples and measurements	-	-	4	11
	Others	-	-	1	3
What was the most enjoyable part of this project?	Make people aware of environmental problems	2	6	-	-
	Team work	2	6	5	13
	The excursion to the river	-	-	5	13
	The exposition at the Faculty	9	26	10	26
	Preparing for the presentation	2	6	-	-
	Carrying out the diagnosis	3	9	-	-
	Carrying out the improvement plan	2	6	-	-
	The measurement of environmental parameters	4	12	7	18
	Surveys in the Street	9	26	10	26
	Others	1	3	2	5
What was the part you liked the least?	Team work	2	7	5	16
	The apathy of the population with the survey	2	7	-	-
	Exposition at the Faculty	3	11	9	29
	Nothing	3	11	4	13
	Make the video for the exposition	4	14	-	-
	Carry out the tasks for the final product	11	40	6	19
	Searching for information on the internet	-	-	2	6
	Others	3	11	5	16
How should your teacher modify this project to make it better next time?	Spend more time	4	13	-	-
	Everything was correct	7	23	16	44
	Explain the project better and guide the students more	5	16	3	8
	Make groups smaller and more homogeneous	3	10	-	-
	Do more practices and excursions	2	7	2	6
	Allow students to make groups	-	-	11	31
	Do more practices for the presentations	2	7	-	-
	Give more value to individual effort	3	10	-	-
	Others	4	13	4	11

5.3. Audience Opinion Questionnaire and Rubric

In the first year, 28 questionnaires and rubrics were collected, while in the second, there were 60. Table 7 shows both the categories obtained after processing the responses of the audience to the questionnaire, as well as the absolute and relative frequencies of each one in both interventions. The percentages were calculated based on the total responses obtained for each question (sometimes a response can be assimilated into more than one category). With the exception of the fourth question, the categories obtained in both years of study turn out to be quite similar. Of the two most frequent categories of each question, for all the questions, at least one category coincides between both interventions, with considerable agreement in the most frequent responses.

Table 7. Categories, absolute and relative frequencies obtained after processing the responses to the questionnaire completed by the audience in both interventions.

		1st Intervention		2nd Intervention	
Question	**Category**	**N**	**%**	**N**	**%**
What did you learn from this presentation, or what did it make you think about?	To be aware of the pollution of the city of Granada and Granada province	14	38	26	37
	To know the environmental situation of our province	9	24	27	38
	In which there is to collaborate actively, changing attitude in my daily actions	5	13	5	7
	That solutions and environmental improvement plans must be provided	4	11	9	13
	Others	5	13	3	4
What were the strengths of this presentation?	Explanatory charts and slides	8	20	14	16
	Everything	3	7	-	-
	The appropriate vocabulary for the topics presented	3	7	-	-
	Clear and well-structured messages	6	15	6	7
	The various types and causes of pollution detected	-	-	28	32
	The solutions and proposals for improvement provided	9	22	15	17
	The good organization	-	-	3	3
	Preparatory work for the presentation	3	7	5	6
	Confidence and completeness in the presentation	5	12	5	6
	The message of environmental awareness transmitted	-	-	5	6
	The end game with mobile	-	-	4	5
	Others	3	7	1	1
How could this presentation be improved?	Implementing more dynamics	5	14	3	4
	Using more audiovisual media	9	25	-	-
	Management of nerves, appropriate tone of voice.	7	19	38	53
	Preparing presentations better	-	-	7	10
	Contributing more experiences and less memorization	2	5	6	8
	Explaining more technical terminologies	-	-	4	6
	It has been unbeatable	5	14	7	10
	Using classrooms in better conditions	4	11	-	-
	Others	4	11	6	8
Any other comments about this presentation?	Interesting. It's been very good overall	19	70	36	60
	They have known how to defend the issues exposed very well	5	18	5	8
	Good organization, coordination and involvement	-	-	2	3
	Sometimes they give an image of insecurity	-	-	3	5
	Some students have not respected their classmates while presenting	-	-	3	5
	The errors due to the students' age are understandable, and their courage in presenting is highly valued.	-	-	11	18
	Denotes good previous work	-	-	2	3
	Others	3	11	9	15

Regarding the rubric completed by the audience, Table 8 shows the frequencies (absolute and relative) per category in both interventions (percentages were calculated based on the total number of responses obtained for each question). As we have already mentioned, other results can be seen in [44]. The overall evaluation by the audience was significantly better in the first year of study compared to the second. This is evident in the generated comparative graphs of relative frequencies (Figure 8).

Table 8. Absolute frequencies (N) and relative frequencies (percentages) per category and rating level in both years of study.

	Speak Properly				Specific Vocabulary				Presentation				Content			
	1st Year		2nd Year		1st Year		2nd Year		1st Year		2nd Year		1st Year		2nd Year	
Assessment	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
Exceptional	19	73.1	2	3.3	16	61.5	14	23.3	24	92.3	37	61.6	22	84.6	30	50
Notable	7	26.9	34	56.7	8	30.7	32	53.3	2	7.7	22	36.7	4	15.4	30	50
Acceptable	0	0	20	33.3	2	7.7	14	23.3	0	0	1	1.7	0	0	0	0
Pending	0	0	4	6.7	0	0	0	0	0	0	0	0	0	0	0	0

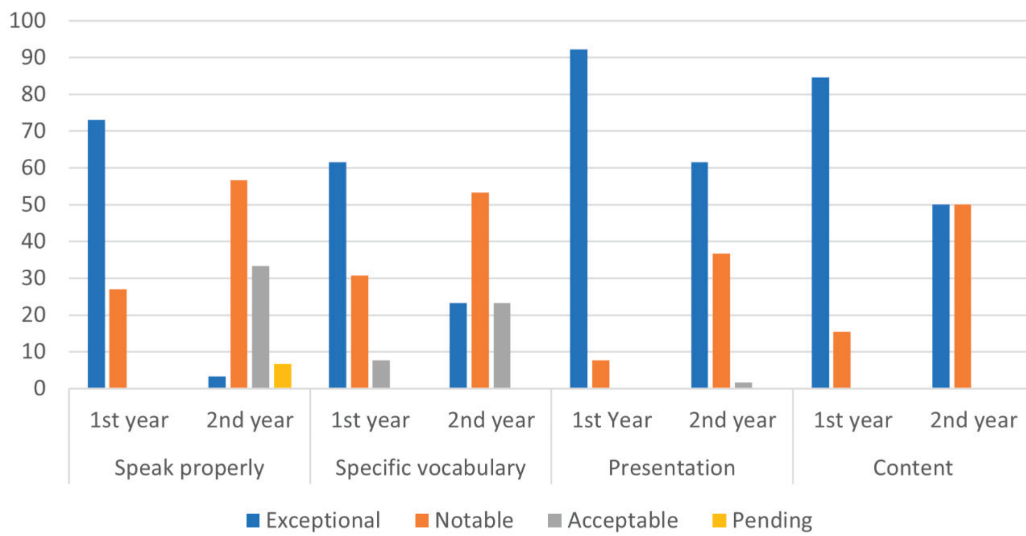

Figure 8. Comparative graph, between both interventions, of the relative frequencies of the assessments of each category of the rubric.

6. Discussion

If we go back to the objectives that led us to carry out the study, they sought to describe, as a case study, the functioning, performance, problems addressed, and didactic implications of PBL applied to the field of EE. On the other hand, this section should serve to provide recommendations for future implementations. After the analysis of the data collected through the three measuring instruments used, multiple conclusions have been drawn, reinforced by the triangulation of the data, by the replication in two interventions across consecutive academic years and by the support of previous studies with key contributions to the subject under study. In this sense, we can affirm that PBL was successfully implemented in both years of intervention, functioning and performing reasonably well, with numerous didactic implications, both positive and negative, detected. Likewise, there was a significant increase in the students' levels of environmental awareness [10,38], as indicated in most of the studies previously quoted, thus demonstrating the effectiveness of this methodology in the field of EE.

Moreover, the results obtained show a better performance and functioning of PBL in the first year of the study, which may be due to the older age and/or the differences in the socio-cultural context of the two schools.

6.1. Researcher's Diary SWOT Analysis

Although in the first year there was a slightly higher number of observations that were classified as Strengths or Advantages, the final balance between Strengths and Opportunities and Weaknesses and Threats was not decisive in any of the intervention years. Although many potentialities and positive effects were evident in its development, the fact that the students had never taken part in a project of this nature meant that there were also a considerable number of setbacks and difficulties in its implementation [21,28], which also resulted in serious disadvantages from the point of view of teaching [40,50], such as workload, noise level, management of cooperative groups and monitoring of students' progress in their work, among others. As for the Motivation category, it was a very frequent strength in both years of intervention, and several studies suggest that PBL increases it among students [29,34,40,51,52]. In our study, this idea was demonstrated from the multiple comments made by the researcher in this regard in his diary, such as follows:

> *"[. . .] However, I see that their motivation is adequate, they constantly ask me questions, especially about the specific tasks to be carried out."*

> *"I must also comment that there are some students who during the first term were quite apathetic and unmotivated (traditional methodology) but now they have changed their attitude somewhat and their motivation has improved, which is evident in their active participation in their group and in their direct questions to the teacher".*

With visible motivation among the participating students, it is a logical consequence that there was good performance (Strength) in the development of the methodology under study; in many cases, these signs of good performance were related to novel and more stimulating tasks not usually carried out in the more conventional methodology [30] (Processing data or photographs, layout of posters, preparation of surveys, etc.). With regard to the Attitude/Participation category (Strength), it is clearly related to the previous ones, understanding that if the students were sufficiently motivated during the project, this facilitated an improvement in their attitude towards the tasks to be carried out and their participation and focus on them to increase [28]. In terms of the most frequent opportunities detected in the SWOT in both years of the intervention, the rich socialization category stands out among the others, understanding as such all the interactions that the students had with "actors" outside the educational center. This had a clear connection with the increased motivation of the students. Some references in this sense are as follows:

> *"At the end of the day they tell me about their experiences, the interaction with people when interviewing them has caught their attention."*

> *"Even at the end of it, some people from the audience went up to the stage to express their opinion spontaneously, which was quite positive for the students."*

> *In reference to the weaknesses, "Performance" was a negative aspect in both years of study, which is evident in some of the observations recorded in the researcher's diary:*

> *"In addition, I denote a lack of autonomy in many of the tasks that I entrust to them. I sincerely believe that it is due to the immaturity of the students and their lack of competence when it comes to facing real problems."*

> *"Performing the review of the portfolios, some students still have not done many of the tasks, despite the fact that it has been repeated and discussed several times individually and in groups."*

These references to situations in which low performance or lack of work is denoted may be due, among other reasons, to the complexity that the development of an ambitious project such as the one in this study can sometimes entail, such as a loss or lack of motivation on the part of students and work overload [21,40,53]. In addition, the category Cooperative groups refers to those difficulties that prevented better functioning within the groups, this fact being supported by previous studies [21,27] and evidenced in some of the researcher reflections:

> *"Students tend not to know how to work in a group, especially in the sense of not knowing how to distribute the work well."*

> *"Some students work considerably less within the group."*

One of the weaknesses in the second year of intervention was ICT, understood as a lack of competence among students in the use of different digital tools necessary for the project, materializing in the use of digital portfolios, spreadsheets or "the cloud". This is a relevant fact since the methodology in question frequently requires a high level of competence in the use of ICT. Regarding threats, there were disparate results in the first and second years of the intervention. In the first year, the category Time management was especially prominent, which also turns out to be a recurring problem in PBL in other areas different from EE [54,55]. In the second year, the most frequent threat was the ICT category. In this case, it was due to the low quality and quantity of computing resources, such as computers or Internet connection. This complicated the future of the environmental project.

6.2. Self-Assessment and Reflection Questionnaire

The responses were more varied and comprehensive in the first year of intervention (grade 10), indicating a better functioning of the PBL. In fact, approximately 92% of the students in the first year (compared to 50% in the second year) remembered and identified the guiding question of the project, which is essential, especially when it is being initiated. This guiding question, along with the posed problem, serves as a reference throughout the project [45]. As mentioned earlier, this disparity may be due to the age differences among the students and/or the socio-cultural context of the educational institutions. The differences in the percentage of correctly indicating the main steps of the project (80% in the first year compared to 30% in the second year) support the aforementioned, with the level of awareness about the project's development in the second year of study falling below desirable levels. This is an indication that the students' performance within this methodology did not turn out to be optimal or could at least have been better. Regarding the third question in the questionnaire, particularly noteworthy was the More time to complete all the tasks category. These tasks refer to the various activities completed throughout the intervention. Many of the responses highlighted the need for tasks that involve interaction with others outside the classroom (rich socialization). This aspect is considered essential for the proper functioning of the PBL methodology [45,56], which aligns with the results of the SWOT analysis of the researcher's diary in this regard. Some of the responses that have led us to think about this were:

> *"Perhaps we would need more days to go out and analyze the environmental situation and carry out surveys."*

> *"I would have repeated the visit to Granada. It was very good to know our city better and what happens to it."*

> *"In interacting with the population."*

Within the commented category, multiple references were also made to the lack of time provided to carry out certain tasks:

> *"I would have preferred to have had a little more time when preparing the presentation and to have done some improvement plan or diagnostic things in a different way, such as graphs."*

> *"The truth is that the only thing I would change would be to give a little more time to do the presentation."*

These approaches suggest that the problems concerning time management were already specified in the SWOT analysis and this fact is widely commented on in the existing bibliography [57–60], which is ambivalent because it is precisely an opportunity for students to learn to develop this competence [61]. Likewise, references in this third question to group work are frequent:

"The groups. There are people who have done absolutely nothing."

"Group work should be done with people you get along with to feel comfortable."

These difficulties with collaborative group work are referred to in previous research as problems to take into account in the development of the PBL methodology [62], thus constituting it as ideal for improving the capacity for collaboration and teamwork [63]. With respect to the fourth of the questions in the questionnaire, the response category In carrying out tasks for final products included all the mentions of the work phases leading to the elaboration of the final product that were the core of the project. This fact indicates that, despite the difficulties that the students might encounter in developing the project, they liked the methodology used in the EE framework [21,30]. Another frequent category of the fourth question was in conducting surveys, which once again confirms the didactic potential that "rich socialization" presents in the methodology in question [45,56]. In the fifth question, the categories Surveys in the street and The exposition at the Faculty stood out. Regarding the surveys, the students indicated in their questionnaires how pleasant and motivating this task was within the project. Furthermore, there were frequent references to the exposition of the final product at the Faculty:

"Go to the Faculty to present; It was a good experience."

"In general, all the parts that have involved contact with people from outside the school environment and in which we have been able to report a little about our project."

"The outings, especially for me, when we presented at the Faculty."

On the other hand, the two commented categories suppose a development of the communication abilities of the students; this is a facet that is greatly enhanced within the PBL methodology [64,65]. In the sixth question, categories appear similar to those of previous questions, such as Teamwork. The students again make references to the unequal workload and effort of the different members [66]. Furthermore, the category Exposition at the Faculty was also frequent. This precisely indicates the need for students to work more on public presentations since it is a challenge for them. Some comments about it were:

"Having to present at the UGR. I was quite embarrassed."

"The one to present, because I was scared to speak in front of so many people."

"Time to make the exposition. It was a lot of fun, but I got really nervous."

However, the most frequent category in this question was Carry out the tasks for the final product, understanding these as the different tasks necessary to achieve the final product. The students complained about the multiple activities they had to carry out, such as PowerPoint presentations, information searches, presentations, learning diary, etc. Finally, with respect to the seventh question, the Everything was correct category evidently predominated, it being understood that the students presented an acceptable level of satisfaction regarding the development of the project. Another of the categories that turned out to be frequent in both years of intervention was Explain the project better and guide the students more. Some of the responses were:

"He should have cared more about helping us with some things."

"Guiding the students more, since there were times when I didn't know what to do."

"It could give us more indications of what would or would not be the right thing to do, although I know that it's a way to encourage our creativity."

The above comments are in line with previous studies, indicating that one of the problems with PBL is precisely that students sometimes feel lost or uncertain, which is inherent to active or "self-directed" methodologies. This fact implies that students learn to control the pace of learning and self-direct their own learning [28,63,67].

6.3. Audience Opinion Questionnaire and Rubric

These two tools proved to be useful for obtaining feedback from people outside the school on the outcome and presentation of the final product of the project in such a way as to serve as a comparison when triangulating the results obtained with the other data collection instruments of the study. In this sense, the evidence obtained shows considerable differences in the performance and functioning of the PBL methodology, being notably superior in the first year of intervention. The categories obtained after processing the instrument were not so homogeneous between the two years of study if we compare them with the researcher's diary and the student questionnaires. With regard to the first question, two categories were the most repeated: To be aware of the pollution of the city of Granada and Granada province and to know the environmental situation of our province, making it clear that in both years of the intervention, there was a strong environmental message from the students to the audience, which is evidence of the good functioning of the methodology applied in addition to the increase in the level of environmental awareness among the participating students [25,26,29,31]. In the second question, the category The solutions and proposals for improvement provided stood out, again highlighting the success achieved with the project. The category Explanatory charts and slides was also noteworthy. PBL aims for students to develop higher-order cognitive processes, such as data collection, data processing, the production of graphs and the drawing of conclusions and proposals based thereon. This was evident in some of the audience's comments in their questionnaires:

"The actual graphs that have been presented on noise, gas levels, etc."

"Population surveys and data presentation."

"The structure of the presentations has been very interesting in which, first, a problem has been raised, a topic to be investigated, they have analyzed it through surveys, samples, data collection and, finally, they have analyzed said data and have proposed improvements."

As for the third of the questions in the questionnaire, in the first year of the study, the most frequent comments were ambivalent; on the one hand, the category Using more audiovisual media stood out, which is a criticism of the exposition, in contrast, It has been unbeatable, highlighting the work of the students, with comments such as:

"I think the cooperation between them is unbeatable; coordination and communication have been excellent."

"Very interesting. Having little time and being in a pretty bad space, I think you have nothing to improve. Very good presentation."

In the second year of the intervention, most of the responses from the audience were included in the category Management of nerves and appropriate tone of voice. There were many comments in this regard:

"Overall, the presentations have been very good, but in some cases, the students experienced lapses due to nerves. It could be improved by ensuring that the students are calmer."

"In some cases, a bit more preparation for when the time to present comes and nerves come into play, using the appropriate tone of voice, and knowing how to search for strategies to avoid getting lost while presenting (reading from the slides)."

Finally, in question 4, the "Interesting. It's been very good overall" category was reiterated, especially in the first year of study:

"All the groups have presented clearly, they have shown that they have a lot of management and fluency with the issue of environmental education. The tone has been correct and the topics covered are very interesting. Congratulations!"

"Organization, coordination, choosing the right aspects and points to present. It can be a heavy subject, but you have defended it adequately."

However, in the second year, many other categories appeared with negative connotations regarding the presentation of the final product: Sometimes they give an image of insecurity or the errors due to the students' age are understandable, and their courage in presenting is highly valued". In any case, the fact that communicative competence is strongly developed in this methodology is reiterated [68].

Finally, it is necessary to refer to the completed rubrics. The audience's assessment was positive in all aspects considered in the relevant rubric for both years. There is a similar behaviour in both years of intervention since the Speak properly and Specific vocabulary sections were less valued than the Presentation and Content sections. However, there were nuances depending on the intervention since those evaluations considered as excellent in all the sections of the rubric were much more frequent in the first year of intervention, this being especially notable in the facet of They speak properly.

6.4. Improvement Proposals for the Implementation of PBL

Once the results obtained have been presented and assessed, and the difficulties in the application of the PBL methodology by the participating students have materialized (such as time management, the functioning of collaborative groups, presentations and/or oral presentations, the lack of autonomy, work overload, loss of motivation or lack of competence in ICT), we understand that it is necessary to carry out some proposals aimed at solving these difficulties.

First of all, we believe that it is essential to provide students with clear guidelines and expectations for their participation in the PBL process, including the delimitation of their roles and responsibilities in cooperative groups. Likewise, it is favorable to design and structure the tasks in such a way that they provide support to the students with the necessary resources and gradually increase the complexity of the problems, laying the foundations for more autonomous learning. Furthermore, it is positive to encourage, through the use of learning diaries, students to reflect on their experiences during and after completing each task, evaluating their own learning process and facilitating their internalization. These diaries should be available to teachers, making it easier to monitor the learning process of students. In addition, it is convenient to ensure that the problems presented are authentic and relevant to the lives of the students, thus increasing their participation and motivation. To solve problems in cooperative groups, it is crucial to promote collaboration and teamwork skills, designing tasks or situations in which students must develop effective communication, problem-solving, and decision-making strategies. With regard to time management, tools such as agendas and calendars should be provided so that they can set goals, track tasks and allocate specific time to work on each one. Likewise, examples of experiences with previous projects can be presented to them so that they have a realistic idea of how much time they may need to complete all the tasks. Work overload, can be managed by making task lists and through the equitable assignment of work (supervised by a teacher). The problems with ICT can be mitigated, however, by adapting activities so that they require fewer technological resources or by providing tutorials, workshops or online learning resources that allow students to acquire the necessary skills to use ICT.

6.5. Limitations of the Study

The results of this study cannot be generalized due to the small sample size. Moreover, despite having been replicated in two educational centers in different contexts, it would be necessary to increase the number of contexts in which the study could be carried out in order to extrapolate the results of the research. Another factor to take into account is that a single teacher implemented the methodology in question in the two years of intervention, which is a fact that could lead to a bias in the functioning and results obtained (Rosenthal effect). Likewise, it is worth mentioning that the results of the study could have been further triangulated with tools such as personal interviews with the students participating in the project or with the analysis of the learning diaries completed by them. Such research efforts could not be undertaken within the scope of this investigation.

Nevertheless, and without detracting from the observations made in the previous paragraph, we believe that this study has opened the way for future research in the field of PBL and EE in the context of secondary education, yielding results and conclusions of relevance to be taken into account in future studies in this field. This section is not mandatory but may be added if there are patents resulting from the work reported in this manuscript.

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

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References

1. Golledge, N.R.; Keller, E.D.; Gomez, N.; Naughten, K.A.; Bernales, J.; Trusel, L.D.; Edwards, T.L. Global environmental consequences of twenty-first-century ice-sheet melt. *Nature* **2019**, *566*, 65–72. [CrossRef] [PubMed]
2. Hickman, C. We need to (find a way to) talk about… Eco-anxiety. *J. Soc. Work Pract.* **2020**, *34*, 411–424. [CrossRef]
3. Shen, M.; Huang, W.; Chen, M.; Song, B.; Zeng, G.; Zhang, Y. (Micro) plastic crisis: Un-ignorable contribution to global greenhouse gas emissions and climate change. *J. Clean. Prod.* **2020**, *254*, 120138. [CrossRef]
4. Rockström, J.; Steffen, W.; Noone, K.; Persson, A.; Stuart Chapin, F.; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; et al. A safe operating space for humanity. *Nature* **2009**, *461*, 472–475.
5. Vega, P.; Suárez, P.A. Planteamiento de un marco teórico de la Educación Ambiental para un desarrollo sostenible. *Rev. Electron. Ensen. Cienc.* **2005**, *4*, 187–208.
6. Ardoin, N.M.; Bowers, A.W.; Gaillard, E. Environmental education outcomes for conservation: A systematic review. *Biol. Conserv.* **2020**, *241*, 108224. [CrossRef]
7. Gutiérrez, J. *La Educación Ambiental "Fundamentos Teóricos, Propuestas de Transversalidad y Orientaciones Extracurriculares"*; La Muralla: Madrid, Spain, 2011.
8. Rodríguez-Marín, F.; García-Díaz, J.E. El activismo que no cesa. Obstáculos para incorporar la metodología didáctica basada en la investigación del alumno a la práctica de la Educación Ambiental. *Investig. Esc.* **2009**, *67*, 23–36. Available online: http://hdl.handle.net/11441/60787 (accessed on 27 April 2023).
9. Perales, F.J.; Ayerbe, J. El trabajo por proyectos y por resolución de problemas en Educación Ambiental: Análisis y tendencias. In Proceedings of the XXVII Encuentros de Didáctica de las Ciencias Experimentales, Badajoz, Spain, 7–9 September 2016.
10. Chinn, C.A.; Iordarwu, K. Theories of Learning. In *Handbook of Research on Science Education*; Lederman, N.G., Zeidler, D.L., Lederman, J.S., Eds.; Routledge: New York, NY, USA, 2023; Volume III, p. 119. [CrossRef]
11. Owen, C. Problem-based learning. In *Learning and Teaching in Higher Education*; Daniels, K., Elliott, C., Finley, S., Chapman, C., Eds.; Edward Elgar Publishing: Cheltenham, UK, 2019; pp. 139–151. [CrossRef]
12. Ayerbe, J. Project-Based Learning in Environmental Education. Implementation in Secondary Education. Doctoral Thesis, University of Granada, Granada, Spain, 2021.
13. Birgili, B. Creative and critical thinking skills in problem-based learning environments. *J. Gift. Educ. Creat.* **2015**, *2*, 71–80. Available online: https://dergipark.org.tr/en/pub/jgedc/issue/38680/449365 (accessed on 27 May 2023).
14. Dolmans, D.H.; Loyens, S.M.; Marcq, H.; Gijbels, D. Deep and surface learning in problem-based learning: A review of the literature. *Adv. Health Sci. Educ.* **2016**, *21*, 1087–1112. [CrossRef]

15. Tan, O.S. *Problem-Based Learning Innovation: Using Problems to Power Learning in the 21st Century*; Gale Cengage Learning: Detroit, MI, USA, 2021; Available online: https://scholarworks.iu.edu/journals/index.php/ijpbl/article/download/28769/37349/86436 (accessed on 17 May 2023).
16. Yew, E.H.; Goh, K. Problem-based learning: An overview of its process and impact on learning. *Health Prof. Educ.* **2016**, *2*, 75–79. [CrossRef]
17. Tejedor, G.; Segalàs, J.; Barrón, Á.; Fernández-Morilla, M.; Fuertes, M.T.; Ruiz-Morales, J.; Gutiérrez, I.; García-González, E.; Hernández, Á. Didactic strategies to promote competencies in sustainability. *Sustainability* **2019**, *11*, 2086. [CrossRef]
18. García Díaz, J.E. *Educación Ambiental, Constructivismo y Complejidad*; Diada: Sevilla, Spain, 2004.
19. Rivarosa, A.; Perales, F.J. La resolución de problemas ambientales en la escuela y en la formación inicial de maestros. *Rev. Iberoam. Educ.* **2006**, *40*, 111–124. [CrossRef]
20. Perales, F.J. La resolución de problemas: Una revisión estructurada. *Enseñ. las Cienc.* **1993**, *11*, 170–178. [CrossRef]
21. Gutiérrez, J.; Pirrami, F. Water as Focus of Problem-Based Learning: An Integrated Curricular Program for Environmental Education in Secondary School. *US-China Educ. Rev.* **2011**, *2*, 270–280.
22. Aguerri, M.; Bravo-Torija, B. El uso de pruebas en la resolución de problemas reales en 4° de ESO: ¿debemos dragar el río Ebro? *Rev. Eureka Sobre Enseñanza Divulg. Cienc.* **2017**, *14*, 302–316. Available online: http://hdl.handle.net/10498/19219 (accessed on 22 May 2023). [CrossRef]
23. Gao, Q.; Hite, R.L. Developing global awareness and twenty-first century skills using PBL on ocean pollution. *US-China Educ. Rev.* **2018**, *8*, 341–351. [CrossRef]
24. De Araújo, D.; Farias, R.; de Lucena, P.; Lindsey, M.; Piñeiro, C.; Dolbeth, M. Improving environmental awareness and ocean literacy through hands-on activities in the tropics. *Appl. Environ. Educ. Commun.* **2022**, *21*, 120–139. [CrossRef]
25. Son, M.H.; Park, H.G.; Cheong, C. Effects of eco-friendly school project activity on middle school students' environmental awareness. *Hwankyungkyoyuk* **2011**, *24*, 34–43.
26. Hashimoto-Martell, E.A.; McNeill, K.L.; Hoffman, E.M. Connecting Urban Youth with their Environment: The Impact of an Urban Ecology Course on Student Content Knowledge, Environmental Attitudes and Responsible Behaviors. *Res. Sci. Educ.* **2012**, *42*, 1007–1026. [CrossRef]
27. Kim, M.; Tan, H.T. A collaborative problem-solving process through environmental field studies. *Int. J. Sci. Educ.* **2013**, *35*, 357–387. [CrossRef]
28. Aragón, L. ¿Cómo es el suelo de nuestro huerto? El Aprendizaje Basado en Problemas como estrategia en Educación Ambiental desde el Grado de Maestro/a en Educación Infantil. *Didact. Cienc. Exp. Y Soc.* **2016**, *30*, 171–188. [CrossRef]
29. Genc, M. The project-based learning approach in environmental education. *Int. Res. Geogr. Environ. Educ.* **2014**, *24*, 105–117. [CrossRef]
30. Al-Balushi, S.M.; Al-Aamri, S.S. The effect of environmental science projects on students' environmental knowledge and science attitudes. *Int. Res. Geogr. Environ. Educ.* **2014**, *23*, 213–227. [CrossRef]
31. Ural, E.; Dadli, G. The effect of problem-based learning on 7th-grade students' environmental knowledge, attitudes, and reflective thinking skills in environmental education. *J. Educ. Sci. Environ. Health* **2020**, *6*, 177–192. [CrossRef]
32. Roesch, F.; Nerb, J.; Riess, W. Promoting Experimental Problem-solving Ability in Sixth-grade Students Through Problem-oriented Teaching of Ecology: Findings of an intervention study in a complex domain. *Int. J. Sci. Educ.* **2015**, *37*, 577–598. [CrossRef]
33. Rosa-Novalbos, D.; Martínez-Aznar, M.M. Resolución de problemas abiertos en ecología para la ESO. *Ensen. Cienc.* **2019**, *37*, 25–42. [CrossRef]
34. Jakab, I.; Zigová, M.; Pucherová, Z. Modernization of Environmental Education with the Use of Project-Based Learning, Outdoor Education and Mobile Learning Supported by Information and Communication Technology. In *Universities in the Networked Society*; Smyrnova-Trybulska, E., Kommers, P., Morze, N., Malach, J., Eds.; Springer: Berlin/Heidelberg, Germany, 2019; pp. 223–248.
35. Yuningsih, Y.; Susilo, M.J. Analogipedia: An android-based module utilizing PBL model based on analogical approach to improve students' creativity. *Anatol. J. Educ.* **2022**, *7*, 45–56. [CrossRef]
36. Baran, M.; Maskan, A.; Yasar, S. Learning Physics through Project-Based Learning Game Techniques. *Int. J. Instr.* **2018**, *11*, 221–234. [CrossRef]
37. Setiawan, B.; Supiandi, M.I. The contribution of metacognitive skills and reasoning skills on problem solving ability based on Problem Based Learning (PBL) model. *Anatol. J. Educ.* **2018**, *3*, 75–86. [CrossRef]
38. Kricsfalusy, V.; George, C.; Reed, M.G. Integrating problem-and project-based learning opportunities: Assessing outcomes of a field course in environment and sustainability. *Environ. Educ. Res.* **2018**, *24*, 593–610. [CrossRef]
39. Portman, M.E.; Teff-Seker, Y. Community-level environmental projects as learning tools for planners: A case study of graduate planning students. *Environ. Educ. Res.* **2017**, *23*, 415–435. [CrossRef]
40. Ayerbe, J.; Perales, F.J. Reinvent your city: Project-based learning for the improvement of environmental awareness in secondary school students. *Enseñ. las Cienc.* **2020**, *38*, 181–203. [CrossRef]
41. Van den Bergh, V.; Mortelmans, D.; Spooren, P.; van Petegem, P.; Gijbels, D.; Vanthournout, G. New assessment modes within project-based education, the stakeholders. *Stud. Educ. Eval.* **2006**, *32*, 345–368. [CrossRef]
42. Markham, T.; Larmer, J.; Ravitz, J.L. *Project Based Learning Handbook: A Guide to Standards-Focused Project Based Learning for Middle and High School Teachers*; Buck Institute for Education: Novato, CA, USA, 2003.

43. Erickson, F. Ethnographic microanalysis of interaction. In *Handbook of Qualitative Research in Education*; Le Compte, M.D., Millroy, W.L., Preissle, J., Eds.; Academic Press: New York, NY, USA, 1992; pp. 201–223.
44. Ayerbe, J.; Perales, F.J. Effects of a Project-Based Learning Methodology on Environmental Awareness of Secondary School Students. *Int. J. Instr.* 2024, *in press*.
45. Hernández-Sampieri, R.; Collado, C.; Baptista, M.P. *Metodología de la Investigación*, 5th ed.; Mc Graw Hill: Madrid, Spain, 2010.
46. Larmer, J.; Ross, D.; Mergendoller, J.R. *PBL Starter Kit: To-the-Point Advice, Tools and Tips for Your First Project in Middle or High School*; Buck Institute for Education: Novato, CA, USA, 2017.
47. Mc Dermott, L.C. Investigación en Educación en la Física. *Rev. Ensen. Física* **1998**, *11*, 17–20.
48. Romero, M.; Martínez, M.; Jiménez, M.R. Evaluación del máster interuniversitario de educación ambiental a través de las percepciones de estudiantes y profesores en un análisis DAFO. *Rev. Eureka Sobre Ensen. Divulg. Cienc.* **2015**, *12*, 347–361. Available online: http://hdl.handle.net/10498/17257 (accessed on 3 May 2023). [CrossRef]
49. Romero, M.; Jiménez, M.R.; Martínez, M. SWOT analysis to evaluate the programme of a joint online/onsite master's degree in environmental education through the students' perceptions. *Eval. Program Plan.* **2016**, *54*, 41–49. [CrossRef]
50. Mihic, M.; Zavrski, I. Professors' and students' perception of the advantages and disadvantages of project based learning. *Int. J. Eng. Educ.* **2017**, *33*, 1–14.
51. Doppelt, Y. Implementation and assessment of project-based learning in a flexible environment. *Int. J. Technol. Des. Educ.* **2003**, *13*, 255–272. [CrossRef]
52. Morgan, J.R.; Moon, A.M.; Barroso, L.R. Engineering better projects. In *STEM Project-Based Learning*; Capararo, R., Capraro, M.M., Morgan, J.R., Eds.; Brill Sense: Paderborn, Germany, 2013; pp. 29–39.
53. Gülbahar, Y.; Tinmaz, H. Implementing project-based learning and e-portfolio assessment in an undergraduate course. *J. Res. Technol. Educ.* **2006**, *38*, 309–327. [CrossRef]
54. Fukuzawa, S.; Boyd, C.; Cahn, J. Student motivation in response to problem-based learning. *Collect. Essays Learn. Teach.* **2017**, *10*, 175–188. [CrossRef]
55. Ruiz-Gallardo, J.R.; González-Geraldo, J.L.; Castaño, S. What are our students doing? Workload, time allocation and time management in PBL instruction. A case study in Science Education. *Teach. Teach. Educ.* **2016**, *53*, 51–62. [CrossRef]
56. Trujillo, F. Aprendizaje Basado en Proyectos. In *Infantil, Primaria y Secundaria*; Ministerio de Educación, Secretaría General Técnica: Madrid, Spain, 2015.
57. Branda, L.A. El abc del ABP: Lo esencial del aprendizaje basado en problemas. *Quad. Fund. Dr. Antoni Esteve* **2013**, *27*, 1–16.
58. Lage, J.C.; Petralanda, I.I. Aplicación del aprendizaje basado en problemas en la asignatura Contabilidad Financiera Superior: Ventajas y desventajas. *Tend. Pedagog.* **2014**, *23*, 45–60.
59. Mergendoller, J.R.; Thomas, J.W. *Managing Project Based Learning: Principles from the Field*; Buck Institute for Education: Novato, CA, USA, 2001.
60. Wurdinger, S.; Qureshi, M. Enhancing college students' life skills through project based learning. *Innov. High. Educ.* **2015**, *40*, 279–286. [CrossRef]
61. Oakes, W.C.; Jamieson, L.H.; Coyle, E.J. EPICS: Meeting EC 2000 Through Service-Learning. In Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition, Albuquerque, NM, USA, 24–27 June 2001.
62. González-Hernando, C.; Martín-Villamor, P.G.; Almeida, S.D.; Martín-Durántez, N.; López-Portero, S. Ventajas e inconvenientes del aprendizaje basado en problemas percibidos por los estudiantes de Enfermería. *FEM Rev. Fund. Educ. Medica* **2016**, *19*, 47–53. [CrossRef]
63. Krajcik, J.S.; Czerniak, C.M. *Teaching Science in Elementary and Middle School: A Project-Based Approach*; Routledge: London, UK, 2014.
64. Capraro, M.M.; Jones, M. Interdisciplinary STEM project-based learning. In *STEM Project-Based Learning*; Capararo, R.M., Capraro, M.M., Morgan, J.R., Eds.; Brill Sense: Paderborn, Germany, 2013; pp. 51–58.
65. Capraro, R.M.; Slough, S.W. Why PBL? Why STEM? Why Now? An Introduction to STEM Project-Based Learning: An Integrated Science, Technology, Engineering, and Mathematics Approach. In *STEM Project-Based Learning*; Capararo, R.M., Capraro, M.M., Morgan, J.R., Eds.; Brill Sense: Paderborn, Germany, 2013; pp. 1–15.
66. Mills, J.E.; Treagust, D.F. Engineering education: Is problem-based or project-based learning the answer? *Australas. J. Eng. Educ.* **2003**, *3*, 2–16.
67. Bell, S. Project-based learning for the 21st century: Skills for the future. *Clear. House* **2010**, *83*, 39–43. [CrossRef]
68. Asian, A. Problem-based learning in live online classes: Learning achievement, problem-solving skill, communication skill, and interaction. *Comput. Educ.* **2021**, *171*, 104237. [CrossRef]

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Science Skills Development through Problem-Based Learning in Secondary Education

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Abstract: We present a study carried out with 16-year-old students in Spain using a problem-based learning approach as a pedagogical mode to develop science skills. The main objective of this work was to analyze the development of science skills through an inquiry process in class. The data were collected through audio and video recordings. The students were given the freedom to choose a problem to solve, and they decided on a near-environmental problem to research. They suggested a research question, formulated a hypothesis, designed experiments, observed, collected data, and searched for information. The teacher acted as a facilitator of resources. Finally, the students communicated the results obtained in their inquiry process. They performed all the above while asking themselves questions they had to answer during the course of the project, which increased in depth as the work evolved. The results of this research present PBL as an optimal methodology to develop scientific skills, such as inquiry practice, by means of asking questions.

Keywords: PBL; inquiry; science skills; science motivation; secondary education

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1. Introduction

Over the years, some researchers have explored the low number of scientific vocations among students, which results in poor scientific literacy in society [1]. This, in turn, leads to a lack of critical thinking (necessary in daily life) and a strong vulnerability to fake news, among other things [2]. Basic scientific education is necessary for many situations in daily life, and, for that reason, there is a need for real scientific literacy that is increasingly rich in scientific and technological content and educates the public in a social context.

Two of the most important factors determining scientific interest are self-confidence and motivation [3], which also influence efficiency in school science. The authors in [4,5] presented results of the low rates of self-confidence in science learning in young Europeans, which leads to low interest in the subject. Moreover, ref. [6] demonstrated that the methodologies used in the teaching of sciences influenced attitudes toward them, thereby establishing the connection between students' attitudes and their later scientific interests. In conclusion, all of the above should be taken into account when designing the teaching of sciences in school, and, according to Solbes et al. [7], this is not yet widely done. In view of all this, it seems clear that science classes should be designed with the aim of helping students investigate their scientific concerns while learning what teachers have to teach. Prior studies reveal that students are interested in solving problems in their immediate environment, that is, if the scientific problems are contextualized in the students' environment, their interest grows [8–11]. In this respect, knowing whether students develop science process skills should be a topic that teachers assess. Therefore, an ideal teaching methodology could consist of students themselves posing problems contextualized in their own environments and based on their own interests [12].

Secondary school teachers should teach content, but also procedures [13]. In this regard, authors like Bevins and Price [14], Jiménez-Aleixandre and Crujeiras [15] and

Mosquera Bargiela et al. [16] believe that scientific practices (inquiry, argumentation and modelling) are methods for teaching science using problem-based learning (PBL) [17], which helps to promote research skills in students and the internalization of new knowledge. For example, González Rodríguez and Crujeiras Pérez [18], Navy et al. [19] and Osborne and Dillon [20] believe in the usefulness of working through PBL to develop the inquiry practice used in experimental activities.

PBL is an educational instruction method, created by Dewey [21]. Content knowledge and problem-solving skills are the goals of this learning vehicle [22]. According to authors such as Hmelo-Silver [23] and Merrit et al. [24], the goals of PBL are grouped into: (a) content knowledge (construct an extensive and flexible knowledge base, academic achievement, knowledge retention, conceptual development), (b) procedural knowledge (develop effective problem-solving skills and self-directed, lifelong learning skills), (c) become effective collaborators, and (d) attitudes (become intrinsically motivated to learn, engaged). PBL is focused on learning through problem-solving and by the integration and application of knowledge in a real-world setting [25], allowing, as a consequence, the development of competencies and skills [26]. Drake and Long [27] investigated the usual PBL design, addressing eight components: problem, small group, students-centered iterative inquiry process, resources, technology, partnership with community, communication of findings, and teachers' roles as facilitators. There are not many published studies on the benefits of PBL in teaching science to secondary school students. Some of these studies offer promising results, such as that PBL favors the development of students' critical thinking [28] and also helps teachers and students learn the practices of scientists [29].

It must be taken into account that the problem is the focus of the learning process, acting as the stimulus for students' motivation and activity [30]. Thus, the problem should be complex, relating to real life and ill-structured, in order to offer students free inquiry and open-ended solutions in a wide range [24,31]. On the other hand, several authors indicated that students should be given the autonomy to discover their own problems and solve them [30,32]. Once the problem is defined, students work collaboratively in small groups [22,29,31], centered in an iterative inquiry process that is greatly promoted by the PBL instructional model [30].

Inquiry is an intentional process of diagnosing problems that requires identifying assumptions, applying logical and critical thinking, and considering alternative explanations [33], and it is also directly related to how scientists study the natural world and propose explanations based on the evidence stemming from their work [34]. According to Pedaste et al. [35] the phases of inquiry are: orientation, experiment design, investigation, conclusion, communication of results and discussion. Inquiry is based on questions that are asked (or self-asked) at the beginning and act as generators and organizers of knowledge [36]. This questioning arouses the desire to find out new things and helps individuals to reflect on their own knowledge and the learning process [15]. In 1994, Graesser and Person [37] classified the type of questions that students could ask into shallow, intermediate and deep. They related the type of question asked by students to the level of reasoning required to ask said question. Consequently, questions with the lowest quality (shallow) are related to verification, comparison, and completing a concept or definitions; reasoning, with an intermediate quality, involves giving examples, interpreting, specifying concrete aspects and quantifying; and finally, deep reasoning appears when questions establish a causal antecedent or consequence, or the orientation towards a goal or expectation. It is possible to conclude the problem-based learning process by analyzing the type of question that the students formulate throughout the inquiry process [28,38].

According to Harlen [39], the most interesting questions students may ask in the learning process are searchable issues, namely, questions that can be answered through research.

Inquiry through experimentation is part of the process for preparing models in the school context in the phases of preparing and testing mental models. It is aimed at solving practical challenges, which is very useful for the procedural understanding of science—that is, understanding the processes that characterize research [18]. In the same vein, according to Hodson [40], students like to know what they are doing because not knowing unsettles them, and they appreciate cognitive challenges as they are able to answer questions for themselves. This means that the tasks that are designed should be suitable for helping students to have enough control and independence, without this interfering in the learning process.

Even today, the development of the PBL methodology based on the student's interest, as a method of teaching science through the practice of inquiry, is not common in Spanish secondary education classrooms. On the other hand, there are real difficulties in teacher training for evaluating student learning through this type of methodology.

Taking the above into account, this work proposes research to evaluate the development of students' science process skills in inquiry by asking questions in a PBL context. That is, we evaluate the second objective of the PBL through the analysis of the type of questions that the students ask themselves in the inquiry process.

Our research questions are: Does the PBL methodology facilitate the development of science skills in class? What type of questions do students ask themselves in a science inquiry practice through problem-based learning designed based on their own interests?

2. Materials and Methods

2.1. PBL Procedure

For the design of our PBL process, we attended to the components described by Merrit et al. [24], which resulted in two interactions (phase 1 and phase 2), as described later in the results section.

The problem: Over one academic year, the teachers used a problem-based model of learning, using question-based inquiry as a vehicle tool. This year-long project was developed within the context of the scientific culture subject, which focuses on educating students to help them to understand the environment in which they live, by providing them with tools to obtain answers to everyday questions. Considering the concerns that the students showed regarding issues in their environment, specifically, they were interested in discovering the process through which the manure from the farms close to the school could be used as fertilizer for plants, given that the accumulation of this waste is a real and imminent environmental problem. Therefore, they suggested researching the use of said waste as fertilizer for vegetables, attempting to answer the following questions: Can manure be used as a fertilizer? What is the best proportion for plant growth? Identifying problems from their real context is considered important [41] as it acts as a motivation source because students feel their work is useful in their nearby community. Starting from this research question, the students had to design the research to find out whether manure can be used and is effective as a fertilizer for plants. Subsequently, they had to conclude if this use could be a viable solution to the environmental problem of manure waste.

The small group: The work was conducted with 10 students (50% girls) aged between 16 and 17 years old, working in a collaborative way. Working in collaborative groups allows students to be engaged in building knowledge, which is shared among them [30].

The iterative inquiry process: The search for solutions to the problem implies the development of an inquiry process based on the formulation of questions. These self-formulated questions, not provided by the teacher, activate their desire for knowledge, facilitate the understanding of new concepts, help them build sequenced knowledge, and arouse their epistemic curiosity. The results section describes this student inquiry process in detail.

Resources and technology: It is important to allow students to make their own decisions during their investigation, including what information they need to locate or how to analyze and evaluate the information to solve the problem [30]. Therefore, the students had access to the laboratory to be able to carry out the experiments they designed to prove or refute their hypotheses. The computers were freely accessible throughout this stage for the free consultation of information.

Partnership with the community: Since the problem that the students raised was related to their immediate environment, the learning process was expanded so they could have direct contact with farmers in the area, as well as other members of the community, such as experts in the chemical industry (fertilizer industry).

Communication of findings: Once the process was finished, the students communicated the results to their classmates, their teachers, and the university teachers who acted as researchers in this work.

Teachers as facilitators: The teaching staff acted as teacher-researchers, collecting the questions that students asked in each phase of the project and, as support, providing access to what was required. As Mosquera Bargiela et al. [16] demonstrated, showing an attitude of support and providing resources to students so that they can answer in the school context encourages their scientific development.

2.2. Assessment/Evaluation

The knowledge the students acquired was assessed using several tools, as recommended by Brenneman [42] and García-Carmona et al. [43]. The project sessions were audio- and video-recorded, as collecting audio and video data helps teachers to analyze the comments pupils make when working in a group, the answers to their questions, and their reactions to several situations; in other words, this tool should be used as much as possible [44]. The teachers kept an observation report in which they recorded the questions that the students asked in each phase of the project. Photos were taken of both the procedures followed and the results of the fertilization tests.

3. Results

The students started with a problem to solve (choose by themselves), and they had to design the procedure in order to obtain results and draw conclusions about this problem. Therefore, one of the most relevant results is the design that the students prepared in order to reach a conclusion about the question—in other words, the development of the PBL phases. As the students had decided the problem, this work relates to the fourth stage presented by Arici and Yilmaz [45], that is, looking for a solution for the problem.

3.1. Phase 1

In the first phase of the project, the students wanted to find out if manure was viable as a fertilizer and at what dose. To discover this, they suggested an experimental study where the variable was the proportion of the fertilizer in an aqueous solution. They subsequently developed their own analytical method based on the existing study "Impact of Artemisia absinthium hydrolate extracts with nematicidal activity on non-target soil organisms of different trophic levels" [46], which consists of measuring the elongation of the roots of an onion bulb (Allium) in a test tube containing water and nutrients. When the onion bulb was rehydrated, there was a stimulation in the growth of cells, which, in turn, enabled the growth of the roots.

The students contacted cattle farmers in the area, who provided them with solid manure (sun-dried pig manure). The first problem they had to solve was the change in the form of the manure, as the test, as described in the procedure, was performed in a liquid medium. After finding relevant information, they dissolved the manure by washing the solid with water. Then, they filtered the water and repeated the washing process five times to achieve greater concentration. This filtered liquid was considered to be at 100% fertilizer concentration, and solutions in water were prepared from that 100% sample.

They prepared five different concentrations of manure in water: 100%, 75%, 50%, 25%, and 0%. The students decided that, given that there could be statistical dispersion in the results, they would perform eight repetitions for each test and would consider the mean value of all repetitions as valid.

After filling all the test tubes with the appropriate concentrations, they prepared the onion bulbs: they peeled 14/21-size onions and put them in the tube with the solution.

When they finished preparing the test, they placed the tubes in an incubator (heater) for 2 weeks at 25 °C to replicate the ideal atmosphere for the growth of this type of onion.

After this period had passed, the students measured the length of the onion roots (Table 1).

Table 1. Growth (in cm) of the onion roots after the experimentation in phase 1.

% Fertilizer	0	25	50	75	100
Tube 1	2.6	2.8	Fail	1.9	1.4
Tube 2	0.6	1	1.4	0.5	1.2
Tube 3	3.2	0.7	0.5	1.3	1
Tube 4	1.5	Fail	Fail	Fail	0.6
Tube 5	3.5	3.6	Fail	1.8	0.5
Tube 6	Fail	Fail	2.3	0.2	0.7
Tube 7	Fail	Fail	0.6	2.6	0.8
Tube 8	Fail	Fail	1	Fail	Fail
Mean value	2.3	2.0	1.2	1.4	0.9

The students analyzed the results obtained: "After performing the experiment, we observe that some onions have not grown. We call these experiments a fail. We attempt to discover why these samples did not grow. To do this, we review the process of introducing the samples in the tubes and realize that some of them were very small and did not make contact with the manure solution. We believe that the roots did not grow because of poor contact with a solution. At the same time, we also observe that some onions were poorly peeled, and this could be another determining factor in their failure to grow.

We will now analyze the tests that did not fail and managed to grow. As we performed 8 tests with each percentage of manure, the final result (mean value) is more accurate. We can see that the highest mean growth corresponds to 0% manure, while the lowest is the one fertilized with 100% manure. We also observe that the highest growth has been with 0% of manure, which leads us to conclude that manure used without any other type of fertilizer has a very low productive effect.

Before approving the results, the students questioned the data by reflecting on what they had obtained and attempting to find an explanation: "When we analyzed the results we were surprised that the best data were obtained with a 0% concentration of manure. After reflecting on these data, we concluded that using too much manure causes the crop not to grow. The cause could be that too much manure results in a large amount of nitrogen in the soil/water and this prevents the crop from absorbing the nutrients correctly, thus hindering its growth. However, we are aware that these results go against practice in the field, because we asked around and rain-fed crops in the local area were only fertilized with farm waste, that is, the manure used in our tests. Therefore, we put forward a new hypothesis, that the conclusions were wrong." The students considered how to check this new premise. After discussing the possible alternatives, they decided to follow two paths. Firstly, they consulted an agricultural fertilizer company. They arranged a meeting and explained the results of the tests to the technical manager, who told them that the first root of an onion is weak and contact with a fertilizer with a high proportion of nitrogen could have damaged the roots in the samples. The students concluded: "before the following batch of experiments, we will leave the bulbs at least one week in water, before putting them in contact with the fertilizer".

Secondly, and at the same time, the students sought an answer from professionals from "We are Scientists"—a program financed by the Spanish Foundation for Science and Technology (FECYT) that offers students the chance to talk to scientists from all fields. In this context, the students summarized the information obtained as follows: "After discussing the results with young scientists, they informed us that if the plant has access to nearby nutrients its roots do not develop very much. In contrast, in treatments without fertilizer, the plant explores in order to find nutrients and, therefore, develops longer roots.

That is why root length is not the factor that determines greater development of the plant, it is just an indicator of how hard it is for the plant to find nutrients. Consequently, we need to observe the effect on the root mass and on the aerial part of the plant".

Taking this information into account, the students reflected on the results obtained once again and concluded that this argumentation explained what they had observed, as the higher concentrations of nutrients produced the shortest roots (concentrations from 50% to 100%), while the roots were longer with lower concentrations (0% and 25%). However, they could not check the development of the bulbs because they had disposed of those samples. Therefore, they decided to create a new design for experiments and established that they would measure the growth of the plant by measuring the length and mass of the stalk, bulb and root. They also introduced a new fertilizer (an industrial rooting agent) to compare the results against those from the manure in the first design.

3.2. Phase 2

In this second phase of the project, taking into account the conclusions obtained in the first phase, the students decided to analyze the growth of the onion bulbs by comparing a commercial fertilizer (using the manufacturer's recommended concentration) and a 25% aqueous solution of the manure used in the first phase. They chose this proportion as it was the most similar to the dilution of the commercial fertilizer.

Before the experiments, based on what they had learned in phase 1, the students let the onion bulbs grow for two weeks using water as the only nutritional sustenance. In these experiments, they started with bulbs without stalks or roots. Then, they performed eight tests with each of the fertilizers and obtained two fails with each fertilizer. Therefore, there were six valid results with each fertilizer. These data are shown in Table 2 and in Figure 1.

Table 2. Results after the experimentation in phase 2, with fertilizer A (25% manure solution) and fertilizer B (commercial rooting agent).

	Fertilizer Type	Stalk Mass (g)	Bulb Mass (g)	Root Mass (g)	% Stalk Mass	% Bulb Mass	% Root Mass	Stalk Length	Root Length
Tube 1	A	1.480	1.027	0.603	47.6	33.02	19.4	25	9
	B	2.001	0.400	2.00	45.47	9.09	45.44	30	11
Tube 2	A	1.610	1.013	0.640	49.34	31.05	19.61	30	10
	B	1.330	1.330	0.600	40.80	40.80	18.40	31	9
Tube 3	A	2.400	2.070	1.461	40.47	34.90	24.63	25	15.5
	B	0.810	1.970	0.880	22.13	53.83	24.04	15	10
Tube 4	A	1.900	1.600	0.560	46.80	39.41	13.79	18	9
	B	1.250	2.130	1.580	25.20	42.94	31.86	7	9
Tube 5	A	1.800	1.400	0.720	45.92	35.71	18.37	22	10.2
	B	1.120	1.400	1.670	26.73	33.41	39.86	17	10.7
Tube 6	A	1.700	1.500	0.630	44.39	39.16	16.45	19	9.7
	B	1.860	1.700	1.100	39.91	36.48	23.61	27	9.5
Mean Value	A	1.815	1.435	0.769	45.75	35.54	18.71	23.2	10.6
	B	1.395	1.488	1.305	33.37	36.09	30.54	21.2	9.9

The students reflected on the results they had obtained: "When we compared the mean values of the tests performed with the two fertilizers, we did not observe significant differences, except in the value of the root mass. With the commercial rooting agent, the weight of the root as part of the whole plant represented a much higher percentage than with the manure. In other words, in proportion to the plant as a whole, the mass of the root increased much more with the commercial fertilizer. We believe that the similar increase observed in root and stalk length and in bulb mass in both tests means that the plant has had sufficient nutrients for growth and did not have to use the bulb's reserves.

Figure 1. Growth of the root of A. cepa bulbs after phase 2.

We can also see that the root length is very similar with both fertilizers. As we have learnt, very long roots mean that the solution is not providing sufficient nutrients to the plant and, consequently, the roots grow longer to reach farther and attempt to get more nutrients. In contrast, when the solution contains sufficient nutrients, the roots are thicker and shorter. Taking this into account, if we observe the root mass, we can see that the mean value of the data obtained using the commercial fertilizer is higher; specifically, the bulbs fertilized with B have 76% more mass. We also observe that the increase in the stalk mass is greater in the bulbs that have been fertilized with manure, with approximately 30% more mass. This could mean that the nutritional content of the manure is higher than that of the rooting agent.

Figure 2 portrays the steps taken in the context of the PBL in each of the two phases.

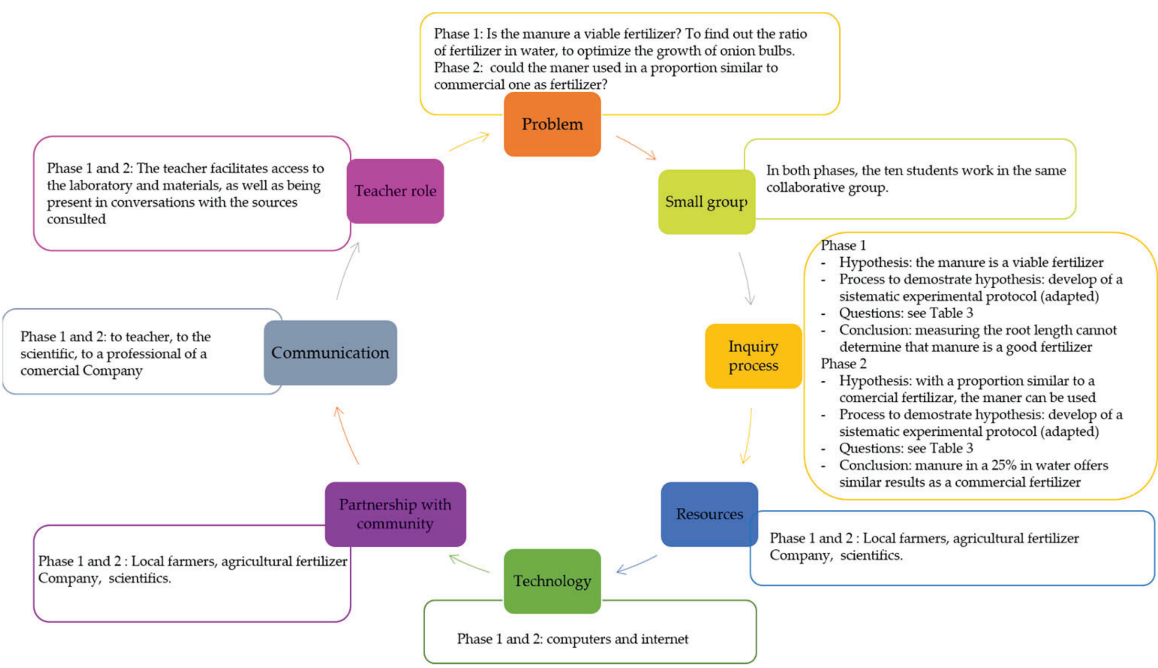

Figure 2. Steps of the PBL process.

Summarizing the science skills identified during the two PBL phases developed, the students identified a problem in their environment, established hypotheses, designed a laboratory protocol in which they took measurements, compared, experimented, identified researchable questions, sought guidance in different scientific sources, compiled results and diffused conclusions.

On the other hand, the questions that the students asked themselves during the process were analyzed and classified into categories according to [38]; these can be observed in Table 3. The questions formulated in a way that they can be answered with "yes" or "no" are shallow questions, usually about verification or comparison. When the questions, despite having to be answered with "yes" or "no", require a connection of ideas, or a detailed analysis, such as previous experimentation, they are considered intermediate questions. This includes questions about quantification and questions for which the students do not expect to find a direct answer. These questions typically begin with "is it possible?", "how many" or "what is". Finally, deep questions contain more than one aspect to be considered, and complex relationships between these aspects, including solution-oriented questions about environmental issues. Deep questions begin with "why" or "how".

Table 3. Categories of questions asked by students during the process.

		Before the Project	Phase 1	Phase 2	End of the Project
Shallow questions	Verification	- Can we research an environmental problem in our environment? - Can manure be used as a fertilizer?	- Are our results correct?		
Intermediate questions	Specific concrete aspects			- Is it possible that each fertilizer boosts the growth of one part of the plant? - Will it be useful for us to compare the manure solution data with another commercial fertilizer?	
	Quantifying		- What is the best proportion for plant growth? - How many repetitions should we do in order for the result of each test to be representative?		
Deep questions	Establish causal antecedent		- Why have not all the bulbs grown? - Why have the best results been obtained with the 0% manure solution?		
	Establish consequence				- Could all livestock waste be used as agricultural fertilizer? - Would there be enough to replace commercial fertilizer?
	Orientation towards a goal or expectation	-How can we research into the environmental problem of manure?	- How can we apply solid manure to bulbs? - How can we check our results?	- How can we measure which of the two is the best fertilizer?	

After completing the project, the students spent one week presenting their results to the teaching staff of the school and to the university lecturers. In addition, in this final phase, they asked new questions for future research: "Would all types of animal waste be suitable as fertilizers?", "In a long term, is an animal fertilizer or a commercial one better?", "Could pruning waste be used as a natural fertilizer?".

Despite not having been analyzed in detail, the results collected by the researchers can conclude that the students maintained a high level of motivation throughout the course. The students worked on issues related to the problem in classes for subjects other than the one in which they developed this problem; they met to work after school hours, discussed the issue with other students who were not part of the project; and asked the teacher to dedicate more hours to this work. The students expressed their desire to continue investigating the research question throughout the year, so this motivation maintained over time led to intrinsic interest.

4. Discussion and Conclusions

In the present work, we have developed a PBL methodology to work on inquiry in science classes in order to develop science process skills.

It is known that science teaching methodologies in secondary education do not favor the development of scientific skills; in the best of cases, the students follow guided practice in the laboratory without needing to formulate hypotheses or ask themselves researchable questions. This type of science teaching does not develop critical thinking, nor does it establish enduring scientific knowledge. If we want our students to develop these skills, we have to design contexts that help them identify a problem to solve, from which secondary questions arise that must be solved through the inquiry process to reach a final conclusion. Therefore, in this work, we start from an initial problem to be solved and analyze whether the PBL methodology, which contextualizes the work, encourages the students to ask themselves researchable questions that expand their knowledge about the initial problem posed. Throughout the process, the students raised the problem to be solved, formulated hypotheses, and designed a laboratory procedure to respond to their hypothesis. Throughout the development, several questions were formulated that broadened the knowledge necessary to solve their initial problem.

A second aim was to analyze the kind of questions students ask in a context of inquiry in order to assess if this methodology allows the students ask themselves relevant questions, from the point of view of the development of scientific skills.

Summarizing our results, the PBL methodology followed facilitates the learning of science, and in this specific case, the acquisition of scientific skills. In this method, the problem is the focus of the learning process and the guide in the inquiry process and in asking questions. In the section below, we comment on the development of the PBL process and the type of questions that students have asked themselves in this process.

4.1. PBL Process and Science Skills Development

The students completed the phases of the PBL process, in this case by deciding on their own problem to learn about—a real and ill-structured problem, contextualized in their environment [41]. They also design the inquiry process in order to establish a protocol to reach possible solutions to the problem. They were looking for solutions to the problem, evaluating them on a laboratory scale, developing experimentation protocols, taking data, repeating so results were reliable, etc. Finally, they presented the results of the inquiry to experts on the topic. Throughout the PBL process, they encountered difficulties in knowing where to turn in search of information, beyond what is usual for them (social networks). So, they needed a little guide to learn about programs like "We Are Scientists".

To verify whether this project has favored working inquiry in the classroom, we consider both the stages of inquiry proposed by Pedaste et al. [35] and the operations included in each stage, as described by Mosquera-Bargiela et al. [16]. The students asked a question that could be researched by the class group and on the school premises. The research topic stemmed from questions they asked through their observation of the environment. This led them to make a hypothesis (manure waste could be used as fertilizer for plants) and to create a complete design for experiments in order to test it. The students, after gathering the necessary materials, performed the proposed experimentation by exploring, collecting data and interpreting the results they had obtained. They searched for an explanation for the unexpected results (discussing among themselves and also looking outside) and consulted experts on the matter. After interpreting the information collected, they were able to redesign a new sequence of experiments and introduce a new variable (the use of commercial fertilizer) as a control variable. This new variable enabled them to check if the results obtained with the fertilizer that they had prepared using manure produced similar results to the commercial fertilizer, as was the case. Once they had made this connection, they compared which was the most effective by studying the root mass and reaching conclusions based on all the information collected during the project. Finally, the students presented the results and conclusions to the teaching staff of the school and to the university lecturers that the school usually works with during the planning of this type of project. The science skills the students developed include identifying problems; formulating researchable questions; formulating hypotheses and predictions; designing and carrying out experiments; observing; measuring and collecting data; interpreting results; and preparing and communicating conclusions.

4.2. Questions

Analyzing the type of questions helps us to assess students' depth of learning. Most of the questions that the students asked themselves were deep, according to the classification scheme proposed by Graesser and Person [37]. These questions establish a causal link or antecedent, for example: "Why have not all the bulbs grown?", or "Why have the best results been obtained with the 0% manure solution?". They also asked questions concerning the objective of the project with the same depth, which involved generalist and systemic thinking. That means the students generalized the knowledge acquired throughout the process and much broader questions were raised, including questions that suggest systemic thinking, where the problem is part of a complex system, such as: "Could all livestock waste be used as agricultural fertilizer?", or "Would there be enough to replace commercial fertilizer?". These types of questions, which to be solved need to have a specific objective and are therefore specific, are difficult to ask if it is not the students themselves who do it [38]. Therefore, it can be concluded that the PBL context favors the posing of deep questions that involve establishing relationships between different types of knowledge and favor metacognition.

The students also ask intermediate questions in which they propose quantifying or specifying aspects of the process, such as: "How can we measure which of the two is the best fertilizer?" or "How many repetitions should we do to obtain representative results in each test?" There are some verification or comparison questions, such as: "Can we do research into an environmental problem in our environment?", or "Can manure be used as a fertilizer?"

We should state that, in general, questions with less depth were asked at the beginning of the project and, as the work advanced, the students' questions became deeper.

The students seemed very motivated at the beginning of the project because they were able to choose the research topic, which was an environmental problem in their immediate environment. Therefore, the students understood their work not only as an academic procedure to work on science but also as the search for a solution to a real and imminent problem. This motivation remained throughout the academic year and became a real and explicit interest in the work they were conducting. The fact that the students were free to study their own interests [12] and that the problems were contextualized in their immediate environment helped in turning this motivation into interest [8–11]. As De Pro [13] stated, these types of project make it possible to study not only content but also procedures, and, most importantly, they promote working with students on the asking of questions, which is the starting point for science learning [14–16].

5. Implications

In the present work, we have developed a PBL methodology to work on inquiry in science classes. Currently, the secondary education curriculum in Spain recommends working on science through learning situations, in which students practice inquiry. However, teachers sometimes lack the tools to design or implement learning situations. The PBL methodology encourages science learning through inquiry, and the present study is a real example of this.

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References

1. McConney, A.; Oliver, M.C.; Woods-McConney, A.; Schibeci, R.; Maor, D. Inquiry, engagement, and literacy in science: A retrospective, cross-national analysis using PISA 2006. *Sci. Educ.* **2014**, *98*, 963–980. [CrossRef]
2. Höttecke, D.; Allchin, D. Reconceptualizing nature-of-science education in the age of social media. *Sci. Educ.* **2020**, *104*, 641–666. [CrossRef]
3. Barmby, P.; Kind, P.M.; Jones, K. Examining changing attitudes in secondary school science. *Int. J. Sci. Educ.* **2008**, *30*, 1075–1093. [CrossRef]
4. Gil-Flores, J. Actitudes del alumnado español hacia las ciencias en la evaluación PISA 2006. [Spanish students' attitudes towards science in the PISA 2006 assessment]. *Enseñanza de las Cienc.* **2012**, *30*, 131–152.
5. George, R. A cross-domain analysis of change in students' attitudes toward science and attitudes about the utility of science. *Int. J. Sci. Educ.* **2006**, *28*, 571–589. [CrossRef]
6. Potvin, P.; Hasni, A. Interest, motivation and attitude towards science and technology at K-12 levels: A systematic review of 12 years of educational research. *Stud. Sci. Educ.* **2014**, *50*, 85–129. [CrossRef]
7. Solbes, J.; Montserrat, R.; Furió, C. El desinterés del alumnado hacia el aprendizaje de la ciencia: Implicaciones en su enseñanza. [The disinterest of students towards learning science: Implications in their teaching]. *Didáctica de las Cienc. Exp. y Soc.* **2007**, *21*, 91–117.
8. Caamaño, A. Enseñar química en contexto. Un recorrido por los proyectos de química en contexto desde la década de los 80 hasta la actualidad. [Teaching chemistry in context. A tour of chemistry projects in context from the 1980s to the present]. *Educ. Química* **2018**, *29*, 21–54. [CrossRef]
9. Fraser, B.J.; Walberg, H.J. Research on teacher-student relationships and learning environments: Context, retrospect and prospect. *Int. J. Educ. Res.* **2005**, *43*, 103–109. [CrossRef]
10. Rodrigues, A.; Mattos, C. Contexto, negociación y actividad en una clase de física. [Context, negotiation and activity in a physics class]. *Enseñanza de las Cienc.* **2011**, *29*, 263–274.
11. Swarat, S.; Ortony, A.; Revelle, W. Activity matters: Understanding student interest in school science. *J. Res. Sci. Teach.* **2012**, *49*, 515–537. [CrossRef]
12. Cascarosa, E.; Mazas, B.; Martínez Peña, B.; Gil Quílez, M.J. What do students think they should know about vertebrate fish? *J. Biol. Educ.* **2019**, *54*, 530–539. [CrossRef]

13. De Pro, A. Enseñar procedimientos: Por qué y para qué. [Teach procedures: Why and for what]. *Alambique Didáctica de las Cienc. Exp.* **2013**, *73*, 69–76.
14. Bevins, S.; Price, G. Reconceptualising inquiry in science education. *Int. J. Sci. Educ.* **2016**, *38*, 17–29. [CrossRef]
15. Jiménez-Aleixandre, M.P.; Crujeiras, B. Epistemic Practices and Scientific Practices in Science Education. In *Science Education*; Taber, K.S., Akpan, B., Eds.; Sense Publishers: Rotterdam, The Netherlands, 2017; pp. 69–80.
16. Mosquera Bargiela, I.; Puig, B.; Blanco Anaya, P. Las prácticas científicas en infantil. Una aproximación al análisis del currículum y planes de formación del profesorado de Galicia. [Scientific practices in children. An approach to the analysis of the curriculum and teacher training plans in Galicia]. *Enseñanza de las Cienc.* **2018**, *36*, 7–23. [CrossRef]
17. Becerra-Labra, C.; Gras-Martí, A.; Martínez-Torregrosa, J. Effects of a Problem-based Structure of Physics Contents on Conceptual Learning and the Ability to Solve Problems. *Int. J. Sci. Educ.* **2012**, *34*, 1235–1253. [CrossRef]
18. González Rodríguez, L.; Crujeiras Pérez, B. Aprendizaje de las reacciones químicas a través de actividades de indagación en el laboratorio sobre cuestiones de la vida cotidiana. [Learning of chemical reactions through research activities in the laboratory on issues of everyday life.]. *Enseñanza de las Cienc.* **2016**, *34*, 143–160. [CrossRef]
19. Navy, S.L.; Maeng, J.L.; Bell, R.L.; Kaya, F. Beginning secondary science teachers' implementation of process skills, inquiry, and problem-based learning during the induction years: A randomised controlled trial. *Int. J. Sci. Educ.* **2021**, *23*, 1483–1503. [CrossRef]
20. Osborne, J.; Dillon, J. *Science Education in Europe: Critical Reflections*; A Report to the Nuffield Foundation; The Nuffield Foundation: London, UK, 2018.
21. Dewey, J. *Experience and Education*; Macmillan: New York, NY, USA, 1938.
22. Wang, H.A.; Thompson, P.; Shuler, C.F. *Essential Components of Problem-Based Learning for the K-12 Inquiry Science Instruction*; CCMB: Los Angeles, CA, USA, 1998.
23. Hmelo-Silver, C.E. Problem-based learning: What and how do students learn? *Educ. Psych. Rev.* **2004**, *16*, 235–366. [CrossRef]
24. Merrit, J.; Lee, M.Y.; Rillero, P.; Kinach, B.M. Problem-based learning in K-18 mathematics and science education: A literature review. *Interdisciplany J. Probl. Based Learn.* **2017**, *11*. [CrossRef]
25. Capraro, R.; Slough, S. Why PBL? Why STEM? Why now? An introduction to STEM project-based learning: An integrated science, technology, engineering, and mathematics (STEM) approach. In *Project-Based Learning: An Integrates Science, Technology, Engineering and Mathematics (STEM) Approach*, 2nd ed.; Sense: Rotterdam, The Netherlands, 2013; pp. 1–6.
26. Bell, J. *Doing Your Research Project*; McGraw-Hill: New York, NY, USA, 2010.
27. Drake, K.N.; Long, D. Rebecca's in the dark: A comparative study of problem-based learning and direct instruction/experiential learning in two 4th-grade classroom. *J. Elem. Educ.* **2009**, *21*, 1–16. [CrossRef]
28. Anazifa, R.D.; Djukri, D. Project-Based Learning and Problem-Based Learning: Are They Effective to Improve Student's Thinking Skills? *J. Pedidikan IPA Indones.* **2017**, *6*, 346–355. [CrossRef]
29. Kolodner, J.L.; Camp, P.J.; Crismond, D.; Fasse, B.; Gray, J.; Holbrook, J.; Puntambekar, S.; Ryan, M. Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design(tm) Into Practice. *J. Learn. Sci.* **2003**, *12*, 495–547. [CrossRef]
30. Chin, C.; Chia, L. Problem-based learning: Using students' questions to drive knowledge construction. *Sci. Educ.* **2004**, *88*, 707–727. [CrossRef]
31. Eherington, M.B. Investigative primary science: A problem-based learning approach. *Austr. J. Tech. Educ.* **2011**, *36*, 53–74. [CrossRef]
32. Runco, M.A.; Okuda, S.M. Problem Discovery, divergent thinking and the creative process. *J. Youth Adolescece* **1988**, *17*, 211–220. [CrossRef] [PubMed]
33. Ariza, M.R.; Aguirre, D.; Quesada, A.; Abril, A.M.; García, F.J. ¿Lana o metal? Una propuesta de aprendizaje por indagación para el estudio de las propiedades térmicas de materiales comunes. [Wool or metal? An inquiry learning proposal for the study of the thermal properties of common materials]. *Rev. Electrónica de Enseñanza de las Cienc.* **2016**, *15*, 297–311.
34. Martin-Hansen, L. Defining inquiry. *Sci. Tech.* **2002**, *69*, 34.
35. Pedaste, M.; Mäeots, M.; Siiman, L.A.; de Jong, T.; van Riesen, S.A.N.; Kamp, E.T.; Manoli, C.C.; Zacharia, Z.C.; Tsourlidaki, E. Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educ. Res. Rev.* **2015**, *14*, 47–61. [CrossRef]
36. Crawford, B.A. Learning to teach science as inquiry in the rough and tumble of practice. *J. Res. Sci. Teach.* **2007**, *44*, 613–642. [CrossRef]
37. Graesser, A.; Person, N.K. Question asking during tutoring. *Amer. Educ. Res. J.* **1994**, *31*, 104–137. [CrossRef]
38. Abrandt Dahlgren, M.; Öberg, G. Questioning to learn and learning to question: Structure and function of problem-based learning scenarios in environmental science education. *High. Educ.* **2001**, *41*, 263–282. [CrossRef]
39. Harlen, W. *Teaching, Learning and Assessing Science*; Paul Chapman Publishing PCP: London, UK, 2004.
40. Hodson, D. Hacia un enfoque más crítico del trabajo de laboratorio. [Towards a more critical approach to laboratory work]. *Enseñanza de las Cienc.* **1994**, *12*, 299–313.
41. Chen, C.H.; Chen, C.Y. Instructional approaches on science performances, attitude and inquiry ability in a computer-supported collaborative learning environment. *Turk. Online J. Educ. Technol. TOJET* **2012**, *11*, 113–122.
42. Brenneman, K. Assessment for preschool science learning and learning environments. *Early Child. Res. Pract.* **2011**, *13*, 1–9.
43. García-Carmona, A.; Criado, A.M.; Cañal, P. Alfabetización científica en la etapa 3-6 años: Un análisis de la regulación estatal de enseñanzas mínimas. [Scientific literacy in stage 3-6 years: An analysis of the state regulation of minimum education]. *Enseñanza de las Cienc.* **2014**, *32*, 131–149.

44. McWilliam, R.A.; Scarborough, A.A.; Kim, H. Adult interactions and child engagement. *Early Educ. Dev.* **2003**, *14*, 7–27. [CrossRef]
45. Arici, F.; Yilmaz, M. An examination of the effectiveness of problem-based learning method supported by augmented reality in science education. *J. Comput. Assist. Learn.* **2023**, *39*, 446–476. [CrossRef]
46. Pino-Otína, M.R.; Vala, J.; Ballestero, D.; Navarro, E.; Sánchez, E.; Mainar, A.M. Impact of *Artemisia absinthium* hydrolate extracts with nematicidal activity on non-target soil organisms of different trophic levels. *Ecotoxicol. Environ. Saf.* **2019**, *180*, 565–574. [CrossRef]

education sciences

Article

Nature-Based Solutions and the Decline of Pollution: Solving Problems to Learn Sustainable Development Goals

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Abstract: The Sustainable Development Goals (SDGs) are important issues that should be learned about in school, particularly those related to sustainable cities and communities. Target 6 of the 11th Goal mentions the special attention that should be paid to air quality. Nature-based solutions are a current theme that should be learned in school to empower students to contribute to planetary sustainability. In this context, a pedagogical intervention was developed through problem-based learning addressing air pollution. After two lessons of 50 min each, students presented a worksheet answered in groups, a group snapshot reflection, and the results of filling out a digital mural before and after the intervention. After a content analysis, the results of this evaluation study were reflected in the 105 students' increasing knowledge about nature-based solutions to improve air quality. A positive appreciation of problem-based learning as an active methodology that motivates and increases students' participation was also referred to.

Keywords: sustainable development goals; nature-based solutions; problem-based learning; air pollution

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1. Introduction

Nature-based solutions (NBS) provide an all-encompassing and sustainable approach to resolving the most pressing societal and environmental problems by working harmoniously with nature. Given the ongoing research and/or innovation investments in this field, the growing number of publications is apparent and is anticipated to rise over the following ten years [1]. Over the past 50 years, there has been a noticeable increase in the desire for the genuine involvement of citizens in creating public policies and making decisions, particularly in sustainability. The extent to and various ways in which citizens actively participate in nature-based solutions (NBS), and how their involvement influences the paths these solutions take, are receiving growing interest [2]. However, the complexity of NBS calls for more innovative and transdisciplinary practices, including collaborative governance and genuine engagement with diverse local communities [3,4].

The Earth system integrates five adaptative subsystems (atmosphere, biosphere, cryosphere, geosphere, and hydrosphere) with delicate dynamics that are essential to promote sustainable development and guarantee humanity's survival, as well as being essential for the maintenance of the bio- and geodiversity of our planet [5,6]. As such, it is not surprising that the need for cities worldwide to adopt NBS is growing significantly. NBS can address various issues, including reducing the risk of natural disasters, improving human well-being in urban and rural settings, enhancing biodiversity, enhancing air and water quality, and mitigating climate change. NBS initiatives include the creation of urban green areas, the adoption of natural stormwater management techniques, and the introduction of environmentally friendly transportation options. Their contribution to the development of climate change resilience and ability to assist communities in adapting to its effects is becoming more widely recognised. By preserving or restoring natural habitats, they can also significantly contribute to biodiversity conservation by promoting wildlife and enhancing the general health of ecosystems.

NBS are becoming more globally well-known within agreements, which are frequently seen as essential tools for accomplishing the sustainability goals of the entire planet. Nevertheless, although there are increasing calls for collaborative governance support of sustainability transitions, there is little empirical evidence regarding the contribution of diverse citizen participation to achieve sustainability objectives [3,4]. This is reflected in the teaching and learning processes of NBS and Sustainable Development Goals (SDGs) at all levels of schools and higher education institutions.

A systematic literature review [7] showed that working memory, cognitive flexibility, and attentional control improve after exposure to the natural environment. Namely, outdoor green spaces in the school context contribute to increased concentration and attention [8,9]. However, NBS is a cutting-edge strategy that has not yet been fully included in schools' curricula and higher education programs. Developing a good curriculum can achieve success in the learning and teaching processes in schools, since the curriculum is a set of learning experiences that the students obtain during the teaching process [10]. To improve teaching and learning experiences in NBS, academics and students from various disciplines urgently require methodologies, strategies, and resources.

As sustainability gains ground as a crucial component of growth and economic advancement, there is an opportunity to incorporate environmental plans and policies into economic and social agendas [11]. Research on NBS's capacity to promote long-term socio-ecological sustainability is of the utmost importance in academic and policy circles [4,12]. This implies that NBS can be incorporated into the curriculum alongside the Sustainable Development Goals. The implementation of SDGs teaching is already well documented in the literature [13–15].

Numerous teaching methodologies and strategies can be employed to teach students in NBS and SDGs. The literature refers to some of these methodologies and strategies, which encompass, for example, hands-on experiences [16], case-based teaching [17], field trips [18,19], STEAM approaches [20,21], and the particularly active approach of Problem-Based Learning (PBL) [22,23]. The latter methodology is active, making students the protagonists of their learning rather than just passive information-receivers [24]. According to some authors [24,25], in this modern approach, students are at the centre of the activity and actively participate in the teaching process, encouraging students to learn about natural and social phenomena.

PBL is acknowledged for its capacity to foster various competencies in students while empowering them to control their learning process. In this approach, the teacher assumes the role of a facilitator, although he or she might encounter challenges. Several PBL implementations demonstrate those difficulties, such as the teacher's inability to organise and conduct lessons or the time it takes for students to become independent and solve problems autonomously.

However, critics contend that Problem-Based Learning (PBL) can be time-consuming and is frequently embarked upon by individuals who may not fully grasp its intricacies [26]. Some authors even state that some facilitators feel that their purpose is only to observe the process and tutorial dynamics and lose the control and authority that they had as a teacher. Nonetheless, its effectiveness in enhancing learning is widely acknowledged across multiple academic disciplines [13,27–30].

Within this theoretical framework, this study aimed to assess whether teaching students about reducing pollution through NBS and employing the PBL methodology could enhance their understanding and competencies in SDGs. The two objectives are encompassed: (i) advocating for the adoption of the PBL methodology in SDGs education and (ii) furthering the integration of NBS instruction, specifically through the application of PBL. Additionally, the study shed light on the PBL facilitator's role and the challenges students faced in initiating questions during PBL.

2. Materials and Methods

2.1. Method

The research methodology applied in this investigation was an evaluation study supported by the qualitative method. An evaluation study is characterised by the gathering of data that can be used to determine the relevance or need for improvement of a resource (book, task, activity, lesson plan, etc.). We employed an evaluation research methodology that aimed to examine if and how interventions, particularly those based on PBL and NBS, can bring about changes in the world of education and, if so, why and how. Given the absence of prior learning about the NBS topic in the participants' curriculum, no prerequisites were identified, and no comparative study was conducted between existing findings and the findings after the intervention. The focus was on determining whether Problem-Based Learning (PBL) and incorporating NBS could positively impact students' learning. Consequently, the study was conducted with qualitative data and some descriptive statistics.

2.2. Sample

The sample comprised 105 students (n = 105) from an urban public school, which integrated five 9th-grade Natural Sciences classes. Class 1 (C1) had 23 students, 12 boys and an average age of 14.7. Class 1 (C2) had 20 students, 13 boys and an average age of 14.5. Class 3 (C3) had 22 students, of both genders (male and female), with eleven students and an average age of 14.8. Class 4 (C4), with an average age of 15, had 12 girls, totalling 25 students. Finally, class 5 (C5) had 12 girls, a total of 20 students, and an average age of 14.7. The total sample had ages between 14 and 16, with an average age of 14.7. Most of the students were males (53.34%), and the second author of this article, a Natural Science Teacher, was the facilitator.

2.3. Research Techniques and Instruments

The techniques used during this evaluation study were registers, usually defined in the literature as artefacts. The instruments were of three types: (i) a register in a digital visual board using Padlet software (Version 207.0.6), (ii) a worksheet/monitoring sheet containing the main problematic scenario, and (iii) a snapshot report. Only the monitoring sheet containing the main problematic scenario underwent validation, as the other two resources were developed by the students. The validation of this tool involved its being drafted by the facilitator after conducting a literature review. The instrument was created following the references of Ann Lambros [31]. After elaboration, it was analysed and discussed by a panel of three experts in PBL and modified until a consensus was reached.

A pilot study determined the reliability of the three evaluation tools with 18 students from another school's 9th-grade Natural Sciences class. Students were presented with the problematic scenario and followed the same procedure, which was designed to apply to the present study group. They used three instruments, and the technique of spoken reflection was employed to enhance the formulation of the tools, ensuring they were fully comprehensible to participants of the same age group as the present evaluation study. After gathering all the comments and suggestions from the students, the same panel of PBL experts discussed and improved the instruments until a consensus was reached.

2.4. Procedure

This study was conducted during two consecutive lessons on Natural Sciences of 50 min each.

The students completed the three tasks in Table 1 during the two PBL lessons. The application of the instruments was not timed, but the average response time is also shown in Table 1.

Table 1. Tasks and research instruments of the study.

Task	Research Instrument	Duration (Minutes)
1 Elaboration of a digital visual board.	Padlet Board register	10
2 Raising questions and answers. Part I: Raising questions. Part II: Answering in the digital visual board.	 Worksheet Padlet Board register	 40 35
3 Development of a group report.	Snapshot Report	15

During the two lessons of the evaluation study, the students were invited to complete the following tasks:

Task 1—Elaboration of a Digital Visual Board

In the first assignment, students were required to envision themselves as members of their local town hall assembly. They were instructed to access a Padlet link using the Google Classroom platform. On this platform, they were tasked with proposing actions to diminish environmental air pollution within their municipality, aligning with target 6 of the 11th SDG (particular attention should be paid to air quality). Due to urbanisation and related mortality, air quality is becoming a more significant issue, and NBS solutions are utilised to reduce pollution [32,33]. The solutions proposed by students were expected to minimise their ecological footprint while embodying nature-centric solutions. The solutions were written on the Padlet digital board.

Task 2—Raisin Questions and Answers

Task 2 (part I)—Answering a worksheet

The worksheet followed the PBL structure outlined in some published works [22,31]. It involved the students engaging with a problem scenario that, in this study, included a dialogue between a father and his son regarding the quality of the air and a recent United Nations report regarding the long-term impacts of air pollution in Europe and North America. In this task, students were required to: (i) identify the facts presented in the problem scenario, and (ii) compile essential driving questions to be answered with problem-solving strategies. The facilitator was pivotal in guiding students towards extracting the most pertinent facts from the scenario. Subsequently, students utilised digital resources, such as websites recommended by the facilitator, to explore nature-based solutions. The websites were mentioned in the worksheet and accessible to all participants via the Google Classroom platform, streamlining the research process. Notably, the provided websites were sourced from reliable and reputable outlets. Following this, students formulated "driving questions". In the end, students had to deliver the worksheet with the essential questions they would like to be answered and write them in the worksheet. Afterwards, the driving questions were gathered, submitted to a content analysis technique and analysed regarding the cognitive order based on the work of various authors [34]. This task was guided by recommendations registered in the literature [35].

Task 2 (part II)—Continuing the elaboration of the digital visual board (Padlet)

Following their analysis and discussion of the website information, students working in small groups were tasked with selecting the most relevant questions. This collaborative sharing of findings with other groups occurred in part II of task 2, and students utilised a Padlet link available on the Google Classroom platform for their presentations. During this process, the facilitator provided feedback to each group, empowering them to take greater ownership of their learning compared to traditional classroom settings where teachers primarily disseminate information [36]. Consequently, the online visual board, Padlet, was employed in two distinct phases: (i) the first phase, undertaken before the application of the problem scenario (Task 1); (ii) the second phase (Task 2—part II), conducted after the discussion of the problem scenario and raising of questions.

Task 3—Development of a Group Snapshot Report

A snapshot report is considered a brief report to provide a "snap" of the work that has been carried out. In this study, in a collaborative work, each group of students developed one over fifteen minutes. The snapshot report had three main topics: (i) a reflection on the problematic scenario that was presented, (ii) what was learned during lessons, and (iii) a self-assessment of the work carried out by the group. Creating these snapshot reports represents a metacognitive effort by the group members to synthesise information, collaborate, enhance their critical thinking competencies, and improve their written communication. Additionally, they assess students' perceptions of the assigned task and gather constructive feedback to help facilitators enhance their performance using Problem-based Learning and digital tools.

2.5. Ethical Considerations

In the present study, ethical procedures implicit in the field of social sciences were employed. Data protection for the participants was ensured in accordance with specific legislation in the country in which the study took place. Initially, informed consent was obtained from the director of the urban public school to guarantee access to the school and the facilitator's participation (the second author of this article). Subsequently, as the students were minors, informed consent was sought from their legal guardians—the parents or other legal persons. Lastly, their assent was obtained to ensure the participants' voluntary and informed collaboration in the study. It was established from the outset that the study would not influence the evaluation of the students, and those who chose not to participate would face no form of retaliation. It should be noted that all students from the five classes agreed to participate. Due to ethical reasons, such as maintaining anonymity and confidentiality, an identifying code was assigned when processing the data from each student and class.

3. Data Analysis

This qualitative study employed a content analysis technique to analyse data. Content analysis is used for making replicable and valid inferences from the data to the study's context [37]. It is a well-suited technique for analysing qualitative data and provides valuable insights into the study's results. This technique is suitable for condensing information, transforming the extensive content of a text into a concise set of content categories following coding rules. This study categorised and coded students' records following a fluid reading of the obtained results. The analysis was conducted by three PBL experts who came together to discuss and reach a consensus after individually analysing the records filled out by the students. The results will be presented separately for each task and instrument.

3.1. Results of Task 1: Elaboration of a Digital Visual Board

It should be recalled that the students completed this task before the presentation of the problem-learning scenario. To determine which examples could be considered NBS, answers given by students were classified as having reference to the work of some authors [38]. Regarding the results from the Padlet digital board, students' proposed solutions to diminish environmental air pollution within their municipality were inserted into two categories: (i) Nature-based Solutions (NBS) and (ii) not Nature-Based Solutions (all other types (Not NBS)) (Table 1). Unfortunately, the measures referred to by students were mainly considered in the category "Not NBS". After the authors' reflection, the solutions from both categories were divided into subcategories—"arboreal", "transportation", "industry", and "rules"—as their content was convergent in these matters. To enhance the solutions that contributed most to reducing air pollution, the online tool "NBS performance assessment" [39] expresses the top 15 measures for improving air quality by resorting to NBS. Those top 15 measures are vertical-made gardens, (wet)retention ponds, creating and preserving habitats and shelters to biodiversity green corridors, green facades, green wall systems, heritage gardens, infiltration basins, intensive green roofs, large urban public parks, pocket gardens/pocket parks, semi-intensive green roof, street trees, urban forest, and the use of pre-existing vegetation. Examples of those solutions are presented in Table 2.

Table 2. Results from categorising the five classes' answers in the Padlet digital board (quotes translated from the original text).

Categories	Subcategories		Examples/Quotes of Solutions Presented by Students	Classes
NBS	Spatial arboreal		Reforestation Municipal Day, where reforestation will occur in the municipality. Tree planting The planting of trees of native or regional species and the expansion of the municipal garden network. More planting of trees to increase O_2 and decrease CO_2. Vertical Gardens do not occupy horizontal space and help reduce CO_2 in the atmosphere	C1 C2 C5
	Not Arboreal	River intervention	Promote the cleaning of rivers: Strategic planning of cities to make the most of river or lake areas.	C3
		Soil intervention	Recycle household waste: Composting	C4
Not NBS (Others)	Transportation		Decrease the price of/free public transportation: Increased use of public and/or electric transportation. Limit car use by increasing the use of public transport.	C1 C2 C4
			Sustainable transportation Build more bike lanes. More cycling or walking, as driving is more polluting for the environment. Assign people electric scooters.	C2 C3 C4
	Industry		Eco-friendly solution: Use filters in factory chimneys. Decrease of excessive production in factories	C1, C2, C3, C4, C5 C4
	Legislation		To legislate: Applicate fines for those who do not comply with the rules. Prohibit the use of fire in danger zones. Tax benefits for individuals who have solar panels.	C1 C1, C5

Analysing the results allows for us to ascertain that students from all classes have limited knowledge about Nature-Based Solutions. Furthermore, most solutions tend to focus on pro-environmental behaviours for sustainability. These findings underscore the necessity for school curricula to incorporate NBS as an integrated theme across various disciplines. It is worth noting that NBS can be linked to Education for the SDGs, enhancing urban citizens' well-being, and investing in circular cities. Integrating green initiatives into urban areas represents an innovative and pressing issue at present. Consequently, teaching NBS is also a way to teach the SDGs.

3.2. Results of Task 2: Raising and Answering Questions

3.2.1. Part I: Raising Questions

The student groups from the five classes answered the worksheet, and the main questions that were raised are presented in Table 3. This task had a high level of supervision from the facilitator as the literature reconises how difficult it is for students to know how to write questions of a higher cognitive order. As such, driving questions raised by students were classified according to [40] five categories: encyclopedic, meaning-oriented, relational, value-oriented, and solution-oriented. Table 3. Questions raised in the worksheet and categorisations of the cognitive level of the questions. The results reveal students' uncertainty regarding NBS. Consequently, the question "What are nature-based solutions?" was raised repeatedly in all five classes. Another joint inquiry was "What are nature-based solutions for reducing air pollution?" This highlights the importance of the PBL methodology because problematisation encourages students to contemplate the most crucial questions to solve the problem presented in the scenario. This approach ultimately leads to a deeper understanding of the meaning and utility of NBS for society. Once again, this activity underscores that students need guidance in learning to pose questions, especially those of higher cognitive levels.

Table 3. NBS categorisation (categorisation based on the top 15 NBS for improving air quality).

Categories of NBS		Subcategories	Examples of Solutions Presented by the Students	Classes
NBS Units	Spatial units	Spatial Arboreal units (street trees, urban forest)	Planting of trees.	C1
			Planting of trees that allow for the native species' expansion.	C2
			Planting trees of native species.	C3, C4
		Spatial Mixed Vegetation Units (large urban park, pocket garden, heritage garden, green corridors)	Creation of green areas with specimens of native plants.	C1
			Municipal gardens with aquaponics techniques.	C2, C4
			Increase the network of municipal gardens.	C3, C4, C5
			Construction of green spaces in urban areas.	C3, C4
	NBS Technological Unitsr	Technological vertical units (green wall system, green façade, vertical mobile garden)	Creation of green walls	C1, C2, C3, C4, C5
		Technological Horizontal Units (infiltration basin, wet retention pond, intensive green roof, semi-intensive green roof)	Creation of green roofs	C1, C2, C3, C4, C5
NBS Interventions		Biodiversity Interventions (create and preserve habitats and shelters for biodiversity, use of preexisting vegetation)	Reforestation	C1, C3, C4
			Using natural or environmentally friendly integration of buildings in the surroundings	C2
			Restoration or management of natural and semi-natural ecosystems.	C3, C5
			Creation of natural habitats.	C3
			Preservation of natural forests.	C4
			Avoid the use of pesticides, giving preference to biological control.	C4, C5

3.2.2. Part II: Answering in the Digital Visual Board

As mentioned earlier, the responses provided by each class post application of the digital visual board, completed after the problem-solving second lesson, were recorded and are presented in Tables 4 and 5. A similar procedure was conducted to evaluate the outcomes after implementation of the first digital visual board intervention during the first lesson (Table 1). The NBS mentioned by students' classifications was based on the hierarchical classification scheme in previous work [38]. After some reflection, the authors ended up setting two content categories: (1) Nature-Based Solution Units (NBS Units) and (2) Nature-Based Solution Interventions (NBS Interventions). Again, the top 15 measures for improving air quality by resorting to NBS were essential to analyse the solutions presented by students. This content analysis is expressed in Table 3.

Table 4. NBS advantages (categorisation made after Watkin, 2019 [39]).

Categories of NBS Benefits	Examples of NBS Benefits Presented by Students. (Quotes)	Classes
Nature (environmental features of soil, air, and vegetation)	Improve air quality.	C1, C3, C4
	Mitigate some of the effects of climate change.	C1
	Moderate impacts of heat waves.	C1, C3, C4
	Reduce global warming and heat islands.	C1, C4
	Reduce air pollution.	C2, C3, C4, C5
	Contribute to the promotion of biodiversity.	C1, C3, C4, C5
	Increase the existence of native trees and plants.	C2, C3
	Value soils.	C3, C4, C5
	Increase carbon storage capacity.	C4
	Mitigate the heat island effect.	C5
People (cultural, education, recreation and economics)	Provide social and economic benefits and help to build resilience.	C1
	Move economies and societies into a sustainable path.	C1
	Improve citizens' quality of life.	C1, C3, C5
	Benefit mental and physical health.	C1, C2, C4
	Reduce health problems, especially respiratory problems.	C2, C3, C5
	Adopt solutions that contribute to the reduction of energy consumption.	C2, C3, C4, C5
	Improve the energy efficiency of buildings.	C2, C3
	Make the city more pleasant and more comfortable.	C4
Water (flood mitigation, drought and flood resilience, water storage and reuse, and groundwater and surface water quality)	Optimise rainwater management.	C4
	Strategic planning of cities to take full advantage of river or lake areas.	C5
	Enhancement of aquifer recharge.	C5

Having other reference research in the field [40], the benefits of the NBS appointed by the students' classes were also divided into three topics—"nature", "people", or "water" These were organised as follows: (i) "nature" benefits mentioned the soil, air, and vegetation as environmental features; (ii) "people" benefits focused on cultural, education, recreation, and economic benefits; (iii) the "water" benefits were all those answers related to water storage and water reuse. This content analysis is displayed in Table 4.

Notably, after the problem scenario presentation, students referred to more NBS, which were learned during the problem-solving lessons. However, Nature-Based Benefits continued to focus on pro-environmental behaviours for sustainability, which is highly positive since it is recommended that school curricula also align with Agenda 2030 for SDGs. Once more, these findings emphasise the crucial need for educational curricula to seamlessly integrate NBS into various disciplines. Incorporating environmentally sustainable practices into urban environments is a forward-thinking and urgent challenge in contemporary society. Therefore, it is imperative to introduce these concepts into middle and secondary education.

3.3. Results of Task 3: Development of a Group Snapshot Report

At the end of the PBL methodology application, the students wrote a snapshot report in 4–5 groups in each class. This snapshot report allowed for the researchers to gather information regarding the PBL methodology. Table 5 presents a content analysis of the snapshots based on relevant quotations provided in the snapshot reports.

The content analysis of the snapshot reports revealed that, in all classes, the problem extracted from the scenario presentation was remarkably similar. Students consistently addressed the issue of air pollution and potential NBS. Across all classes, students mentioned that they had learned that nature-based solutions are vital for ensuring planetary sustainability and improving air quality. Group work proved beneficial for learning, making classes more dynamic, although not all group members consistently contributed at a high level. Consequently, the PBL methodology is seen as a positive approach, enhancing the teaching process and enabling students to develop the necessary content. It is important to note that collaborative work competence, written communication, digital competencies, and critical thinking were all developed through the proposed activities.

Table 5. Content analysis of the snapshots (quotes translated from the original text).

Classes	The Problem Raised as Understood by the Students	What Students Say That They Have Learned	Self-Assessment of the PBL Group Work
Class 1	What are Nature-based Solutions that reduce air pollution, and what are their advantages?	To reduce atmospheric pollution, vertical gardens, green roofs, reforestation, and expansion of vegetable gardens should be built.	Not everyone collaborated similarly; however, all members did well in consolidating the matter.
	The problem was presented to us digitally, which motivated us to work more sustainably and with less paper use.	We learned numerous solutions to pollution and how to combat it sustainably.	We were a rather talkative and distracted group.
Class 2	The main problem is air pollution, which decreases the amount of oxygen in the air, which causes more people to develop breathing problems.	We learned that the air is polluted and about nature-based solutions and their consequences.	Everyone contributed to the completion of the work. We share tasks with everyone.
	It was easy to understand and conclude. It was presented in a way that occurs in everyday life, facilitating the understanding of the subject matter.	How to prevent air pollution and the importance of solutions based on nature.	We enjoyed working together, and everyone learned something.
Class 3	The problem presented is "The air that surrounds us". We enjoy learning more about this issue, which motivates us to learn about Nature-based Solutions.	We learned that we must preserve our planet.	We work better in a group, and these classes are better.
	In our opinion, the problem helped us understand the mistakes that society makes and some of the advantages of having a better quality of life in the future	These nature-based solutions helped us to understand the problem in a more specific way.	We find it interesting since we can cooperate and combine ideas to obtain the best possible result.
Class 4	Decreased air quality. Cardiorespiratory problems. Atmospheric pollution.	We learned measures to reduce atmospheric pollution and general advantages of solutions based on nature.	We performed well as a group. The group work was more dynamic, and there was more interest in doing the work.
	The presented problem motivates us to learn about the problems that occur in the atmosphere caused by humans.	With this experience, we learned that we must adopt measures to reduce pollution to obtain better living conditions and to have a better planet.	This work was creative, different and more about learning how we look for information.
Class 5	The problem was related to what we can do in our daily lives, to reduce atmospheric pollution, presenting solutions based on nature.	We learned the importance of Nature to save our planet and also the consequences of our actions.	Our working group worked well, although some elements were more participatory than others.
	In this group work, the problem presented was atmospheric pollution, and through the theme, we became aware of how human beings affects the environment.	We learn and know new measures for the implementation of a better environment, such as, for example, the creation of green roofs and walls.	Our working group has a healthy environment, and we work well together.

4. Discussion

The results from the first task, expressed in Table 2, show that almost all the measures appointed in the five students' classes had three main focuses: promote the use of transportation with less environmental impact (such as building more bike lanes), act through the implementation of legislation (particularly taxation) or limit pollution by industries (mainly through the filtration of polluting gases). This observation is consistent with the idea that industry is frequently appointed as bearing a responsibility for air pollution in students' minds [41]. Therefore, students, in general, were not familiar with the concept of NBS.

Suggestions of NBS measures to reduce air pollution were scarce and focused on spatial arboreal units, favouring "tree plantation" (although two more types of NBS measures were appointed, these were not directly implicated in the decreasing of polluted air, but in river management and soil conservation). This finding might be related to the fact that the NBS concept is not officially mentioned in the Natural Sciences syllabus in Portuguese schools from the 7th to 9th grades. Another reason is possibly related to the scientific literature, in which NBS is a relatively recent issue [42,43]. For example, considering the bibliometric analysis of some authors [43], the first articles mentioning NBS as an issue are dated from 2012. It is also noted that discourse on NBS is not yet totally embedded in the decision-making processes. In 2013, the European Commission tried to establish the NBS concept within the range of ecosystem-based approaches, and the calls for projects in this field were launched approximately seven years ago [42]. In this line of thought, it is plausible to assume that this time frame did not allow for the effective empowerment of citizens about this matter.

In employing the PBL, it is noteworthy that, following the intervention, students demonstrated a relevant awareness of the NBS that aligned with what they had learned during the problem-solving sessions. While there were some variations among classes, it is striking that the questions raised by students exhibited similarities, possibly due to the consistent scenario and the facilitator's experience. This could also be due to the nature of the exercise and the fact that it was uniformly applied, reflecting a thought-out instructional design.

The consistent success of PBL as a methodology across all the classes to which it was applied is a significant observation that is worth highlighting. Nonetheless, an extensive body of literature attests to the efficacy of PBL as a constructive approach for facilitating students' comprehension of scientific concepts and nurturing the diverse competencies essential for success in the 21st-century job market [44,45]. It is equally notable that the literature frequently highlights students' challenges in formulating questions, particularly those of moderate or advanced complexity [34]. This underscores the critical requirement for a skilled facilitator who can actively stimulate and bolster the development of self-confidence and autonomy within the student's learning journey [46,47].

The digital board utilised within the PBL methodology received positive feedback from students, significantly contributing to the success of this methodology. Through PBL, students engaged with the subject matter and integrated the acquisition of digital competencies, which are increasingly relevant. This approach bridges the gap between the teaching process and students' real-world experiences, but can also aid them in becoming proficient in using digital tools [48].

5. Conclusions

This study has provided valuable insights. It revealed that, when implementing the PBL methodology, students significantly improved their understanding of NBS and their role in reducing pollution. Equally important is the connection made between the study's objectives and the 2030 Agenda for SDGs. This highlights how the presented problem aligns with global sustainability goals. The research underscores the pivotal role of the facilitator in guiding students' learning journeys, ultimately enhancing their performance and helping them attain academic success. These findings support the existing literature on the development of diverse competencies fostered by this methodology and emphasise the urgency of integrating PBL, the sustainable development objectives, and the theme of nature-based solutions into educational curricula. While the positive impact of the PBL methodology is evident, there is still room for further refinement and expansion of its application across various disciplines. Moreover, it can be effectively integrated into different approaches, such as the STEAM approach. This approach is particularly noteworthy as it fosters competency development and promotes greater inclusivity, especially for underrepresented groups like girls, in fields where they are not yet adequately represented. It can also assess success when applied to current scientific content, such as the SDGs and NBS, as in this evaluation study. Being an active methodology, despite originating in the 1960s, it remains relevant in promoting the development of competencies necessary for employability in the 21st century, such as cooperative work, problem-solving, and the development of knowledge, digital competencies, and critical thinking.

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References

1. Herranz-Pascual, K.; Garcia-Pérez, I.; Zorita, S.; García-Madruga, C.; Cantergiani, C.; Skodra, J.; Iraurgi, I. A Proposal of a Tool to Assess Psychosocial Benefits of Nature-Based Interventions for Sustainable Built Environment. *Sustainability* **2023**, *15*, 8046. [CrossRef]
2. Kiss, B.; Sekulova, F.; Hörschelmann, K.; Salk, C.F.; Takahashi, W.; Wamsler, C. Citizen participation in the governance of nature-based solutions. *Environ. Policy Gov.* **2022**, *32*, 247–272. [CrossRef]
3. Wamsler, C.; Raggers, S. Principles for supporting city–citizen commoning for climate adaptation: From adaptation governance to sustainable transformation. *Environ. Sci. Policy* **2018**, *85*, 81–89. [CrossRef]
4. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. Nature-based solutions to address global societal challenges. *IUCN Gland. Switz.* **2016**, *97*, 2016–2036.
5. Ribeiro, T.; Orion, N. Educating for a Holistic View of the Earth System: A Review. *Geosciences* **2021**, *11*, 485. [CrossRef]
6. Vasconcelos, C.; Orion, N. Earth Science Education as a Key Component of Education for Sustainability. *Sustainability* **2021**, *13*, 1316. [CrossRef]
7. Stevenson, M.P.; Schilhab, T.; Bentsen, P. Attention Restoration Theory II: A systematic review to clarify attention processes affected by exposure to natural environments. *J. Toxicol. Environ. Health Part B* **2018**, *21*, 227–268. [CrossRef]
8. Browning, M.H.E.M.; Rigolon, A. School Green Space and Its Impact on Academic Performance: A Systematic Literature Review. *Int. J. Environ. Res. Public Health* **2019**, *16*, 429. [CrossRef]
9. McCullough, M.B.; Martin, M.D.; Sajady, M.A. Implementing Green Walls in Schools. *Front. Psychol.* **2018**, *9*, 619. [CrossRef]
10. Supriyoko, S.; Nisa, A.F.; Uktolseja, N.F. The nature-based school curriculum: A solution to learning-teaching that promotes students' freedom. *J. Cakrawala Pendidik.* **2022**, *41*, 643–652. [CrossRef]
11. Tomaskinova, J.; Geneletti, D.; Dicks, L.; Grace, M.; Collier, M.; Longato, D.; Stoev, P.; Sapundzhieva, A.; Balzan, M. Capacity-building as an instrument to foster the implementation of nature-based solutions. *Res. Ideas Outcomes* **2021**, *7*, e77666. [CrossRef]
12. Wilkinson, C.; Saarne, T.; Peterson, G.D.; Colding, J. Strategic Spatial Planning and the Ecosystem Services Concept—An Historical Exploration. *Ecol. Soc.* **2013**, *18*, 569–585. [CrossRef]
13. Aragon-Correa, J.A.; Marcus, A.A.; Rivera, J.E.; Kenworthy, A.L. Sustainability Management Teaching Resources and the Challenge of Balancing Planet, People, and Profits. *Acad. Manag. Learn. Educ.* **2017**, *16*, 469–483. [CrossRef]
14. Dayrit, F.; Enriquez, E. Teaching Sustainability in Science: The Case for Chemistry. *Philipp. J. Sci.* **2023**, *152*, ix–xi. [CrossRef]
15. Bierbaum, R.; Lazaroff, M. From Theory to Practice: The Student Experience Evaluating Development Projects Focused on Nature-Based Solutions. *Sustainability* **2022**, *14*, 5722. [CrossRef]

16. Thomas, M.D.; O'Connor, F.W.; Albert, M.L.; Boutain, D.; Brandt, P.A. Case-based teaching and learning experiences. *Issues Ment. Health Nurs.* **2001**, *22*, 517–531. [CrossRef] [PubMed]
17. Esteves, H.; Fernandes, I.; Vasconcelos, C. A Field-based Approach to Teach Geoscience: A Study with Secondary Students. *Procedia Soc. Behav. Sci.* **2015**, *191*, 63–67. [CrossRef]
18. Lima, A.; Vasconcelos, C.; Félix, N.; Barros, J.; Mendonça, A. Field trip activity in an ancient gold mine: Scientific literacy in informal education. *Public Underst. Sci.* **2009**, *19*, 322–334. [CrossRef]
19. Kwack, H.R.; Jang, E.J. Development and application of a STEAM program using classroom wall gardens. *J. People Plants Environ.* **2021**, *24*, 365–376. [CrossRef]
20. Marín-Marín, J.-A.; Moreno-Guerrero, A.-J.; Dúo-Terrón, P.; López-Belmonte, J. STEAM in education: A bibliometric analysis of performance and co-words in Web of Science. *Int. J. STEM Educ.* **2021**, *8*, 41. [CrossRef]
21. Vasconcelos, C. Teaching Environmental Education through PBL: Evaluation of a Teaching Intervention Program. *Res. Sci. Educ.* **2010**, *42*, 219–232. [CrossRef]
22. Pinto, T.; Dias, A.G.; Vasconcelos, C. Geology and Environment: A Problem-Based Learning Study in Higher Education. *Geosciences* **2021**, *11*, 173. [CrossRef]
23. Crisol-Moya, E.; Romero-López, M.A.; Caurcel-Cara, M.J. Active Methodologies in Higher Education: Perception and Opinion as Evaluated by Professors and Their Students in the Teaching-Learning Process. *Front. Psychol.* **2020**, *11*, 1703. [CrossRef]
24. Anđić, D.; Mažar, S. Teachers' Connectedness to Nature, Education for Sustainable Development and the Contemporary Teaching of the Subject "Nature and Society" in Croatian Schools. *J. Teach. Educ. Sustain.* **2023**, *25*, 86–97. [CrossRef]
25. Kilroy, D.A. Problem-based learning. *Emerg. Med. J.* **2004**, *4*, 411–413. [CrossRef] [PubMed]
26. Giangrande, N.; White, R.M.; East, M.; Jackson, R.; Clarke, T.; Coste, M.S.; Penha-Lopes, G. A Competency Framework to Assess and Activate Education for Sustainable Development: Addressing the UN Sustainable Development Goals 4.7 Challenge. *Sustainability* **2019**, *11*, 2832. [CrossRef]
27. Iwinska, K.; Jones, M.; Kraszewska, M.; Civitas, C. (Eds.) *Widening Interdisciplinary Sustainability Education*; Collegium Civitas: Warsaw, Poland, 2018. [CrossRef]
28. Barth, M.; Godemann, J.; Rieckmann, M.; Stoltenberg, U. Developing key competencies for sustainable development in higher education. *Int. J. Sustain. High Educ.* **2007**, *8*, 416–430. [CrossRef]
29. Brennan, C.; Molloy, O. A system dynamics approach to sustainability education. *Syst. Res. Behav. Sci.* **2020**, *37*, 875. [CrossRef]
30. Lambros, A. *Problem-Based Learning in K-8 Classrooms: A Teacher's Guide to Implementation*; Corwin Press: Thousand Oaks, CA, USA, 2002.
31. Stieb, D.M.; Smith-Doiron, M.; Quick, M.; Christidis, T.; Xi, G.; Miles, R.M.; van Donkelaar, A.; Martin, R.V.; Hystad, P.; Tjepkema, M. Inequality in the Distribution of Air Pollution Attributable Mortality Within Canadian Cities. *GeoHealth* **2023**, *7*, e2023GH000816. [CrossRef]
32. Mata, T.M.; Oliveira, G.M.; Monteiro, H.; Silva, G.V.; Caetano, N.S.; Martins, A.A. Indoor Air Quality Improvement Using Nature-Based Solutions: Design Proposals to Greener Cities. *Int. J. Environ. Res. Public Health* **2021**, *18*, 8472. [CrossRef]
33. Dahlgren, M.A.; Öberg, G. Questioning to learn and learning to question: Structure and function of problem-based learning scenarios in environmental science education. *High. Educ.* **2001**, *41*, 263–282. [CrossRef]
34. McConnel, T.; Parker, J.; Eberhardt, J. *Problem-Based Learning in the Earth and Space Science Classroom, K-12*; National Science Teachers Association (NSTA): Arlington, TX, USA, 2017; pp. 7–32.
35. Barell, J. *Problem-Based Learning—An Inquiry Approach*, 2nd ed.; Corwin Press: Thousand Oaks, CA, USA, 2007; p. 35.
36. Krippendorff, K. *Content Analysis: An Introduction to Its Methodology*; Sage Publications: Thousand Oaks, CA, USA, 2018.
37. Castellar, J.; Popartan, L.; Pueyo-Ros, J.; Atanasova, N.; Langergraber, G.; Säumel, I.; Corominas, L.; Comas, J.; Acuña, V. Nature-based solutions in the urban context: Terminology, classification and scoring for urban challenges and ecosystem services. *Sci. Total Environ.* **2021**, *779*, 146237. [CrossRef]
38. NBS Performance Assessment. Available online: https://icra.shinyapps.io/nbs-list/ (accessed on 10 July 2023).
39. Watkin, L.J.; Ruangpan, L.; Vojinovic, Z.; Weesakul, S.; Torres, A.S. A Framework for Assessing Benefits of Implemented Nature-Based Solutions. *Sustainability* **2019**, *11*, 6788. [CrossRef]
40. Boyes, E.; Myers, G.; Skamp, K.; Stanisstreet, M.; Yeung, S. Air quality: A comparison of students' conceptions and attitudes across the continents. *Compare* **2007**, *37*, 425–445. [CrossRef]
41. Faivre, N.; Fritz, M.; Freitas, T.; de Boissezon, B.; Vandewoestijne, S. Nature-Based Solutions in the EU: Innovating with nature to address social, economic and environmental challenges. *Environ. Res.* **2017**, *159*, 509–518. [CrossRef]
42. Mendes, R.; Fidélis, T.; Roebeling, P.; Teles, F. The Institutionalization of Nature-Based Solutions—A Discourse Analysis of Emergent Literature. *Resources* **2020**, *9*, 6. [CrossRef]
43. Varías-Palacios, R.A.; Llontop-Ynga, E.; Urillo-Tapia, J.P.; Murillo-Tapia, P.; Tenorio-Vilchez, C. Research Skills in High School Students: A Systematic Review. *Rev. Iberoam. Psicol. Ejerc. Deporte* **2023**, *88*, 109–112.
44. Amanda, F.F.; Sumitro, S.B.; Lestari, S.R.; Ibrohim, I. The Correlation of Critical Thinking and Concept Mastery to Problem-solving Skills: The Role of Complexity Science-Problem Based Learning Model. *Pedagogika* **2022**, *146*, 80–94. [CrossRef]
45. Boud, D.; Feletti, G. (Eds.) *The Challenge of Problem-Based Learning*; Kogan Page: London, UK, 1991.
46. Gavrić, N.; Radivojević, D. Problem-based and Inquiry-based learning in the Teaching of Nature and Society. *J. Educ. Soc. Multicult.* **2022**, *3*, 99–116. [CrossRef]

47. Dang, D.; Vartiainen, T. Digital Strategy in Information Systems: A Literature Review and an Educational Solution Based on Problem-Based Learning. *J. Inf. Syst. Educ.* **2022**, *33*, 261–282.
48. Goh, D.; Kale, U. From Print to Digital Platforms: A PBL Framework for Fostering Multimedia Competencies and Consciousness in Traditional Journalism Education. *J. Mass Commun. Educ.* **2015**, *70*, 307–323. [CrossRef]

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Article

Digital Redesign of Problem-Based Learning (PBL) from Face-to-Face to Synchronous Online in Biomedical Sciences MSc Courses and the Student Perspective

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Abstract: PBL is a widely used teaching approach that is increasingly incorporating digital components. Although, by its nature, a face-to-face approach is the preferred mode of delivery, its digital counterpart is gaining ground. The current paper discusses the digital redesign of PBL in an MSc in Biomedical Sciences. Face-to-face and online PBL followed the seven steps of the PBL process, and each case was completed in three sessions. For the delivery of online PBL, collaborative tools were utilized, including CiscoWebex, the online platform for synchronous meetings, and OneDrive, shareable PPT, and Moodle for synchronous and asynchronous self-directed learning. Three cohorts were followed, and students had both face-to-face and online PBL experiences. Student feedback was obtained using focus groups, and data analysis utilized a deductive and inductive approach. Our data indicate that CiscoWebex is a suitable and user-friendly platform for synchronous online PBL. The students enjoyed both formats and stated that online PBL is an effective teaching approach for promoting student learning. In regards to student interaction, the face-to-face mode was preferred, while online PBL was perceived as more organized. The redesign allowed for effective student learning and could pave the way forward for a fully online MSc program in Biomedical Sciences.

Keywords: online PBL; PBL in STEM; biomedical sciences; immunology; MSc students; student perceptions

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1. Introduction

Problem-based learning is an educational approach commonly used in tertiary health education programs. This is because it promotes the development of skills that are key to health professions, including critical thinking, collaboration, problem-solving, and self-directed learning [1]. Traditionally, PBL utilizes a real-case scenario, small-group work, and student-centered learning. By its nature, a face-to-face approach is the preferred mode of delivery. Currently, there is a trend to incorporate digital technology into PBL either fully or in part [2].

This is not surprising as synchronous e-learning provides a flexible environment for learning. This can be attributed to several factors, including the availability of a plethora of resources such as virtual classrooms and shareable whiteboards (WB) and documents [3,4]. The fact that it may be synchronous still allows for teacher–student and student–student interactions using electronic tools (such as the 'raise hand' feature) rather than reading body language. Still, this may limit the ability of the student to read non-verbal cues and decrease effective communication. Cost efficiency is another key advantage of e-learning, and the savings are transferred to both the education institution (e.g., infrastructure, staffing) as well as the learner (e.g., travel, time) [5,6].

The COVID-19 pandemic contributed to the push toward online education, providing the opportunity for creative online teaching. [7]. As previously suggested, PBL is well-suited for online teaching. To illustrate, PBL works best with a small number of participants (8–12), and this does not overload the network. This allows for simultaneous work that facilitates effective synchronous communication. In addition, the online environment may allow for the participation of individuals that are shy and do not participate in face-to-face PBL [8]. It is also possible that shy students may hide behind technology, decreasing participation. Furthermore, PBL relies on both synchronous and asynchronous teaching. The latter is particularly important for self-directed learning, which is one of the key characteristics of PBL. Students may continue interacting and sharing information through platforms such as Moodle or Blackboard. By engaging with the digital world, students become part of a learning community and may embrace life-long learning in the future [8].

Even if it is becoming more common to provide PBL components digitally, studies that have already been conducted, albeit with a small sample size, have shown encouraging results. There is no discernible performance difference between traditional and online PBL formats, according to the research, despite ongoing difficulties with student involvement and technological adaption [8,9]. Therefore, additional in-depth research is required to fully comprehend the efficiency of PBL presented online.

Student communication is one of the key skills gained in PBL, and it is not yet clear whether this skill is comparably achieved in online PBL. This may relate to student perception as well as actual information shared. A study by Lajoie et al. (2014) indicated that discussion was just as rich in the online setting, while the students noted that the flow was disrupted as they had to use the 'raise hand' tool [6,10]. Notably, Leavy et al. (2022), that transitioned from traditional to online PBL in an undergraduate health sciences unit in an Australian university highlighted that as the process was refined, both students and tutors became more comfortable with the technology, and collaboration improved [11].

The framework for this research is grounded on the constructivist theory upon which PBL is built. The constructivist approach is based on the premise that knowledge is constructed by the learners rather than passively taken in [12]. As such, in constructivist teaching, students are actively involved and utilize existing knowledge to tackle real-life problems. Online education runs the risk of a low-level learning experience. This may occur when traditional teaching material is transferred directly to an online setting without taking into consideration the online learning environment. As such, when moving from the traditional face-to-face setting to the online mode, this basic premise of the PBL teaching approach needs to be addressed. As such, the current study was also grounded on the computer-supported collaborative learning (CSCL) pedagogical approach. The constructivist approach discussed above is the basis for the CSCL environment, and it 'provides a framework to bring individual learners together to achieve a shared learning goal by managing their learning processes' [13].

The current study had two research questions:

1. Can a face-to-face traditional PBL curriculum be delivered digitally, and what are the best tools?
2. How do students perceive PBL in the two delivery settings (face-to-face vs. online)?

2. Materials and Methods

2.1. Setting and Participants

The study was conducted from 2019 to 2023, and three cohorts of students participated (2019–2021; $n = 7$, 2020–2022; $n = 10$ and 2021–2023; $n = 13$). All students enrolled in the MSc in Biomedical Sciences (Immunology concentration) at the University of Nicosia in Cyprus were invited to participate in the study following completion of the MSc and on a voluntary basis to avoid bias. Informed consent was obtained from all participants. The MSc requires three Semesters for completion. Students attended a course that incorporated PBL each semester and attended PBL either face-to-face or online. In all courses of the MSc in Biomedical Sciences, the case studies took the format of long-case PBL. Each case took three sessions to be completed. The long cases follow the seven-step Maastricht model. All classes were hybrid, including both PBL and lectures. The lecture component comprised basic immunology information to bring students to the same level prior to PBL. In Semester 1, students were given a lecture with an overview of PBL, and the course had two case studies interspersed with lectures to introduce the teaching method. In the subsequent semesters, PBL was the predominant mode of teaching. The three cohorts were exposed to different combinations of face-to-face and online PBL delivery. Details are provided in Table 1. All students received training on how to use the online tools through the Distance Learning unit of the University of Nicosia. Students also attended an 'Introduction to PBL' session by the tutor the week prior to PBL delivery in Semester 1.

Table 1. Courses and mode of teaching in three cohorts.

	Number of PBL Cases (n = # of Weeks of the Course)	Cohort 1 2019–2021 (n = 7)	Cohort 2 2020–2022 (n = 10)	Cohort 3 2021–2023 (n = 13)
Semester 1: Cellular and Molecular Immunology	2 (6)	Face-to-face	Online	Face-to-face
Semester 2: Autoimmunity and Inflammatory Disorders	4 (12)	Online	Online	Online
Semester 3: Immunodeficiency Disorders and Control	4 (12)	Online	Face-to-face	Face-to-face

2.2. Face-to-Face and Online PBL Delivery

One course from each semester was designed for both face-to-face and online delivery. Tools were chosen to ensure close adherence to the PBL delivery. Face-to-face delivery was the normal mode of delivery and included the use of a physical classroom that included a round table and a whiteboard (WB). In this case, all case material was handed out and printed sequentially.

Face-to-face PBL was redesigned for online delivery following a careful selection of online tools. The selection relied on (a) ability of the tool to promote PBL principles and (b) availability of the tools (either free or through university licenses). CiscoWebex was used as the online platform for synchronous teaching. This platform incorporates several features that support effective synchronous communication, including real-time visual/audio communication, screen-sharing, live chat, 'raise hand' and 'emotion icons', as well as recording and archiving of sessions. Some of the features are shown in Figure 1. To encourage student participation, the following steps were taken: (a) students were instructed to leave their cameras ON at all times and microphones OFF if they did not speak, (b) the 'raise hand' tool was used to ensure everyone had a voice, and importantly, (c) the facilitators were experienced PBL tutors.

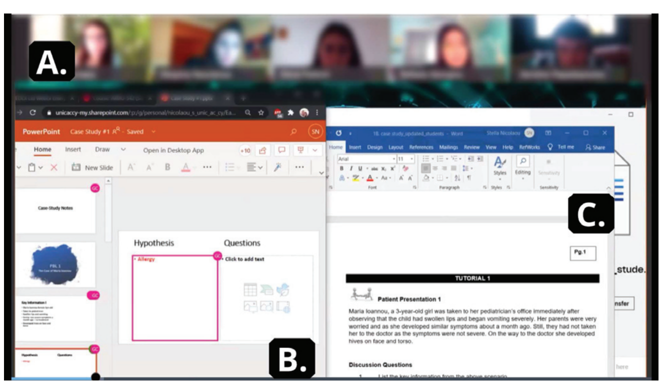

Figure 1. A screenshot from CiscoWebex during a PBL session. (**A**) participants leave their cameras ON, (**B**) the shareable PPT allows for live interaction, and (**C**) the case study is presented to the students.

2.3. Focus Groups

To obtain the student opinion on PBL and answer our research question, all students from the three cohorts who trained using both face-to-face and online PBL were invited to participate. The participation rate was 73% (Table 2). Prior to the focus group, we constructed a semi-structured guide and organized questions around two areas (a) PBL in general and (b) different modes of teaching PBL (face-to-face vs. online). Open-ended questions designed to stimulate discussion included, among others, prompting to discuss PBL in general, comparison of different modes of delivery, the virtual environment and tools, and adherence to PBL principles. The focus groups were conducted online using the CiscoWebex platform by two researchers that acted as a moderator or note-taker in each focus group. One of the researchers taught one of the three courses, whilst the other was not involved. Focus groups lasted for about one hour and were recorded and transcribed verbatim.

Table 2. Student enrolment number and focus group participation.

	Cohort 1 2019–2021	Cohort 2 2020–2022	Cohort 3 2021–2023	Total
Number of Students #	7	10	13	30
Focus Group	7	7	8	22
% participation	100%	70%	62%	73%

2.4. Qualitative Data Analysis

A thematic analysis of the three focus groups was conducted by the two researchers who had experience with PBL and thematic analysis. Specifically, the two researchers performed the following steps independently: familiarized themselves with the data and then summarized the data to identify meaning units, condensed meaning units, and codes that were subsequently refined into categories and themes. The coding relied both on a deductive (pre-determined areas of inquiry) and an inductive approach (generated codes directly from the data). Once these steps were completed, the two researchers discussed and agreed on a final list of categories and themes [14].

3. Results

3.1. Redesigning Long Case PBL from Face-to-Face to Online

As with most traditional PBL programs, the one discussed here followed the seven steps of PBL and was delivered face-to-face (Figure 2).

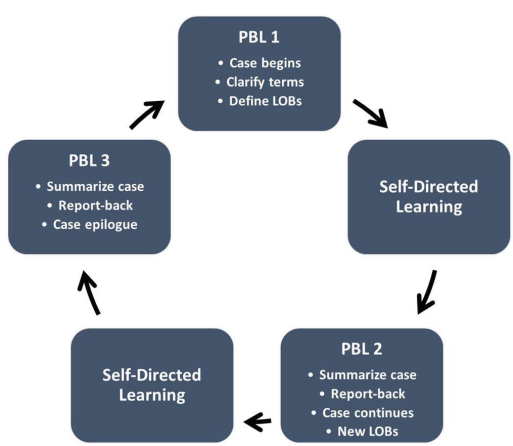

Figure 2. Overview of long-case PBL.

During the redesign process, all steps of the PBL process were defined in detail, and online tools that could facilitate each step were identified (Table 3). Specifically, for synchronous collaboration, the classroom was substituted with the CiscoWebex platform; the WB and markers were substituted with a shareable PowerPoint (PPT) (shared through Microsoft OneDrive). Knowledge was shared through the open-source learning management system, Moodle, to facilitate asynchronous collaboration. The structure of the three sessions is shown in detail in Supplementary Table S1.

Table 3. Face-to-face and Online PBL process tools used.

	Face-to-Face PBL	Online PBL
PBL 1	Printed handout Whiteboard (WB) and markers Take a photo/copy of the information on the WB	Webex meetings (Share screen) OneDrive—share the PowerPoint (PPT)
Self-Directed Learning	Personal notes on paper/computer/any other mode	Upload LOBs on Moodle
PBL 2	Student notes or photos of the WB	Moodle and shareable PPT
	WB and markers	Shareable PPT
Self-Directed Learning	Personal notes on paper/computer/any other mode	Upload LOBs on Moodle
PBL 3	Student notes or photos of the WB	Moodle and shareable PPT
	WB and markers	Shareable PPT

WB: Whiteboard; PPT: PowerPoint.

3.2. Student Perceptions

Initially, cohort-specific analysis was performed to identify themes, categories, and codes. Our analysis did not show any major differences between the three cohorts, and as such, the data were pooled together. The two themes and most categories were identical for all three cohorts. Some differences in codes were observed, but all codes were seen in at least two of the three cohorts. The thematic analysis of the data generated two broad themes that included 5–6 categories and 21–22 codes per theme. The first theme identified was 'PBL as a teaching approach', which included ideas that students expressed about PBL as a teaching method in general. The second theme was 'Online PBL', containing opinions about their experience from the online setting. These are described below by Theme and corresponding categories and are summarized in Table 4.

Table 4. Summary of qualitative analysis of focus groups.

Theme	Category	Code
PBL as a teaching approach	Core Characteristics	Student-centered/Interactive
		Small Group/Collaboration
		Authentic problem
		Self-directed learning
		Concentration
	Tutor	Group dynamics
		Facilitates learning
	Knowledge/Learning	Knowledge retention
		Learning Objectives

Table 4. *Cont.*

Theme	Category	Code
		Pre-existing knowledge
		Holistic approach
		Material covered/learn how to learn
		Confidence In knowledge gained
		Learning Curve
	Skills	Communication skills
		Organization
		Teamwork
		Critical evaluation of the literature
		Time management
	Experience	Fun/interesting
		Energy in class
	PBL and other modes of teaching	Lectures
Online PBL	Core characteristics	Student-Centered
		Small Group/Collaboration
		Self-directed learning
		Report-back
	Knowledge/Learning	Knowledge retention
	Skills	Communication skills
		Teamwork/Collaboration
		Contribution
	Experience	Adjustment/transition
		Comparable
		Prefer face-to-face
		Prefer online
		Convenient
	Technology	Cameras
		Organization
		Technical issues
		Computer
		Shareable PPT
		Recording
		Platform

3.3. Theme 1: PBL as a Teaching Approach

3.3.1. Category 1: Core Characteristics

One important aspect of this project was to ensure that the main characteristics of PBL were identifiable in both delivery modes. This was to make sure that the redesigned online mode did not take away from the PBL process. All three cohorts identified the key characteristics of PBL, including that it is student-centered, that it relies on small groups and collaboration, that it is case-based and realistic, that it is facilitated by a tutor, and that learning is also driven outside of the session using self-directed learning. Specifically, students stated that the process is interactive and that it develops around the learner, recognizing the difference between one-way teachings. A student said:

'. . .it's not just learning stuff through the tutor, but we say our opinions'

In regards to collaboration, students noted they could cooperate and share their opinions within the group. A student mentioned:

'. . .and also it was interesting to see the different opinions between the students and how each perceived the case study.'

Students also appreciated that PBL is case-based, exposing the learner to authentic problems, making this more applicable and realistic. A student said:

'. . .because we would see it step by step how an actual scientist, an actual doctor would come to a conclusion about a diagnosis, it was actually a lot more representative of how laboratory work goes on and it was a lot more representative of real life.'

In addition, being part of the process and contributing to learning in practice engaged learners to be more attentive and concentrated.

'. . .it was easier for me to be focused during PBL. . .

Students also commented on self-directed learning, one of the most important elements of PBL. By definition, here, students have to perform private research on their learning outcomes using valid scientific sources and report back. Students commented on the importance of self-directed learning and added that although time-consuming, it allowed them to increase their database literacy. A student explained:

'. . .time-wise, we didn't have a lot of time to go through all the diseases in a PBL case but besides that, we did get some directions (through self-directed learning) on how to approach every disease and research it. . . and learn about it and actually not have to memorize everything by heart, but actually going in depth about it and learn a lot more as we would in the PBL on our own.'

3.3.2. Category 2: Tutor

According to the students, the tutor plays a crucial role in PBL, as this is the person that organizes and plans the sessions. Further, the students noted that the tutor handles group dynamics, ensuring everyone participates. As one student said:

'I think because (the tutor) wanted us all to participate. . . (he/she) asked us questions directly and we answered.'

Another role identified by the students was that tutors guided and prompted students to use and share their knowledge so they came up with a conclusion as a team. The tutor did not provide answers but instead put learners in a place where they could find the solution. A student explained:

'. . .when we were at a dead end. . ., not giving us the answer and by (asking the) right question it helped figure out (the answer) and sometimes the question made us think more and more deeply.'

3.3.3. Category 3: Knowledge and Learning

Students discussed the concept of knowledge from four different perspectives: (a) pre-existing knowledge, (b) acquired knowledge through learning outcomes generated and report-back, (c) learning curve, and (d) knowledge retention. On pre-existing knowledge, a student noted:

'. . .(we had to) put in force all our knowledge in order to solve an issue. . .'

On learning outcomes and report-back, students appreciated the contribution of the group. For example, a student mentioned:

'You have an assignment that you have to think about when you come back (to PBL)... everybody says what they think, so we may come to a general conclusion...'

One area where student opinions varied was confidence in the knowledge gained. The majority felt confident about the answers and commented that they had prepared them for exams. As one student said:

'I never felt that the level was low because my classmates prepared and it was supervised, so we got the correct points at the end and we improved our answers at the level the tutor wanted. I believe they were appropriate for the exam.'

On the other hand, a minority revealed that they felt insecure about their answers and the information provided by other students. A student stated:

'it would be nice if we had pointers on which information is important and should be included in the answer.'

Students strongly declared that in terms of knowledge retention, PBL is an effective way for learners to understand and remember things better. Specifically, they mentioned that they felt more prepared for their assessment/exams. A student stated:

'...when it's time for the exams we are more prepared (with) PBL...'

While another one explained:

'With PBL, it was more effective remembering the information about a specific topic because it gives you the motive to contribute to problem- solving in contrast to a traditional class.'

For almost all students, the PBL method was something they had never experienced before, and the learning curve between cohorts varied. The predominant view was that their confidence increased with each PBL. A student noted:

'...the first time, the first session it was stressful, but later it worked...'

Finally, students felt that through PBL, they obtained holistic knowledge. As one student said:

'...We had a more holistic approach to a disease or a disorder and because we didn't focus only on the immunological mechanism, but also in symptoms and treatment, it was very helpful.'

3.3.4. Category 4: Skills

Students highlighted the numerous skills gained during PBL. They mentioned communication skills in the context of presenting and explaining to peers. Students realized that they had to make every effort to find, rephrase, and present information to their peers. As a student described:

'I had to do my research and write it down in my own words in a way that I could understand and present to my colleagues in a way that they would understand.'

Another skill students reported was the critical evaluation of the literature. They admitted that during the initial sessions, they reported back any information found on a topic, irrespective of whether it was relevant or irrelevant. After a few meetings, they were able to report back exactly what they needed to. For instance, a student noted:

'...it helped me a lot to be very direct of what we have to say...'

All groups identified teamwork and working towards a common goal as important skills gained in PBL. Through the PBL sessions, they learned to coexist and cooperate with different personalities and people coming from different fields. As students expressed:

'we come from different backgrounds, so we worked as a team better because we got to know each other so we used our strengths separately and as a group.'

Students were also able to critically evaluate the literature while working with time constraints. Especially for those who have a job and are performing it in parallel, a student said:

'…you learn how to manage your time'

while another student stated:

'it was extremely helpful for me because you obviously study before you attend a PBL session'

3.3.5. Category 5: Experience

Students found the PBL sessions enjoyable, interesting, and a fun break from lectures. They also obtained positive energy from class, which left them with a nice impression. A student said:

'…I do feel like PBL was a lot more fun and a lot more interesting.'

While another said:

'…it was a friendly team…'

3.3.6. Category 6: PBL and Other Modes of Teaching

Students also compared their PBL experience with lectures. Specifically, they believed that lectures support PBL because they lay the groundwork for the PBL sessions. For instance, a student said:

'I think they complete each other because when you do the lectures you get information and when we did the PBL, we use that information and through the cases we understood it better.'

Overall, students were very positive about PBL as a teaching approach.

3.4. Theme 2: Online PBL

In the second theme, students explored their experience with online PBL. Here, they shared their opinions on PBL sessions in the online setting and reported differences and similarities identified between online and traditional face-to-face delivery. Some of the categories identified were similar to Theme 1, but the codes varied. The student perceptions are discussed below.

3.4.1. Category 1: Core Characteristics

Once again, students highlighted the core characteristics of PBL and acknowledged their presence in the online setting, albeit with some variations. According to students, online PBL remains student-centered, but they felt that it was more 'guided' as compared to face-to-face PBL. In this context, 'guided' did not mean tutor-led; instead, it referred to the flow of the information and how the discussion was orchestrated. A student explained:

'…we had to raise our hands and wait and sometimes (the tutor) had to directly ask one of us to answer the question, it was a lot more guided…'

As a result, students contributed to the process one by one. This actually worked well for some students as it gave them time to think about their answers, so they were able to make significant contributions. As one student said:

'…online we had to think about our answer more. We had to wait for everyone else to finish and raise hands. We had to form the answer in our head better than face-to-face…'

In regards to self-directed learning and report-back, they were comparable in face-to-face and online environments. One student said:

'Searching information for the questions and reporting them back was identical face-to-face and online.'

3.4.2. Category 2: Knowledge and Learning

The matters of knowledge retention or assessment preparation were perceived by students to be similar in both modes of delivery. This was due to the fact that they felt that the online setting did not affect knowledge acquisition in any way. As two students said:

'It was the same actually, I didn't expect this (but) it was the same like you are in the class.'

'I didn't prepare more in one method or the other. It was pretty much the same'

3.4.3. Category 3: Skills

One area that students focused on was skill acquisition. Those included communication skills, teamwork/collaboration, and contribution. Some students expressed the view that the learning environment was conducive to learning and that they communicated effectively. One student noted:

'Even if we didn't meet at all it worked very well. It was as if we knew each other. We were feeling comfortable I believe.'

Still, other students felt that their collaboration and student interaction were hindered by the online delivery. Specifically, they noted a lack of 'teamwork spirit'. For example, one student said:

'. . .face to- face was more of a group work than online because we were all together. . . we could have a conversation without interrupting. . . mute, unmute etc.. . .'

On the other hand, for some students, the 'guided conversations' they had online were perceived as an advantage as their participation increased in the online setting. As one student mentioned:

'. . .we all participate in [the] online setting, everyone can say even a word, even a small opinion.'

3.4.4. Category 4: Experience

This was another area that generated a lot of discussion among the students as their experiences varied. In one form or another, they all (a) experienced PBL for the first time (this was discussed above) and (b) transitioned from face-to-face to online or vice versa. The discussion focused mainly on the transition from face-to-face to online. The vast majority of the students found the transition manageable with no problems. One student said:

'It wasn't a big deal. . .the transition wasn't bad for me.'

Still, for a few students, an adaptation period was necessary before they settled into the online mode. As one student said:

'The first time was terrible but now I'm used to it and you should turn all courses into online.'

In regards to their overall impression of both settings, they found the experience comparable but still expressed a preference for one over the other. Specifically, students were split into those who prefer the face-to-face and those who prefer the online setting. To illustrate, students that preferred the face-to-face mode of delivery mentioned that they enjoyed the interaction with their classmates, the university setting, and their ability to have a face-to-face conversation. One student said:

'. . .I like the fun of going to the University, in class, we see each other we get together face-to-face. I prefer face-to-face, I don't prefer online but I didn't find any difficulties with online. . .'

While students that preferred online PBL said:

'Personally, I prefer the online because I was in my place, in my environment, it was much easier.'

In addition, for some students who live far away, the preference was also linked to convenience as it saved them the travel and time. As a student explained:

'Online was more convenient as students stayed at home'.

3.4.5. Category 5: Technology

This category is specific to this theme since it concerns tools used in this mode of delivery. Students highlighted several tools that they found useful or even better than their face-to-face counterparts. They all agreed that the use of computers and cameras was useful for synchronous collaboration. Beyond that, they found the PPT file was an effective tool to collate and organize information. As one student stated:

'PPT was easier to collect information because it was more organized vs. the white board'

The second reason is that it was shareable. That is, while one person was occupied serving as the scribe, all others focused on the case study, and at the end of the day, they all had the same information in one file. As one student described:

'. . .with the online, because we didn't have to copy the WB and because we have everything on the PPT, we didn't have to worry about that, and we were just worried about answering the questions and participating in the conversation.'

In addition, students found the university platform very accessible and user-friendly. They did not face any difficulties in the transition from paper to digital documents and submissions. A student comment:

'I'm not very familiar with technology. . . but as for the online PBL, with the shared PPT and Moodle that we could upload our answers et cetera, it was very accessible and easy to use with a common computer and some basic knowledge.'

Despite the conveniences offered by the online tools, some students faced some technical issues during online PBL meetings. Specifically, they had connection issues that prevented them from listening to what was said. As one student explained:

'. . .(I had) trouble hearing that question, so I couldn't answer it or I had to listen to what everyone else was saying to understand'

For most students, this was easily fixed as they could watch/listen to the recordings later on. This gave them a chance to catch up even if they had some gaps or missed a session. A student noted:

'Unfortunately, I had technical issues. However, it's good that in this way (online) we have the recordings and this is very useful because we can listen again to things that we didn't have the opportunity (to listen to) when we were in class.'

Overall, as noted by the students, online PBL delivery was inherently different from face-to-face delivery in regard to the tools used. However, as far as learning, understanding, and preparation for the exams were concerned, the students noted that they were comparable.

3.5. Student Recommendations

Upon conclusion of the focus groups, students were asked to describe their ideal PBL session and provide recommendations. The most common recommendation was to promote blended learning in the sense that some sessions would be online while others would be face-to-face. In all cases, they suggested that synchronous PBL was best. Others indicated that online PBL might allow people from different locations to participate. They also suggested the implementation of some online tools into the face-to-face delivery setting. That included the replacement of the WB with the interactive PPT in an attempt to increase organization and clarity, as they found some writing illegible. Also, they suggested that all sessions be recorded to allow for a review of the material.

4. Discussion

The current study discusses the digital transformation of three MSc immunology PBL courses from face-to-face to online delivery. Online tools were carefully selected, and student perceptions were investigated using focus groups. Our findings suggest that most students are familiar with technology and did not have major problems transitioning from the face-to-face to the online environment. Further, they stated that learning in both environments was the same and that the PBL core characteristics were maintained. Still, although students believed that their participation was the same or even increased, the quality and quantity of the comments varied. Specifically, in the online environment, they commented less, but their comments were more substantial as they were unable to just add a word here and there.

4.1. Student Interaction

Digital PBL allows for student interaction, collaboration, exploration, and knowledge construction [2]. Our students indicated that although they felt able to participate, the flow of the discussion in the online environment was disruptive as they had to 'ask for permission' before they were able to comment. This happened because when they were online, they had to follow a process where they raised their hands (digitally), unmuted, talked, muted again, and then the next student followed. The tutor supervised this process. As a result, students felt that they could only contribute information if it was perceived as 'significant' while minor contributions were bypassed. Others have also noted that online delivery limits the ability of the student to read nonverbal communication and make a decision when it is a good time to add to the discussion [6,15,16]. This is especially important when no cameras are used in an attempt to decrease connectivity issues [15]. The literature suggests that other students found this disruptive as well, while others viewed these features as a way to increase organization as well as maintain student engagement [6,17]. Interestingly, Lajoie et al. (2014) also found that technology slowed down the interaction; however, the discussions were just as rich [10].

Interestingly, the majority of the students felt more confident about participating in the online environment as they were less inhibited, while students believed that their contribution was equal in both settings. This is not surprising as the use of a computer may benefit shy individuals and actively decrease anxiety [8,15].

Student interactions are often facilitated and monitored by the tutor. In the online setting, in addition to these roles, the tutors also needed to manage other cognitive demands imposed by online platforms as well as different collaboration strategies that are used [11,15]. As such, tutors would benefit from training on how to deliver PBL online. According to some of the students in this study, the online session was more dependent on the tutor in the sense that they had to control the flow through the raise hand tool, and so it felt 'guided'. This was not observed in other studies where the tutors noted a decrease in their intervention in the online environment, and the tutors stated that the sessions ran more efficiently [8,10]. Interestingly, our students did not identify any significant disruptors in face-to-face PBL, probably because they were focusing on the online mode of delivery.

4.2. Learning and Assessment

Regarding learning and assessment, our students and others reported that they were equally satisfied with the knowledge gained [8,15]. Still, other students indicated that their learning was disrupted by online delivery [6]. In studies where knowledge was evaluated, and with the exception of one study that showed lower performance of online PBL on learning outcomes [14], they either found no difference in the performance of students in online PBL or a moderate improvement [2,5,8,18,19]. In regards to skills, in a study by Foo et al. (2021), tutors assessed student PBL performance (participation, communication, preparation, critical thinking, and group skills) and found that the distance learning group performed statistically lower, although the difference was small (by 0.21–0.42 points on a scale from 0–10) [20]. The differences observed in these studies may be attributed to the use of different online tools and variations in fields of study and culture. Notably, these data are important to consider when designing or revising courses, and as such more research is warranted in the field.

4.3. Technology

The 21st century has seen unprecedented growth in technology. Current students are familiar with digital tools in general and are able to adapt to new tools provided. As such, it was not surprising that the students in the current study were either familiar with or were able to use the online tools and adapt to the online version of PBL in a short amount of time. A number of effective online tools have been incorporated into digital PBL in a variety of online courses, including Blackboard Collaborate, AdobeConnect, and Zoom. The current study used CiscoWebex [6,10,15,16]. The current study used an interactive PPT, which seemed to be very effective, while other studies incorporated a virtual WB [6]. The students noted that it helped them organize their learning and suggested including it in traditional PBL as well. Technology allows students to perform several tasks simultaneously, for example, using the chat box, writing on the WB, and searching the internet. This may be helpful as interaction may continue regardless of whether a student is speaking [6,15]. However, care should be taken as these can also act as distractors and may prevent PBL from being delivered effectively.

The use of new technologies may present additional challenges, including confidence in the process and the technology, and additional support may be needed to promote key PBL skills such as teamwork and digital literacy [11]. Technical issues are expected in online education, and thus, the selection of tools and the ability to use them from any computer and most internet capabilities is very important. Students may become distracted, frustrated and perceive online education negatively if they face technical issues frequently [6,15]. Indeed, some students indicated that they faced technical issues, but with the use of recordings and asynchronous learning, they were able to learn effectively.

4.4. Preferred Approach

While in the present study, there was a split decision regarding their preferred mode of delivery, others have reported that the majority of students showed increased satisfaction online [2,8,18]. Some students indicated that one of the reasons for preferring online PBL is that it saves travel time and cuts down on cost. This was reported in other studies as well [5,6]. Students also indicated that a combination of traditional PBL and online tools or blended learning would also be effective.

4.5. Study Limitations and Future Research

The current study had some limitations. The first one is that it was conducted with students in an MSc curriculum at one university. As such, the results may not be generalizable to students of other disciplines. Still, most of our findings are supported by other researchers. Further, our students were diverse in regard to age, educational background, and country of origin, which may contribute to transferability as well. Another limitation of the study was that one of the researchers was involved in teaching some of the courses, and this may result in bias. Notably, measures were taken to limit student bias. Those included (a) focus groups were run at the end of the MSc and after all grades had been submitted, (b) participation of the students was voluntary, and (c) no incentive for their contribution was given. As such, we believe that student bias was limited and effectively managed.

Digital PBL is gaining ground, and the literature is promising as to its effectiveness. Future studies may focus on other factors that may affect the PBL process. This includes the PBL tutors and how their role changes as well as longitudinal studies to investigate student outcomes (learning and skills). The student experience is also important, and the current paper contributes to this as well.

5. Conclusions

The current study suggested a method for the digital redesign of traditional PBL in Biomedical Science courses. The students adapted to the new setting successfully and noted that their learning was comparable to the face-to-face format. Students also commented that although the online environment delayed collaboration, it still allowed for participation and discussion. The students also noted that the redesign allowed for skill development such as communication skills, teamwork, collaboration, digital literacy, self-directed learning, and effective student learning. Based on our data and taking into consideration the growth in distance learning education, we propose that synchronous online PBL is an effective alternative to face-to-face PBL.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci13080850/s1, Table S1: The detailed breakdown of the face-to-face and online PBL process.

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References

1. Trullàs, J.C.; Blay, C.; Sarri, E.; Pujol, R. Effectiveness of problem-based learning methodology in undergraduate medical education: A scoping review. *BMC Med. Educ.* **2022**, *22*, 104. [CrossRef] [PubMed]
2. Tudor Car, L.; Kyaw, B.M.; Dunleavy, G.; Smart, N.A.; Semwal, M.; Rotgans, J.I.; Low-Beer, N.; Campbell, J. Digital Problem-Based Learning in Health Professions: Systematic Review and Meta-Analysis by the Digital Health Education Collaboration. *J. Med. Internet Res.* **2019**, *21*, e12945. [CrossRef] [PubMed]
3. Barbetta, P.M. Technologies as Tools to Increase Active Learning During Online Higher-Education Instruction. *J. Educ. Technol. Syst.* **2023**, *51*, 317–339. [CrossRef]
4. Muca, E.; Cavallini, D.; Odore, R.; Baratta, M.; Bergero, D.; Valle, E. Are Veterinary Students Using Technologies and Online Learning Resources for Didactic Training? *A Mini-Meta Analysis. Educ. Sci.* **2022**, *12*, 573. [CrossRef]
5. Servos, U.; Reiss, B.; Stosch, C.; Karay, Y.; Matthes, J. A simple approach of applying blended learning to problem-based learning is feasible, accepted and does not affect evaluation and exam results-a just pre-pandemic randomised controlled mixed-method study. *Naunyn-Schmiedeberg's Arch. Pharmacol.* **2023**, *396*, 139–148. [CrossRef] [PubMed]
6. Erickson, S.; Neilson, C.; O'Halloran, R.; Bruce, C.; McLaughlin, E. 'I was quite surprised it worked so well': Student and facilitator perspectives of synchronous online Problem Based Learning. *Innov. Educ. Teach. Int.* **2021**, *58*, 316–327. [CrossRef]
7. Turnbull, D.; Chugh, R.; Luck, J. Transitioning to E-Learning during the COVID-19 pandemic: How have Higher Education Institutions responded to the challenge? *Educ. Inf. Technol.* **2021**, *26*, 6401–6419. [CrossRef] [PubMed]
8. Ng, M.L.; Bridges, S.; Law, S.P.; Whitehill, T. Designing, implementing and evaluating an online problem-based learning (PBL) environment--a pilot study. *Clin. Linguist. Phon.* **2014**, *28*, 117–130. [CrossRef] [PubMed]
9. Jin, J.; Bridges, S.M. Educational Technologies in Problem-Based Learning in Health Sciences Education: A Systematic Review. *J. Med. Internet Res.* **2014**, *16*, e251. [CrossRef] [PubMed]
10. Lajoie, S.P.; Hmelo-Silver, C.E.; Wiseman, J.G.; Chan, L.; Lu, J.; Khurana, C.; Cruz-Panesso, I.; Poitras, E.; Kazemitabar, M. Using Online Digital Tools and Video to Support International Problem-Based Learning. *Interdiscip. J. Probl. -Based Learn.* **2014**, *8*, 60–75. [CrossRef]
11. Leavy, J.E.; Della Bona, M.; Nelson, B.; Leaversuch, F. A comparison of face-to-face and fully online problem-based learning: Student results and staff experiences, 2014–2020. *Health Promot. J. Aust.* **2022**, *33* (Suppl. S1), 57–66. [CrossRef] [PubMed]
12. Schmidt, H.G.; Rotgans, J.I.; Yew, E.H.J. Cognitive Constructivist Foundations of Problem-Based Learning. In *The Wiley Handbook of Problem-Based Learning*; Wiley: Hoboken, NJ, USA, 2019; pp. 25–50.
13. Pedagogical Framework for Online Learning. Available online: https://www.cedefop.europa.eu/files/etv/Upload/Information_resources/Bookshop/341/28_en_majumdar.pdf (accessed on 20 June 2023).
14. Erlingsson, C.; Brysiewicz, P. A hands-on guide to doing content analysis. *Afr. J. Emerg. Med.* **2017**, *7*, 93–99. [CrossRef] [PubMed]

15. Chen, R. Learner Perspectives of Online Problem-Based Learning and Applications from Cognitive Load Theory. *Psychol. Learn. Teach.* **2016**, *15*, 195–203. [CrossRef]
16. Nagge, J.J.; Killeen, R.; Jennings, B. Using a course pilot in the development of an online problem-based learning (PBL) therapeutics course in a post-professional PharmD program. *Curr. Pharm. Teach. Learn.* **2018**, *10*, 231–234. [CrossRef] [PubMed]
17. Kristianto, H.; Gandajaya, L. Offline vs online problem-based learning: A case study of student engagement and learning outcomes. *Interact. Technol. Smart Educ.* **2023**, *20*, 106–121. [CrossRef]
18. Alsaif, F.; Neel, L.; Almuaiqel, S.; Almuhanna, A.; Feda, J.; Alrumaihi, N.; Alanazi, O.; Almansour, M.; Saeed, M.F.; Soliman, M. Experience of Sudden Shift from Traditional to Virtual Problem-Based Learning During COVID-19 Pandemic at a Medical College in Saudi Arabia. *Adv. Med. Educ. Pract.* **2023**, *14*, 453–461. [CrossRef] [PubMed]
19. Taradi, S.K.; Taradi, M.; Radic, K.; Pokrajac, N. Blending problem-based learning with Web technology positively impacts student learning outcomes in acid-base physiology. *Adv. Physiol. Educ.* **2005**, *29*, 35–39. [CrossRef] [PubMed]
20. Foo, C.; Cheung, B.; Chu, K. A comparative study regarding distance learning and the conventional face-to-face approach conducted problem-based learning tutorial during the COVID-19 pandemic. *BMC Med. Educ.* **2021**, *21*, 141. [CrossRef] [PubMed]

education sciences

Review

Virtual Galleries as Learning Scaffolds for Promoting Problem-Based Learning

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Abstract: Extensive research into the effectiveness of problem-based learning (PBL) in primary and secondary education has been carried out over the past few years. PBL is an appealing, promising, but also challenging educational approach for both students and teachers. To overcome challenges, one of the most popular proposed strategies is to build learning scaffolds that gradually help students to effectively resolve the emerging sub-problems and tasks. Moreover, the massive impact of technology on students' lives, and the transition from in-person to distance teaching (especially during the COVID-19 pandemic) highlights the necessity of using virtual worlds and digital tools to facilitate and amplify collaboration and communication, both synchronously and asynchronously. This paper introduces the virtual galleries method as a scaffold for applying PBL approaches in both physical and distance learning environments, within the field of STEM education. Virtual galleries are perceived as a practice that motivates learners to collaborate, express their ideas on solving a problem, and present them as interactive and immersive experiences, while allowing others (peer-learners and educators) to evaluate the produced solutions. In this context, it is argued that virtual galleries can facilitate PBL by serving as a conceptual framework for scaffolding the learning process, thus enabling the acquisition of new PBL-driven skills.

Keywords: virtual galleries; learning scaffold; problem-solving; collaborative learning; distance learning; STEM education

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1. Introduction

During the past few years, several educational attempts and a lot of research has been conducted to effectively adopt PBL in primary and secondary education [1–4]. Even though PBL is a rather appealing and quite promising approach in education [1,5,6], researchers and educators [1,5,7–9] stress that the entire process is quite challenging, not only for students (especially the younger ones) but also for teachers, since both of them are unfamiliar with the new roles that they have to adopt (i.e., constructing knowledge and progressively becoming self-driven learners for the former, and acting as facilitators for the latter). To tackle challenges and to avoid pitfalls and misconceptions, one popular strategy is to build learning scaffolds that progressively aid students in efficiently addressing the emerging sub-problems and tasks, without discouragement and loss of interest [1,5]. Therefore, this paper begins by reviewing several theories and research that have been conducted in the field of PBL in recent years. Section 2.1 aims to briefly explain what PBL is, underline parameters that characterize this concept, and highlight several suggested and applied methods and strategies toward the successful implementation of this approach in education.

Given the massive impact that technology has on students' lives, as well as the shift from face-to-face to e-learning teaching due to the COVID-19 pandemic, other suggested strategies revolve around the use of virtual worlds and digital tools that can efficiently support and enhance collaboration and communication, in synchronous and asynchronous ways [10–13]. In this regard, research on the type of learning environments and tools that can sustain and promote PBL is performed (and presented in Section 2.2), with a particular emphasis on the culture of virtual and distance learning, which was significantly boosted in recent years due to the COVID-19 pandemic. The findings of this brief research, combined with PBL theories, reveal a gap in the current literature. Despite the availability of various tools and services that can foster and boost PBL practices in both physical and distance learning environments, there is a lack of a conceptual framework to scaffold this learning process using a PBL approach.

In this context, the virtual gallery concept is introduced and suggested as a scaffold for promoting and implementing PBL approaches in both physical and distance learning environments. Section 3 begins with a brief definition of the virtual gallery approach and cites previous examples of its application. In this paper, a virtual gallery is not solely a digital space for exhibiting several items. It is perceived as a wider method that inspires learners to collaborate using physical and digital tools both individually and as a team, to effectively illustrate, organize, and present their ideas as an interactive 3D spatial narrative. Through the cited examples, several findings and hypotheses are highlighted regarding the utility of the virtual gallery approach in STEM education. Subsequently, Section 3.2 further explores this argument by outlining a feasible implementation of this approach within the framework of PBL. The stages involved in this process are presented through a diagram illustrating the relationship between setting up a virtual gallery and ways of addressing and proposing a possible solution to a given problem, leading to recommendations on how virtual galleries can be used as a scaffold to promote PBL. It is suggested that the virtual gallery approach can aid in a gradual and effective familiarization of students with the PBL concept, while facilitating the acquisition of new PBL-driven skills. Furthermore, it is argued that this methodology has the potential to introduce innovative approaches that will inspire and encourage learners to perceive learning as an interactive and collaborative journey of exploration, inquiry, creation, and sharing.

2. Researching PBL Theories and Types of Learning Environments That Can Sustain PBL

2.1. Review of PBL Approaches

PBL was initially proposed and applied in higher education (and particularly in medical schools in North America) as a more effective and alternative—in respect to traditional—learning approach, while over the last 25 years there have been multiple efforts to introduce this method to primary and secondary education [1–4]. Some of the aims of PBL are to help students to understand and investigate a problem, to discover solutions to emergent demands, to work collaboratively and to communicate their ideas during this process, to evaluate the results (through self and peer assessment), and, ultimately, to increase their critical and high-order thinking skills [1,5] (which are considered powerful and crucial cognitive and meta-cognitive skills, also acknowledged as some of the so-called 21st century skills).

Ref. [5] defines PBL as an "instructional approach," revolving around learners who act as researchers, by trying to combine theory and practice and by applying the gained knowledge and skills to find a possible solution to a defined and real-world problem. The problem that is used in PBL does not have a single solution [6]. Therefore, more than one interpretation and approach can meet the demands of the initial question, while the field of research is not limited, meaning that more than one discipline or subject might need to be studied and explored. Learners who are engaged in PBL do not necessarily have prior or/and sufficient knowledge of the subject they are investigating, nor have they been exposed to a similar example [2], so they need to delve into different fields—both individually and as a team—to search for information and generate a solution. Due to these facts, it is argued that students are more motivated since they are responsible not only for discovering a reasonable solution for a rather multifaceted problem, but also for identifying the different aspects of the problem and setting the right parameters to resolve it [5]. These actions are among the four stages that [14] highlight as typical in a PBL case: the need to clarify the problem, to identify the underlying needs to properly address this problem, to study and learn at an individual level to acquire new skills and knowledge, and then to apply the skills and knowledge to solve the initial problem. At its core, PBL is a self-directed learning process, but with the need for constant evaluation of and reflection on the emerging ideas, both at the individual and team level. The ultimate goal is a viable solution that can be meaningfully applied in the real world.

Even though PBL is an appealing concept, it is not a simple or/and straightforward learning method. In fact, it is quite challenging for both teachers and students [1,5,7]. Contrary to traditional learning approaches, in PBL learners are responsible for directing and regulating the learning process as well as monitoring "their own understanding" [8], while teachers have to act as facilitators, by discreetly assisting them, mostly through questions that will help learners focus on significant aspects of the problem [5,9]. This process is difficult since both students and teachers are unfamiliar with these new roles. The former may not have developed to a high level the cognitive skills (e.g., critical thinking, problem solving) necessary to deal effectively with an ill-structured problem. The latter should be properly trained to become facilitators and to assist students in operating at a metacognitive level (i.e., perceiving and critically reflecting on the acquired knowledge) [1,8].

To overcome these difficulties and successfully implement PBL in secondary education, while avoiding pitfalls and misconceptions, a range of strategies must be adopted and employed. Toward this end, one of the essential parameters that several researchers highlight is collaboration and interaction between learners, especially those who are working on the same group [1,5,14]. Teachers/Facilitators need to inspire students to effectively work as teams by suggesting methods such as setting goals and internal deadlines, discussing and reflecting on others' ideas, as well as allocating roles. Many researchers are also putting emphasis on the significance of building learning scaffolds that will assist students to progressively resolve the emerging tasks, without disappointment and loss of interest [1,5]. For instance, ref. [1] proposed the concept of "postholes": a number of shorter problems that can be used as examples for smoothly introducing students to the PBL method. Setting checkpoints or having some kind of progress recording (such as a goal chart or a diary) is another strategy for keeping students engaged. This strategy ensures that the steps taken to solve the problem are consistent with its content. This approach will enhance students' awareness of the correlation between the produced outcomes and the initial inquiry, consequently leading to a better understanding of the acquired knowledge [5]. Ultimately, teachers should keep in mind that the designed tasks of PBL, as well as the immanent demands, should be authentic, meaning relevant to real-world cases [15], and compatible with learners' cognitive skills [8] (p. 139). In this sense, it is also proposed that some discussion and negotiation between learners and facilitators should take place before establishing the final task. Moreover, it is argued that if learners are exposed to a problem that activates prior knowledge, then the entire process is more engaging for learners [7], and the new knowledge that is formed and gained is more meaningful [2].

In many cases, the educators blend PBL with other learner-centered strategies such as project-, case-, and inquiry-based learning [3,5], which are also oriented toward self-directed learning and promotion of skills such as collaboration, communication, critical thinking, and problem-solving, but—in comparison to PBL—their final outcomes are more concrete. Due to these similarities, these strategies are sometimes used by the facilitators as scaffolds for PBL. Project-based learning, in particular, is considered by several researchers as almost identical to a PBL approach, with rather minor differences [3,6,15]. One of them is that, unlike PBL, in project-based learning, the facilitators may choose to give direct instructions to the learners to help them find a viable solution [15]. Another one is that it relies on the final outcome, which in PBL is defined as a solution, but in project-based learning the terms "product" and "artifact" are used [3]. Other than that, both methods are characterized by collaborative learning and knowledge construction resulting from several interrelated stages, including brainstorming, researching, planning, testing, evaluating, and reflecting on the results [16]. Focusing on the learning outcomes, and particularly on improving students' engagement and critical thinking, ref. [17] suggest a hybrid model, called "Constellation 3: project-led problem-based learning," that combines both approaches by using the project as a container and a space that fosters PBL practices, toward knowledge acquisition. The notion of "constellations" reflects the existence of a variety of PBL approaches, constituting patterns that are not "just within the types of PBL" but extended to other fields of pedagogical practice [9] (p. 4). In this sense, ref. [9] suggests that it would probably be more fruitful and meaningful "to explore components and concepts that together can begin to build pedagogies for PBL," leading to the production of new ideas, the imagination of new futures, and the blurring of boundaries found in particular practices.

Implementing such a practice could potentially aid in the development of PBL learning techniques that are not merely trying to trace over or rely on some sort of "gold standard PBL" [9] (p. 3), which may be misleading regarding the objectives of a given problem, but that instead pave the way for innovative methods that emphasize motivating and encouraging students to perceive learning as a dynamic process of exploring, questioning, creating, sharing, and, ultimately, "as an opportunity to challenge, change and transform the world" [9] (p. 7).

2.2. Learning Environments and PBL

The selection of the strategies and pedagogies (that can promote and scaffold PBL) is also related to, and affected by, the type and the structure of the environment where the learning process occurs [9]. According to socio-constructivist and cultural perspectives, learning is inextricably bound to the interplay between learners and the environment fostering learning practices [10]. Therefore, and in order to meaningfully promote learning, it is crucial for educators/facilitators to select an environment that effectively serves the objectives of the chosen educational methodology, as well as the tasks to be carried out [10]. As mentioned above, for PBL to be successful, it is essential to have an environment that encourages collaboration and interaction not only between learners, but also between learners and facilitators. For instance, ref. [1] (p. 43) argued that learning environments fostering PBL need to promote collaboration since it permits students "to draw on each other's perspectives and talents in order to more effectively devise solutions for the problem(s) at hand." Therefore, it is equally important that the learning environment gives opportunities to students for expressing and practicing different ideas, as well as for sharing experiences.

According to [18], an "effective learning environment" is defined as an educational setting (in physical or virtual mode) that fosters discussion and interaction among learners and facilitators in such ways that leads to the construction of knowledge and problem solving through collaborative learning. However, concerning in-person teaching, the time in the classroom is often limited, and there is not enough for effective and fruitful collaboration between students [19]. Toward this end, new technologies and the available educational digital tools can play a significant role [15]. By providing means that encourage discussion, argumentation and negotiation, brainstorming, planning, creation, and experimentation, in synchronous, asynchronous, and remote modes, these technologies can support distant interaction and productive collaboration, while extending learning practices beyond the time in class. The culture of distance learning through virtual classroom settings was significantly boosted in the last few years due to the COVID-19 pandemic and the emerging restrictions.

During the COVID-19 pandemic, there was a massive shift toward virtual and digital environments, as substitutes for in-person communication and interaction, prompting the exploration of alternative approaches (including PBL) through the lens of virtual tools and environments. Consequently, the educators sought tools to counterbalance the "loss of physical presence" and create more engaging online learning [11]. However, collaborative learning in virtual spaces is considered an even more demanding process since learners are exposed to "new ways of communication and collaboration" [10]. Moreover, the shift to new technologies does not imply a better or more effective learning approach and, consequently, a better educational quality unless new forms of meaningful and interactive learning are supported and encouraged [12]. As [13] pointed out a few years ago, the use of virtual environments for educational purposes can be considered successful if the promoted learning experience feels real to learners and engages them in the learning process by creating a sense of presence in a cognitive and emotional way.

In this context, it has been argued by [11] that one obvious option for implementing PBL online is to use virtual tools that do not support the linear and fixed narrative that typically characterizes traditional and paper-based PBL, but instead emphasize immersion and learner engagement by challenging them to collaborate online to solve different tasks. Regarding online collaboration, ref. [10] believes that in order to meaningfully support learning processes, collaborative virtual environments should provide three crucial affordances, namely (1) technological, (2) social, and (3) educational affordances, which concern, respectively, the technological means and tools, the properties boosting social interaction, and the learning behaviors that are shaped. But as [10] argues, "it is unlikely that a single platform can meet the interaction needs of this joint activity." Therefore, he highlights several tools that can promote these qualities, such as forums and social networks that boost the sense of community and presence as well as dimensions related to cognition, tools that promote collaborative authoring and annotation, tools working as digital repositories for information (blogs), as well as e-portfolios, functioning as personal diaries where personal achievements in the form of artifacts and self-reflecting writing items are collected. For e-portfolios in particular, ref. [10] argues that they have great "potential for metacognitive activities such as planning and organizing, monitoring, and regulating collaborative learning," especially when they "are considered as collaborative systems, providing opportunities for assessment, self-assessment, and co-evaluation."

The aforementioned tools can support various aspects of teaching and learning, and they appear to include practices cited by [9] for boosting PBL, such as providing communication channels, fostering team building, and promoting experimentation and co-production, while enabling students to choose means that match their personal interests and abilities. Nevertheless, they seem to lack one significant parameter. They do not suggest or establish a concrete concept for the learning process to occur. It is argued that the concept of virtual galleries can offer this framework, bringing forward strategies of collaboration, creation, interaction, and sharing between learners.

3. The Virtual Galleries Concept as a Scaffold for Promoting PBL

3.1. Introducing the Concept of Virtual Galleries

In general, a virtual gallery is defined as any digital space that tries to promote some kind of artwork through a more or less interactive environment. The level of interactivity within the environment is closely linked to the approach and design of the virtual gallery (i.e., whether as a webpage or a 3D model) and the navigation methods deployed to engage users/visitors. However, in the context of this paper, virtual galleries are more than just digital spaces for displaying artwork; they are alternative narrative mechanisms and flexible spatial configurations in which the students can organize and reflect their ideas and thoughts, in multimodal formats (i.e., as images, texts, videos, etc.) and in meaningful and interactive ways. Additionally, virtual galleries are perceived as a means for building communities (around specific topics/themes), enhancing communication (between community members), and facilitating the exchange of information and experiences. Moreover, given that virtual environments are not trying to substitute reality but, rather, enhance it with new potentialities, a virtual gallery is ultimately considered a tool for amplifying and expanding physical learning experiences. To exemplify the concept and application of virtual galleries for educational purposes, two use cases will be briefly presented in the following subsections.

3.1.1. Use Case 1: The BeReady Project

The idea of using a virtual gallery as a pedagogical method came up after research on available tools that can support project-based methods for teaching online STEM-related courses. This research was performed in the context of the BeReady project [20], an Erasmus+ project revolving around the continuation of teaching STEM subjects during the COVID-19 pandemic. In this project, a handbook [21] was produced, gathering several digital/virtual tools with powerful features that can enable learners to collaborate online, as well as create and illustrate their ideas in multimodal ways, while fostering actions such as ideation, communication, planning, and sharing.

These tools were combined in light of several learning scenarios, including the production of 3D virtual experiences, in the form of virtual galleries. Considering the space of a virtual gallery as an infrastructure for better organizing and presenting content, thus generating immersive narratives enhanced with spatial and embodied aspects, but also as a space that can support collaboration, creativity, interaction, and sharing between learners, it was argued that such an approach can be a rather powerful method for teaching STEM subjects online [22,23]. This argument was reinforced after implementing the learning scenario of virtual galleries with teachers from secondary schools during four webinars [22].

The participant teachers (20 in total) formed four teams and were instructed to select a topic of personal interest (e.g., science in ancient Greece, aspects of AI, etc.) and present it through a virtual gallery, using the Artsteps application [24], a free-licensed tool that permits the creation of virtual galleries from scratch. The teachers collaborated online both individually and as teams to gather information, produce artifacts with various tools proposed in the handbook, strategize the embedding of information into the virtual gallery, place the artifacts, plan a guided tour, and exhibit the outcomes to others [22]. Although they used multiple digital services and tools to collaborate and produce the content for their gallery (such as [25–27], etc.), the virtual gallery served as the pivotal point around which the entire learning process was coordinated. At the end of the webinars, the teachers were asked to provide feedback on their experience by completing an online questionnaire.

According to their feedback, the teachers identified the process as a good example of how a STEM project can be effectively carried out online [23]. They appreciated the balance between theory and practice and the initiation of dialogue on a specific topic through the virtual gallery concept. They also valued the autonomy to choose a topic relevant to their personal interests and to gain expertise in new tools that promote interdisciplinarity. Some teachers implemented the acquired knowledge in their classes. During webinar 4 [22], a teacher reported that a student at their school used the concept of virtual galleries to deliver a presentation on the subject of optics in physics. This immediate implementation provides evidence that the concept of virtual galleries is both interesting and pertinent to the needs of the school community. One weakness identified was the Artsteps tool's inability to facilitate simultaneous collaboration within the same environment. Even though team members can access the 3D model of the virtual gallery by using the same registration code, they cannot observe modifications made by one user instantaneously. To tackle this problem, the teachers worked on the 3D model in a rotational manner. They also scheduled online meetings to discuss the achieved outcomes and the next steps toward finalizing their virtual gallery.

3.1.2. Use Case 2: The CULPEER Digital Project

The virtual gallery method was also employed during the CULPEER Digital project [28,29]. In this project, a group of students (aged 18 years old) worked together using the Artsteps application to create their own virtual gallery, thus promoting intercultural exchange and cultural peer-to-peer learning in a digital format. The participating students were encouraged to identify a contemporary cultural aspect of Greece with links to the daily lives of Greek people. The students were inspired by their daily use of the Athens metro and proposed promoting the presence of art within Greek public transportation, since they noticed that the majority of the metro stations are embellished with artwork, such as painting, sculptures, and installations, created by Greek modern artists. Therefore, initially they chose to gather data on the showcased artwork situated in different metro stations in a shared Google document. They uploaded representative images of the artwork, and for each one, they recorded the title and the artist's name, accompanied by a brief description. Then, they used the Artsteps application to produce an interactive virtual gallery exhibiting the gathered data, allowing engagement with groups of learners from around the world and making all these objects of Greek modern culture visible to a wider audience. During this project, it was highlighted that the students enjoyed the entire process. They encountered no difficulty in using a 3D modeling environment such as Artsteps, and they felt creative and enthusiastic about producing their own content. To overcome the limitation of Artsteps regarding online collaboration, the students were encouraged to have a physical meeting to work jointly on the 3D model of the virtual gallery.

3.2. Toward a New Approach for Facilitating PBL

Although the number of participants was limited, the aforementioned experiences led to some valuable insights and hypotheses. It was observed that a virtual gallery can serve as a digital space that consolidates a variety of items and ideas, united by a common theme, thus generating numerous and immersive narratives. It was also noted that the tools and methods used to produce a virtual gallery can be easily implemented by both students and teachers, (with the former needing less time to become acquainted with the new digital skills). Furthermore, the whole procedure was perceived as a creative process that fosters collaborative learning. Based on these observations, and considering the theories of [9] regarding the integration of components and concepts from different pedagogical practices, it is suggested that virtual galleries have the potential to facilitate different learning approaches, including PBL, in both physical and distance learning environments. Moreover, it is argued that virtual galleries can function as a concrete concept for scaffolding collaborative learning and problem solving in light of PBL. In this respect, ref. [21] can be a valuable source for discovering tools that can facilitate PBL practices. The following paragraphs delve into the creation of a virtual gallery through the use of 3D modeling software such as Artsteps, along with certain tools included in [21]. The stages involved in this process are presented, together with recommendations on how virtual galleries can be used as a scaffold to promote PBL.

3.3. The Virtual Gallery Scaffold

Figure 1 contains a diagram that illustrates the relationship between the steps involved in setting up a virtual gallery (left sequence) and the process of addressing a problem and proposing a possible solution (right sequence), and how the former can serve as a scaffold for promoting the latter.

As shown in the left section of Figure 1, the process of developing a virtual gallery can be divided into five main steps. The first step is to determine the main topic. Then, to facilitate the process, the designer creates a preliminary 3D model of the virtual gallery to serve as a basic infrastructure and a starting point for the following steps. This 3D model is subject to change, according to the needs that arise after the production of the artifacts. The next step involves the generation, production, design, and selection of artifacts. The artifacts can be any item that reflects the central topic. An artifact can be perceived as an image, a text, a 3D object, a video, or/and an audible item. The creator can choose any means to produce their artifacts. Depending on her/his intended representation, s/he can employ any physical or digital medium that will help her/him to produce it. Therefore, the creator can use a wide range of tools, from sketch pads and notebooks to cameras, as well as from image-generating software to 3D modeling software. If more than one creator is involved in the process, they can allocate roles based on their individual skills and talents. After producing the artifacts, the designer/creator must consider the order in which they will be presented to another person/visitor, so as to reflect and spatialize the main theme in the most effective way. Consequently, this process will enable the creator to determine the placement order of the artifacts in the virtual gallery, creating a flow of information that will generate meaningful narratives, leading also to make some final decisions regarding the spatial configuration of the virtual gallery (i.e., the number of the rooms in the 3D model, how they are interconnected, etc.). Again, if there are multiple creators, they can discuss and reflect on others' creations to reach a unanimous agreement on how the artifacts will be arranged. Toward this end, the creator(s) can consider incorporating mechanisms that will allow visitors to become more immersed in the entire 3D spatial narrative and experience. Potential mechanisms include providing titles for each section or item, additional texts and directional signs, etc. After considering all these aspects, the artifacts are placed in the 3D space of the virtual gallery by the creator, who may also choose to design a guided tour for visitors to follow while present within the virtual gallery. Once the virtual gallery has been prepared, the creator may invite other individuals/visitors to navigate the space, interact with the artifacts, and provide feedback on their experience.

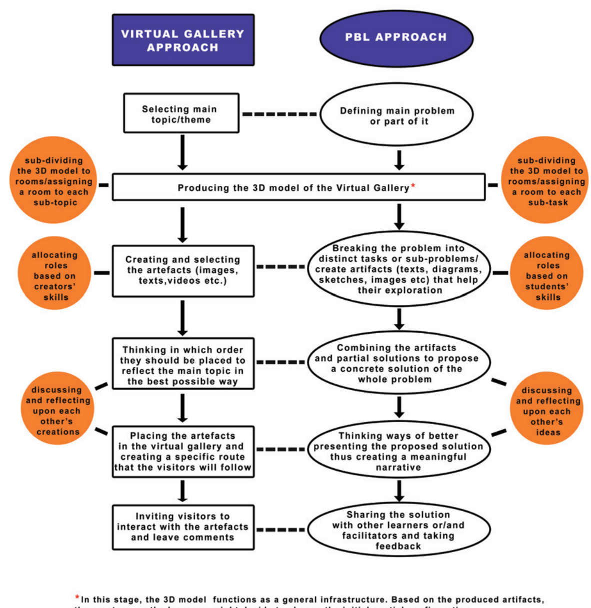

Figure 1. Diagram depicting the relationship between setting up a virtual gallery (**left sequence**) and addressing a problem and suggesting a feasible solution (**right sequence**).

It is argued that the implementation of the virtual gallery approach can act as a scaffold in PBL, leading students to become familiar with the method and to gradually learn to reach potential solutions to problems in STEM education. In this context, the central topic of the gallery will be the main problem (or part of it), and the artifacts will be all the possible approaches toward the solution. Breaking down a problem into distinct tasks or sub-problems and transforming ideas into tangible artifacts may assist learners in comprehending and addressing the initial inquiry, facilitating the identification of emergent demands and underpinning needs. For instance, consider that the initial problem is to "Design a sustainable water purification system": to supply a community with clean and safe drinking water (Figure 2). To address this problem, students should work as a team and consider various factors, such as the sources of contamination, the methods of purification, and the environmental impact, through the lens of different disciplines, including chemistry, engineering, and environmental science. This real-world issue can be deconstructed into sub-problems by encouraging each group member to select one of the aforementioned factors and to analyze it through a discipline that aligns with her/his interests. This allocation of roles can inspire students to use different methods of representation and allow them to choose techniques that correspond to their individual skills (such as creating diagrams, producing images, composing brief written pieces, etc.). This approach could help them in drawing on each other's talents and perspectives (by expressing their ideas in a more or less verbal way), leading to a better collaboration. Before starting their independent research, the teacher can advise the students to create a preliminary 3D model of their virtual gallery in order to give them inspiration for the design and presentation of their artifacts.

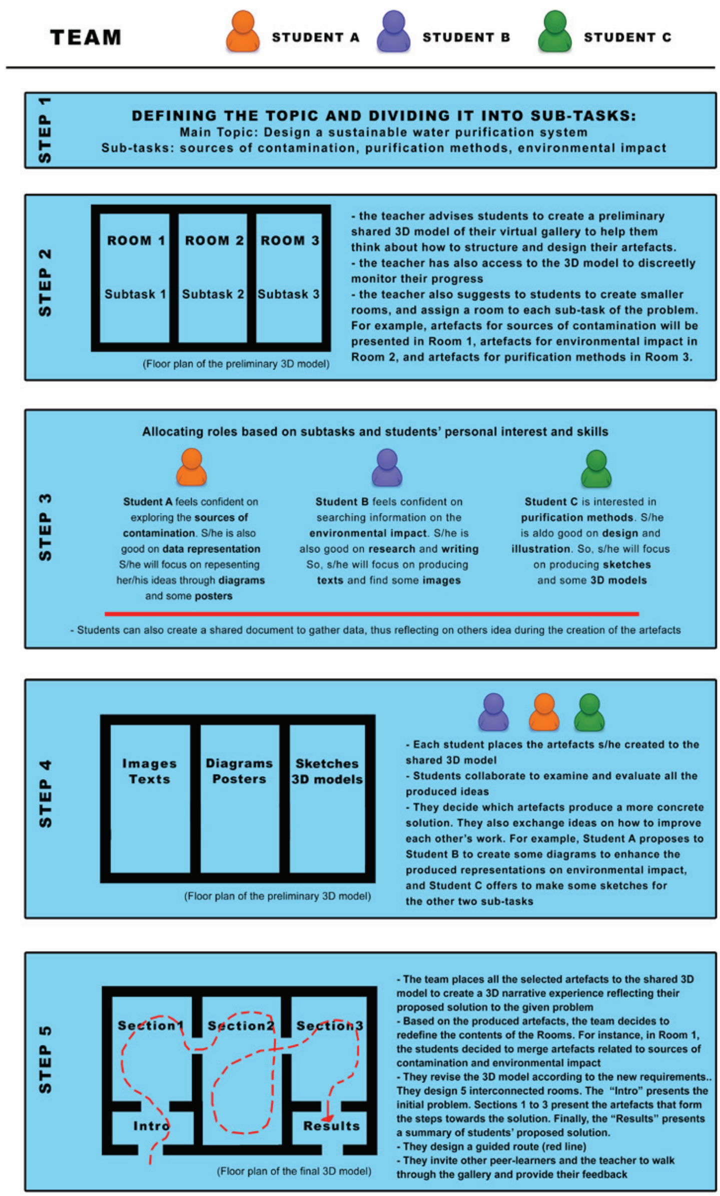

Figure 2. Image depicting the steps to address the problem of the "Designing a water purification system" scenario, by implementing the concept of virtual gallery.

To facilitate this process, the teachers can encourage learners to come up with a title that describes the artifact they are creating, which will help them approach the task. As the 3D space of the virtual gallery can be divided into smaller rooms, teachers can suggest students assign a room to each sub-task of the problem. This method could aid students in dividing problem solving into tasks more easily, as each one can select a specific gallery room to work in. For instance, in the "water purification system" scenario, each student could be assigned a room where they would present the results of their independent research. Additionally, this process (including role allocation) can be advantageous not only for learners but also for teachers as it offers them methods for checking the intermediate steps toward solving a problem and the coherence of the produced approaches with the initial inquiry. It also facilitates them to discreetly monitor the students' cognitive abilities and provide appropriate guidance for successfully developing PBL-relevant skills.

During the production of the artifacts, the learners should work both collaboratively and individually. After generating several possible approaches (in the form of artifacts), students can examine and evaluate their own and others' ideas, deciding which artifacts can be combined to produce a more concrete solution for the problem. With the aim of arranging their ideas in a spatial configuration and incorporating interactivity and navigation parameters, they are increasing their awareness of how to integrate all the proposed approaches, so as to generate a meaningful solution. The last step is to place all the selected artifacts in the virtual gallery, design a guided tour that fully reflects the proposed solution as a 3D narrative experience, and share the outcome with teachers (and other peer-learners) by inviting them to walk through the gallery, interact with the proposed approach, and provide their evaluation and feedback.

In summary, it is argued that the concept of the virtual gallery can serve as a scaffold for promoting PBL, particularly in secondary education. It is a concept that aids in dividing a specific problem into smaller tasks, enabling students to recognize emerging needs more effectively. It is also a method that supports collaboration and teamwork, and it allows the allocation of roles based on specific skills and talents. Furthermore, it is a strategy that tries to draw on prior knowledge and experience through means and tools that are familiar to students or that are easy to be taught (i.e., virtual environment, sketchpads, 3D modeling, etc.). By adding the spatial parameter to problem-solving, thus turning the entire process into a more tangible procedure that brings into play embodied aspects (i.e., locomotion/navigation and interactivity), it is postulated that students might feel more confident finding ways to materialize their ideas and experiment with different narrative mechanisms toward feasible solutions.

4. Discussion

This paper argues that the virtual galleries approach can serve as a learning scaffold for promoting PBL in physical and digital educational environments. A virtual gallery is perceived as a wider method that motivates learners to employ several physical and digital tools toward organizing, rendering, and presenting their ideas as spatial and interactive 3D narratives. Previous implementation of virtual galleries [20,22,23,28] as a method for teaching STEM subjects online suggested that it is a promising educational approach. This is because it encourages collaborative learning and creativity in an easily accessible and user-friendly environment for both teachers and students. These findings align with recommendations from researchers such as [9,17] who have proposed blurring the boundaries found in specific practices by exploring and combining components and concepts from various approaches to build pedagogies for PBL. It is also in line with suggested strategies [1,5] for constructing learning scaffolds in the form of short tasks to gradually introduce students to different steps of PBL. Consequently, it can be assumed that the approach of the virtual gallery may serve as a learning scaffold toward introducing PBL. This assumption is supported by the fact that the virtual gallery environment enables the subdivision of a problem into distinct tasks and the transformation of ideas into tangible artifacts, thus making easier for learners to comprehend a given problem and identify the immanent needs. It is also sustained by the fact that a virtual gallery promotes collaboration, interactivity, and the exchange of ideas among students, and it does that by encouraging the use of a variety of tools that match students' personal interests and abilities. Furthermore, both educators and learners can provide feedback by evaluating and commenting on the results. Therefore, this environment exhibits the three affordances outlined by [10], namely technological, social, and educational, and it does not rely on a single platform or service, which is in accordance with [10]'s assertion that "it is unlikely that a single platform can meet the interaction needs of this joint activity." Instead, it serves as a concept for scaffolding PBL approaches, suggesting a framework that integrates several practices and learning qualities such as collaboration, interaction, and sharing. Additionally, it proposes an innovative approach to facilitate the process of PBL learning, which does not rely on a "gold standard PBL" practice (as stated by [9]), but aims to pave the way for methods that motivate and stimulate students to learn through exploration, questioning, creation, and sharing.

The initial assumption was further investigated by showcasing how the methods inherent in PBL can be implemented through the steps of producing a virtual gallery. To present these steps, a diagram (illustrated in Figure 1) was created. In this context, it is suggested that the main problem (or parts of it) can serve as the central topic of the gallery, while the sub-tasks aimed at solving the problem can be seen as the artifacts of the gallery. In this way, students gain an understanding of the specific tasks that must be solved, which facilitates the identification of emerging requirements and underpinning needs. This is also in line with [11]'s suggestions regarding the online implementation of PBL and the use of virtual tools that encourage learners to immerse themselves and engage in collaborative problem-solving tasks. Tools included in [21] can support various activities toward the production of the virtual gallery and its contained artifacts.

Some proposed strategies include the integration of mechanisms typically used for organizing galleries. These are the addition of section titles, short texts, and directional signs, as well as dividing the gallery space into several rooms (encouraging segmentation and categorization by topic). Teachers may propose these mechanisms to help students more effectively identify the needs that must be addressed through the created artifacts. The spatial segmentation, along with the freedom for students to use tools and techniques that match their skills and talents, can facilitate role allocation. In addition, by encouraging students to use familiar tools and techniques, the virtual gallery method brings forward the application of existing knowledge and skills to the acquisition and development of new ones.

Some virtual galley creation tools, such as Artsteps, have limitations regarding collaborating on a 3D model and monitoring real-time changes made by another team member. These drawbacks can be overcome by implementing strategies such as virtual or in-person meetings of the team, or by using the same account to work on a shared 3D model in a rotational manner. Another aspect that has emerged is the opportunity for social interaction not only between students, but also among those who are invited to visit and explore the gallery. This may lead to the development of new forms of meaningful and interactive learning. The addition of the spatial dimension to problem-solving is another interesting aspect that is stressed, which brings into play embodied parameters such as interaction and navigation. It is argued that this factor may increase the students' confidence in finding ways to represent their ideas and experiment with different narrative mechanisms for proposing potential solutions, since they are engaged in learning processes that create among others a sense of presence.

5. Conclusions and Future Directions

This paper has identified a gap in the current literature concerning the absence of a conceptual framework that can facilitate and scaffold the learning process through the lens of PBL, in both physical and distance educational environments. In this context, it is argued that the concept of virtual galleries can provide this framework by serving as a learning scaffold for promoting PBL. It is a strategy that helps learners to better comprehend a given problem and identify its emerging needs. This is achieved through the segmentation of the problem into discrete tasks and transforming them into tangible artifacts. In addition, it is a method that enables the exchange of ideas and collaboration in both physical and online settings, while offering straightforward and progressive steps toward problem solving at both individual and team levels. Thus, it is perceived as an effective approach that gradually familiarizes learners with the PBL concept. Furthermore, it is a method that makes use of existing knowledge and skills to acquire and enhance new ones, by motivating students to employ tools and techniques that align with their individual interests and capabilities. This parameter, along with the integration of spatial dimensions, can also facilitate role allocation. Integrating spatial dimensions into problem solving transforms the entire process into a tangible and interactive procedure that incorporates embodied parameters such as navigation and interaction, thereby potentially heightening the learner's sense of presence. This may also enhance their understanding of how to deploy their proposed solution, so as to generate a meaningful narrative experience. Moreover, virtual galleries have the potential to enhance the learning experience and facilitate collaborative problem-solving, as they provide educators and other peer-learners the opportunity to explore and evaluate the presented content within the virtual environment.

Overall, it is argued that the concept of virtual galleries represents a promising approach for facilitating the implementation of PBL in both physical and distance learning environments, and it can foster methods that inspire and encourage students' self-driven learning. To verify this assertion, forthcoming research will concentrate on experimentally deploying this concept within the context of science education, in order to evaluate and assess the impact of this approach. Limitations regarding software features for online collaboration should be further investigated, while also considering alternative solutions and emerging software. The incorporation of the spatial dimension, along with certain embodied parameters, is promising and opens prospects for future research in this direction (including the role of embodied experience in the acquisition of knowledge within 3D virtual learning environments).

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References

1. Ertmer, P.A.; Simons, K.D. Jumping the PBL Implementation Hurdle: Supporting the Efforts of K–12 Teachers. *Interdiscip. J. Probl. Based Learn.* **2006**, *1*, 40–54. [CrossRef]
2. Wirkala, C.; Kuhn, D. Problem-based learning in K-12 education: Is it effective and how does it achieve its effects? *Am. Educ. Res. J.* **2011**, *48*, 1157–1186. [CrossRef]
3. Jensen, K.J. A Meta-Analysis of the Effects of Problem- and Project-Based Learning on Academic Achievement in Grades 6–12 Populations. Ph.D. Thesis, Pacific University, Seattle, WA, USA, 2015. Available online: https://digitalcommons.spu.edu/cgi/viewcontent.cgi?article=1004&context=soe_etd (accessed on 13 February 2023).
4. Roberts, A.; Nganga, L.; James, J. Classroom Examples: Problem-Based Learning in Secondary Education. *Open Access Libr. J.* **2022**, *9*, e8656. [CrossRef]
5. Savery, J.R. Overview of Problem-based Learning: Definitions and Distinctions. *Interdiscip. J. Probl.-Based Learn.* **2006**, *1*, 3. [CrossRef]
6. Hmelo-Silver, C.E. Problem-Based Learning: What and How Do Students Learn? *Educ. Psychol. Rev.* **2004**, *16*, 235–266. [CrossRef]
7. De Simmon, C. Problem-Based Learning in Teacher Education: Trajectories of Change. *Int. J. Humanit. Soc. Sci.* **2014**, *4*, 17–29.

8. Savery, J.R.; Duffy, T.M. Problem-Based Learning: An Instructional Model and Its Constructivist Framework. In *Constructivist Learning Environments: Case Studies in Instructional Design*; Wilson, B., Ed.; Educational Technology Publications, Inc.: Englewood Cliffs, NJ, USA, 1995; pp. 135–150.
9. Savin-Baden, M. What are Problem-Based Pedagogies? *J. Probl. Learn.* **2020**, *7*, 3–10. [CrossRef]
10. Herrera-Pavo, M.A. Collaborative learning for virtual higher education. *Learn. Cult. Soc. Interact.* **2021**, *28*, 100437. [CrossRef]
11. Jivram, T.; Kavia, S.; Poulton, E.; Sese Hernandez, A.; Woodham, L.A.; Poulton, T. The development of a Virtual World Problem-Based Learning tutorial and comparison with interactive Text-based tutorials. *Front. Digit. Health* **2021**, *3*, 611813. [CrossRef] [PubMed]
12. Corchado, N. Technology is Changing Collaborative Learning. *eLearning Ind.* **2022**. Available online: https://elearningindustry.com/technology-is-changing-collaborative-learning (accessed on 15 February 2023).
13. Mantovani, F.; Castelnuovo, G. Sense of presence in virtual training: Enhance skills acquisition and transfer of knowledge through learning experience in virtual environments. In *Being There: Concepts, Effects and Measurement of User Presence in Synthetic Environments*; Riva, G., Davide, F., IJsselsteijn, W.A., Eds.; Ios Press: Amsterdam, The Netherlands, 2003; pp. 167–182.
14. Vosinakis, S.; Koutsabasis, P.; Zaharias, P. An Exploratory study of Problem-Based Learning in Virtual worlds. In Proceedings of the IEEE Xplore—3rd International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES), Athens, Greece, 4–6 May 2011.
15. Lehman, J.D.; George, M.; Buchanan, P.; Rush, M. Preparing Teachers to Use Problem-centered, Inquiry-based Science: Lessons from a Four-Year Professional Development Project. *Interdiscip. J. Probl. Learn.* **2006**, *1*, 7. [CrossRef]
16. Alimisis, D. Teacher Training in Educational Robotics: The ROBOESL Project Paradigm. *Tech. Knowl. Learn.* **2019**, *24*, 279–290. [CrossRef]
17. Hanney, R.; Savin-Baden, M. The problem of projects: Understanding the theoretical underpinnings of project-led PBL. *Lond. Rev. Educ.* **2013**, *11*, 7–19. [CrossRef]
18. Scultz, C.; Kim, S. Authentic Problem-based Collaborative Learning Practices for Professional Development in Teacher Education. *Int. J. Educ. Leadersh. Prep.* **2008**, *3*, n2. Available online: https://files.eric.ed.gov/fulltext/EJ1067208.pdf (accessed on 30 June 2023).
19. Ng, M.L.; Bridges, S.; Law, S.P.; Whitehill, T. Designing, implementing and evaluating an online problem-based learning (PBL) environment-A pilot study. *Clin. Linguist. Phon.* **2013**, *28*, 1–14. [CrossRef] [PubMed]
20. The BeReady Project, Erasmus+ 2020-1-PL01-KA226-SCH-095959. Available online: https://www.beready.pw.edu.pl/index/ (accessed on 30 June 2023).
21. Papasarantou, C.; Alimisi, R. The BeReady Handbook. Report in the Framework of the BeReady Project. 2023. Available online: https://www.beready.pw.edu.pl/downloads/ (accessed on 30 April 2023).
22. Aksamit, D. IO2—Four Online Course for Teachers. Report in the Framework of the BeReady Project. 2023, pp. 18–22. Available online: https://www.beready.pw.edu.pl/doc/IO2-summary.pdf (accessed on 20 October 2023).
23. Papasarantou, C. Designing Engaging Online Experiences in STEM: From the BeReady Handbook to the Creation of a "Virtual Gallery". BeReady Final Conference in Warsaw, Poland. 27 April 2023. Available online: https://www.youtube.com/watch?v=9EpbxDL8gTY (accessed on 20 October 2023).
24. Artsteps. Available online: https://www.artsteps.com/ (accessed on 28 June 2023).
25. Google Docs. Available online: https://workspace.google.com/ (accessed on 28 June 2023).
26. Mural. Available online: https://www.mural.co/ (accessed on 5 February 2022).
27. Canva. Available online: https://www.canva.com/ (accessed on 10 April 2022).
28. CULPEER Digital Project, Erasmus+ KA220-ADU. Available online: https://culpeer-digital.eu/ (accessed on 30 August 2023).
29. About Virtual Galleries. Available online: https://culpeer-digital.eu/digital-method.php?id=2 (accessed on 18 October 2023).

education sciences

Systematic Review

A Systematic Review of Preservice Science Teachers' Experience of Problem-Based Learning and Implementing It in the Classroom

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Abstract: This study investigates whether problem-based learning (PBL) is used in preservice science teachers' education, how it develops their pedagogical approach, and what they understand about PBL and its implementation in the classroom. The study utilized a systematic review of the related literature in the field of PBL, with a focus on preservice science teachers' education. It used a specific search strategy to identify the literature following the inclusion and exclusion criteria, adhering to the PRISMA guidance and generating a flow diagram. In addition, the Mixed-Methods Appraisal Tool was used to appraise the quality of the articles. The results show that PBL is not fully utilized in preservice science teachers' training and just a few relevant articles have been published in this area. The study reveals that PBL is an effective pedagogical approach in teaching and learning and preservice science teachers should be engaged in the process of learning by taking part in the PBL design process and experiencing it in the classroom as students of their instructors to learn from the process. Continuing professional development would help preservice science teachers to develop the knowledge and skills to design and implement PBL in their classrooms.

Keywords: problem-based learning; preservice science teachers; STEM education; critical-thinking skills; pedagogy

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1. Introduction

Problem-based learning (PBL) is a pedagogical tool that originated from McMaster University medical school in 1969 [1,2] and has since been embraced in educating medical students through problem solving. It has been used predominantly in the medical field [1,3,4] and other disciplines are embracing it due to its impact on teaching and learning and promoting critical-thinking skills. PBL is a student-centered constructivist approach to learning [5,6] that allows students to create knowledge through social interactions with their peers and working collaboratively towards understanding problems and finding solutions to them [7,8]. PBL is based on solving real-life problems using scenarios, and all participants actively find solutions through researching, discussing, and sharing knowledge [8–10]. Essentially, PBL facilitates a self-directed approach to learning [1,5,11,12], with students working collaboratively towards a common learning outcome, promoting deeper learning and the application of knowledge. It is not about collecting facts, but helping students to engage in inquiry processes, building and applying knowledge through collaborative learning, eliciting feedback, and promoting critical- and creative-thinking skills [13,14]. Due to its emphasis on active learning, McPhee [15] and Kuvac and Koc [16] argue for its inclusion in teacher-training programs to help preservice teachers understand the PBL pedagogy and how to implement it in their classrooms.

PBL enables teachers to promote inquiry skills, creativity, and collaboration among students [17] and should form a core aspect of teachers' training. Vasconcelos [18] (p. 229) argues that "PBL is a process with learning and peer coaching potential that defines the challenge of learning and solving a problem as a feature of the proximal zone development".

Meanwhile, Sutton and Knuth [19] conclude that it can promote students' social, emotional, and civic development. De Witte and Rogge [20] suggest that student achievements and a positive effect on motivation and class atmosphere are the key benefits of PBL. To some extent, these purported benefits contrast the opinions of Lonergan, Cummin, and O'Neill [21], who conclude that PBL may appear to be effective in developing students' knowledge, especially students who are considered to be high-ability, but may be less effective in promoting their problem-solving skills; they also conclude that it may not be effective for other groups of students. The other groups of students referred to may be low-ability and may possibly be those with special educational needs and disabilities (SEND), who require further support to experience the benefits of PBL. This could include using differentiated tasks that focus more on the creative aspects of PBL to create opportunities for all students to learn. In this regard, there needs to be a more inclusive approach to learning which would rely on the expertise of the teacher to promote the learning process.

The same benefits that are realized by students engaged in PBL may also apply to preservice science teachers. For example, Wang [22] concludes that PBL develops preservice teachers' professional knowledge, learning engagement, reflective abilities, teamwork, and practical applications. Preservice teachers also develop a deeper understanding of the principles of instruction courses and how to apply PBL in their teaching methods. This improved the quality of their teaching and the ability to create a positive atmosphere for discussion and use multiple evaluation formats. In the same vein, Blackbourn et al. [23] suggest that PBL in preservice teachers' training can promote instructional methods employed by the teacher, inclusive learning, and student outcomes. PBL instruction can also increase preservice teachers' science content knowledge and critical-thinking skills, their attitudes toward science, and their capacity for collaboration [24]. It can also improve the integration of science and mathematics [25]; STEM belongs to this category, thereby promoting an interdisciplinary approach to teaching and learning. For example, Altunisik, Uzun, and Ekici [26] suggested that problem-based STEM practices can enhance conceptual understandings among preservice science teachers. Syring et al. [27] concluded that PBL allowed students to benefit from interventions regarding cognitive load and motivation. This can improve working and long-term memory, and the ability to understand PBL pedagogy to promote learning. Contrastingly, Caukin, Dillard, and Goodin [28] conclude that efficacy scores increase during teacher preparation and student teaching and then decline after the first year of teaching. This may be a result of the lack of continuity in the PBL pedagogy and the lack of experienced teachers to support the preservice teachers in continuing to embed PBL in their teaching.

In a study involving experts in the field of PBL, Smith et al. [29] identified four effective principles of a PBL model of school-based STEM education. They included problems embedded in rich and relevant learning contexts: flexible knowledge, skills, and capabilities; active and strategic metacognitive reasoning; collaboration based on intrinsic motivation. This provided evidence-informed support for experienced and preservice teachers wanting to adopt PBL as a pedagogy. Barrows [4] proposed ten steps for PBL: encounter an ill-defined problem; have students ask questions about what is interesting, puzzling, or important to find out; pursue problem finding; map problem finding and prioritize a problem; investigate the problem; analyze results; reiterate learning; generate solutions and recommendations; communicate the results; conduct self-assessments. Hung's [30] (p. 123) 3C3R model, a systematic conceptual framework, builds upon the nine-step PBL problem design processes and includes the following: "setting goals and objectives; conducting content/task analysis; analyzing context specification; selecting and generating PBL problem; conducting PBL problem affordance analysis; conducting correspondence analysis; conducting calibration processes; constructing reflection component and examining inter-supporting relationships of 3C3R components". There are other frameworks for carrying out PBL, but the effectiveness of PBL relies on choosing the right approach. This implies that, for teachers to adopt PBL in their classrooms, they must go beyond what individual teachers have to offer, redesigning the curriculum to embrace PBL strategies;

importantly, they must utilize established frameworks to become familiar with the process of designing and implementing PBL. However, teachers can adapt it to the needs of their students to maximize learning.

2. The Challenges of Implementing PBL in the Classroom

The benefits of PBL have been discussed here; however, there are discrepancies in its adoption in the classroom, especially in the processes involved. Loyens et al. [31] blame a lack of conceptual clarity in the PBL environment, where essential components of PBL were not always articulated or addressed in studies claiming to implement these approaches. This can affect the type of assessments and the validity of the PBL process. This confusion may have arisen because PBL is a constructivist approach to learning, as the literature explored in this systematic review shows; educators promoting constructivist learning in their classrooms may simply present it as a PBL process without due attention to the problem design and implementation processes of PBL, which can be complex and time-consuming. Tapilouw et al. [32] concluded in their study that preservice science teachers have difficulties in implementing problem-based learning and suggested that problem-based learning materials should be incorporated into the science-teacher-training program to reduce the obstacle. This aligns with the views of DeSimone [14], who suggests that teachers must engage in effective self-regulatory thinking and actions to address problems by selecting and evaluating critical and relevant resources to meet the needs of students as well as working collaboratively with other teachers in a PBL environment.

Connolly, Logue, and Calderon [33] conclude that adopting a PBL approach increases preservice teachers' research skills but limits the transferability of learning to teaching. They propose a cross-institutional professional collaboration between teachers and educators to improve the use of PBL; this concurs with the views of Navy and Kaya [34], who suggest that it will also aid an integrated form of assessment, enhancing the further benefits of PBL. Ruiz-Gallardo et al. [35] (p. 52) suggest that the drawbacks of PBL may include students "experiencing uncertainty about the breadth and depth of the knowledge required, the time needed for self-directed study, time overload and working in groups, a misunderstanding of PBL and a lack of confidence in their ability to be successful". Goodnough [36] echoed working in larger groups as part of the challenges of PBL. Others assert that the success of PBL depends on the following factors: the context of the problem, purposeful learning, and personal habits [37]; time spent on tasks and the learning sequence [12,35,38]; the creation of a culture of collaboration and interdependence to scaffolding students' learning [39]; a shift from teachers being the knowledge transmitters to the facilitators of learning by supporting students' independence [40]. These inconsistencies in terms of designing PBL call for a greater understanding and implementation of this pedagogy in preservice science teachers' training.

Studies have shown that teachers' pedagogical knowledge is a limiting factor in promoting problem-based learning in the classroom [38,41,42]; therefore, it is sparingly implemented by secondary school teachers [43], especially in science lessons. Peterson and Treagust [44] contend that PBL has not been extensively used in science teacher education, and little work has been carried out to study how PBL can be used in preparing preservice science teachers to teach science in their classrooms [45]. Navy and Kaya [34] reported that PBL has received increasing attention, but the literature lacks a sufficient base of studies exploring how prospective teachers perceive PBL and integrated STEM instruction. This also includes the question of how to design and implement PBL in classrooms. Peterson and Treagust [44] suggest that science involves the integration of knowledge of the subject contents, the curriculum, learners, and the pedagogy of teaching and self-directed learning. Therefore, it places preservice science teacher education in the position of being suitable for a PBL program. However, this has not been the case due to a lack of knowledge and skills to design and implement it in the classroom. Contrastingly, studies have shown that PBL has been utilized in developing experienced science teachers' pedagogy [18,46,47], enabling them to promote problem-solving skills such as collaboration, applying prior knowledge, and eliciting feedback processes among students [38]. However, very little is known about how PBL is promoted among preservice science teachers, their understanding, and how to design and implement it in the classroom, let alone how it would improve their pedagogical approach.

Preservice science teachers can benefit from PBL, but they should have the relevant knowledge and skills to design problems and activities that may promote this learning among students. There seems to be less evidence pointing to supporting preservice science teachers' planning and implementing PBL in the classrooms. Consequently, preservice science teachers may not be aligned with this type of constructive pedagogy and would require support. PBL is a pedagogical tool that would enable science educators to provide opportunities for preservice science teachers to experience situations that they may face in their classrooms and where this is not promoted in teachers' training, it becomes a limiting pedagogy. Therefore, our interests lie in how PBL has been utilized in preservice science teachers' training; additionally, we consider how teachers can be supported in understanding this pedagogy. This involves designing and implementing it in their classrooms and continuing to develop the skills even after qualifying as teachers.

3. Research Questions and Aims

This systematic review aims to summarize and synthesize the empirical literature on preservice science teachers' experience and understanding of PBL; explore the academic literature around PBL that has been carried out in preservice science teachers' training. To achieve these aims, this study gathers the research aims, scopes, methodological approaches, and the type of PBL frameworks used. We investigate whether there is evidence that PBL has been utilized as a pedagogy in science-teacher-training provisions, and provide direction for future investigation. Our research questions include the following:

How does PBL develop preservice science teachers' pedagogical approaches?

What do preservice science teachers understand about PBL and its implementation in the classroom?

4. Methods

4.1. Design

A systematic review was utilized. We presumed that there would be varying studies in the field and were interested in the breadth of the literature and the types of studies that have been conducted on PBL about preservice science teachers' experiences, the benefits of PBL, and addressing the question of how PBL can be implemented in the classroom. We extended our search to cover science education to give us a whole array of studies in the field rather than being limited to a single outcome of interest. Given our focus, we employed a systematic review combined with a systematic search. This is achieved following the steps suggested by Arksey and O'Malley [48], that is: (1) identifying the research question; (2) identifying relevant studies; (3) study selection; (4) data extraction; (5) data summary and synthesis. We used the textual narrative synthesis approach [49,50] to incorporate diverse forms of evidence from qualitative, quantitative, mixed-methods, and quasi-experimental designs to inform our discussions and synthesis of findings as they relate to our study. The nature of this systematic review surrounds educational intervention; thus, we found it appropriate in both instances to follow the latest PRISMA guidance [51]. This included adhering to The PRISMA statement's 27-item checklist followed by generating a revised flow diagram (see Figure 1) detailing our reporting approach for the items included within the review.

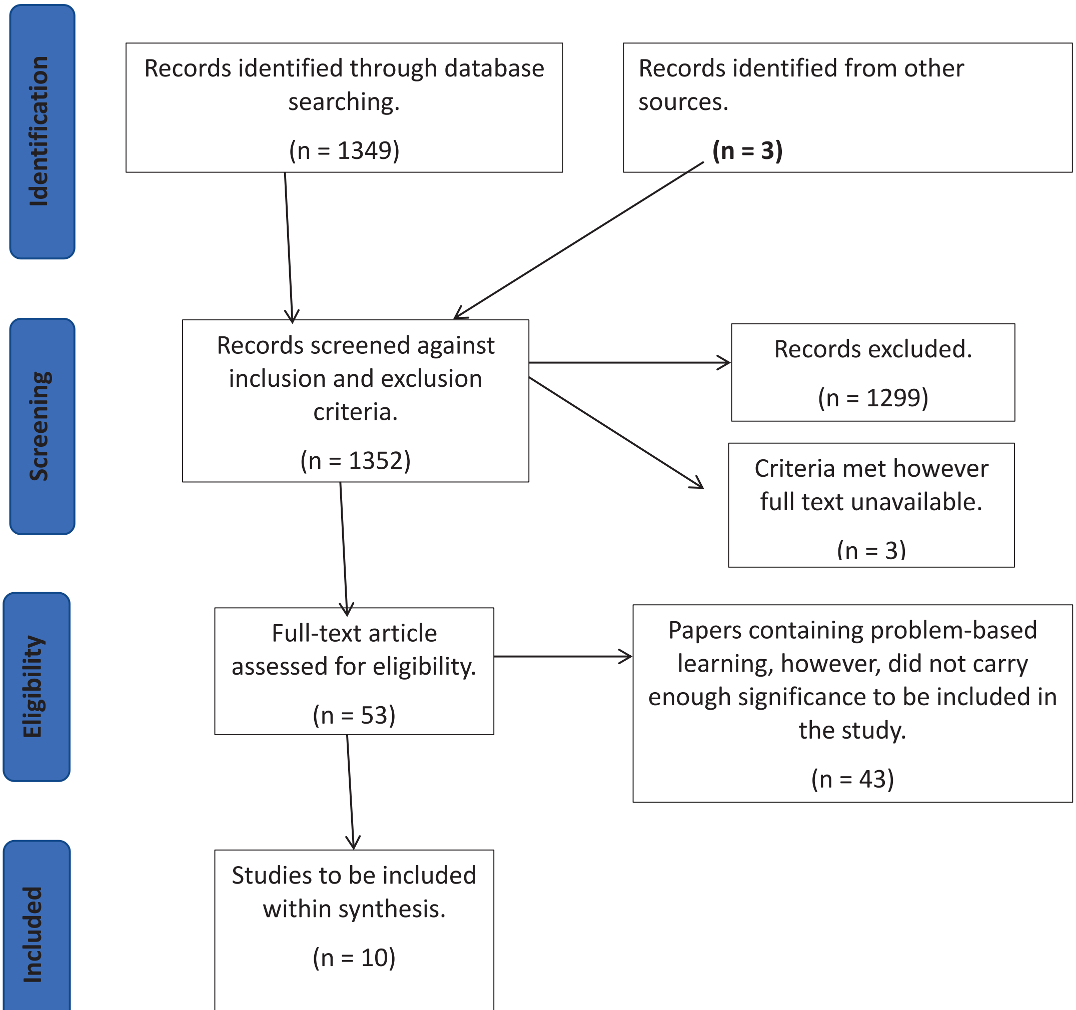

Figure 1. PRISMA flow diagram.

4.2. Search Strategy

A systematic search was undertaken on the 19th of August 2023 using Scopus, Education Research Complete, Academic Search Premier, Teacher Reference Centre, Web of Science, Taylor and Francis Online, and Scholar. Due to discrepancies between search engine results and data extraction, the researchers decided to repeat the search on 2 October 2023. In addition, the resulting papers were hand-searched for specific references, which may have been missing. The last search was carried out on 3 January 2024 to check for any further studies that relate to our inclusion criteria (See Table 1).

Search terms were developed to reflect the concept in question. The final terms were: TITLE (problem-based learning OR problem-centered teaching*) AND TITLE-ABS-KEY (biology* OR science) AND TITLE-ABS-KEY (chemistry* OR science) AND TITLE-ABS-KEY (physics* OR science) AND TITLE-ABS-KEY (science* OR STEM) AND TITLE-ABS-KEY ("high school" OR "secondary school" OR "public school" OR "university") AND TITLE-ABS-KEY ("Trainee science teachers" OR "Pre-service science teachers") AND NOT

TITLE-ABS-KEY (health* OR mathematics OR medicine*). The search was limited to publications from 1969 onwards as PBL began to gain prominence during this time [2].

Table 1. Inclusion and exclusion criteria.

Inclusion	Exclusion
The study evaluated or explored PBL approaches as they related to some type of student skill or knowledge and preservice science teachers' pedagogy.	The study did not report how PBL is related to student skill or knowledge and preservice science teachers' pedagogy but acknowledged that it can be useful.
The study was identified explicitly as a PBL study, where steps in carrying it out can be identified by the user.	The study was a report or evaluation of the outcomes of PBL, with no definite way/steps for carrying it out.
The study mentioned the type of PBL framework/instructions used.	No mention of the PBL framework used but simply acknowledges that PBL is effective in promoting learning.
The PBL was primarily focused on preservice science teachers and can include science subjects, technology, and engineering.	The PBL was primarily focused on preservice teachers in other subject areas, including education, mathematics, and medicine.
The PBL was primarily focused on preservice science teachers or science trainee teachers.	The PBL focused on other subject areas outside of science, for example, education.
The study was carried out in a secondary school, university, or college/teachers' training institutions.	Studies were carried out in primary schools or other educational settings or than those in the inclusion criteria.
The study was peer-reviewed and had extractable data.	Book chapters, conference papers, or other papers without extractable data (such as opinions, editorials, magazines) or theses.
The study was published in 1969 or later, and available in English.	The study was published before 1969 or in a language other than English.

4.3. Inclusion and Exclusion Criteria

The search returned 1349 results; these were reduced to 1200 after duplicates were removed (see Figure 1 PRISMA diagram). After an initial screening, 50 articles were identified. The reference lists of these articles were searched, with 3 further papers included and assessed against the inclusion and exclusion criteria (See Figure 1).

A total of 43 papers containing PBL, however, did not carry enough significance to be included in the study. These papers may have aspects of the inclusion criteria but did not discuss PBL or its effects in sufficient detail or relevance to be included in our study: for example, a study addressing problem-based vs. project-based learning, but with a focus on project-based learning. After applying these criteria and screening the full text of the remaining articles, 10 articles were left that met our inclusion criteria (Table 1). All authors participated in the first, second, and final screenings. These were overseen by the lead researcher who checked the screening of other authors and resolved any conflicts.

4.4. Data Extraction and Synthesis

Data from the included studies were extracted by all the authors and categorized according to the source, authors, year, title of the research, the country where the research took place, the study aims and objectives, research methods and design, sample size, type of PBL framework used, study outcomes, and quality appraisal scores (See Table 2). We synthesized our findings based on what studies revealed about utilizing PBL in preservice science teachers' education and how it develops their pedagogical approach, along with what preservice science teachers understand about PBL and its implementation in the classroom. This fulfills the textual narrative synthesis approach [50] and helps us to arrange our studies into homogenous groups with our research questions. This meant that we could compare similarities and differences across the various studies reported.

Table 2. Summary of studies included in the review.

Author	Year	Country	Sample	Type of PBL Framework	Study Aim	Research Method	Outcomes	Quality Appraisal
Thomas et al.	2013	USA	29	Constructivist	The purpose of the study was to determine pre-service teachers' perceptions of delivering problem-based learning, and how pre-service teachers differ on personal science teaching efficacy beliefs and science teaching expectancy outcomes with respect to elementary and secondary pre-service teaching?	Quantitative	The result suggests that initially, the preservice teachers were undecided whether they could perform PBL but the training they received improved their understanding of PBL, confidence and science teaching efficacy. Preservice teachers should be provided with the opportunity to observe master teachers modelling PBL and be students of PBL to experience the impact of learning science in that way. It also develops preservice teachers' pedagogical content knowledge, approaching PBL from various disciplines in science and suggesting making links between PBL and other constructivist successful pedagogies.	No
Turk & Seyhan	2022	Turkey	24	Walton's argument model-supported PBL approach	The purpose of this research is to determine the conceptual understanding of pre-service science teachers about "Colligative properties", which are aimed to be taught within the scope of the Chemistry-II course, within the framework of the argumentation-supported problem-based learning method	Qualitative	The result suggests an improvement in their ability to address misconceptions about the subject. However, their conceptual understanding of colligative properties did not increase at the desired level. It concluded that the inability to fully understand the concept of the particulate nature of matter will lead to misconceptions in other chemistry topics. The authors claimed that argumentation was used to close the missing information learning gap of the PBL method.	Yes

Table 2. *Cont.*

Author	Year	Country	Sample	Type of PBL Framework	Study Aim	Research Method	Outcomes	Quality Appraisal
Aryulina & Riyanto	2016	Indonesia	n/a	PBL model and instruction	This study aimed to develop a problem-based learning model in Biology education and obtain an expert evaluation of the appropriateness of the developed model.	Qualitative	The result produced a PBL model design following five steps; problem identification, problem-solving planning, problem-solving implementation, problem-solving result presentation, and problem-solving reflection. Expert evaluation of the model showed that it was in accordance with the characteristics of problem-based teaching and appropriate to use in developing inquiry teaching competency of preservice teachers.	No
De Simone	2008	Canada	76	Constructivist	The aim of this study was to inform and prepare prospective teachers for the diverse and complex problems that arise in both the classroom and within pedagogy.	Quasi-experimental	There must be a synergy between theory and practice to allow the success of PBL for prospective teachers. While the design, planning, and implementation of problem-based learning is expensive, it is a powerful strategy for teaching in complex, collaborative systems. Efforts need to be made to allow PBL to be affordable which will allow educators to implement the discussed strategies in their teaching.	Yes
Kuvac & Koc	2019	Turkey	51	"Seven Jump" Model by Schmidt (1983)	This study attempted to investigate the effect of problem-based learning (PBL) on the environmental attitudes of preservice science teachers.	Mixed method	The findings of the study revealed a statistically significant increase in favour of the experimental group preservice science teachers' environmental attitudes. An increase in environmental attitudes was also found in the control group; however, this increase was not statistically significant. As a result, PBL was found to be more effective than the traditional teaching approach in the development of environmental attitudes in preservice science teachers.	No

Table 2. *Cont.*

Author	Year	Country	Sample	Type of PBL Framework	Study Aim	Research Method	Outcomes	Quality Ap-praisal
Selcuk, G.S.	2010	Turkey	25	"TV Box" scenario	The purpose of this study was to evaluate the effects of the Problem-Based Learning (PBL) method on students' achievement in approaches and attitudes towards an introductory physics course.	Quasi-experimental pre/post-test design	The outcome shows that the problem-based learning method encouraged a deep approach to learning, and improved interest and attitude towards the physics course and students' achievements.	Yes
Sumarni et al.	2022	Indonesia	72	STEM-PBL-local culture learning	This analyses the effect of applying problem-based learning with a STEM approach integrated with local culture (STEM-PBL-local culture) on improving creative thinking and problem-solving skills and determines the relationship between creative thinking and problem-solving skills.	quasi-experimental research (pretest and post-test).	The results show significant differences between the experimental and control groups. Students in the experimental group who received STEM-PBL-local culture experienced an improvement in creative thinking and problem-solving skills in the medium category, while the control group experienced an improvement in the low category.	Yes
Goodnough, K.	2003 (a)	Canada	28	Barrows (1996) model	This study examined issues that arose during the development and implementation of a modified form of traditional problem-based learning at one Canadian university. It explored PBL in the context of preservice education, investigating how it could be used to foster an inquiry-based approach to preservice preparation and how preservice teachers perceived PBL as a means of learning.	qualitative	PBL has challenges when working in larger groups however in all identified cases the benefits of PBL outweigh the drawbacks. It promoted an inquiry learning experience as students explored problems, examining their complexity and finding practical ways to address the problems in the context of a classroom.	Yes

Table 2. *Cont.*

Author	Year	Country	Sample	Type of PBL Framework	Study Aim	Research Method	Outcomes	Quality Appraisal
Goodnough, K.	2003 (b)	Canada	28	PBL as an instructional approach	Explore problem-based learning (PBL) as an instructional approach in a large pre-service science education course. It addresses how the teacher educator would structure PBL to foster student engagement in learning, enhancing pedagogical content knowledge through self-study, and students' feedback to inform practice.	Qualitative	PBL and other active learning strategies should be used in teacher preparation programs. Eliciting ongoing feedback from students is essential if PBL is to be refined and adapted for varying groups of students. It would be best to work collaboratively with colleagues to share, discuss, and analyze this feedback. Furthermore, the use of PCK provides a useful framework to make the knowledge base of higher education teaching explicit	No
Wahyudiati, D.	2022	Indonesia	80	PBL instruction	This study aims to determine the effect of applying problem-based learning models on critical thinking skills and scientific attitudes of pre-service chemistry teachers in Basic Chemistry 1.	quasi-experimental research	The result suggests that the PBL model contributed to the critical thinking skills and scientific attitudes of students. These included analytical skills and attitudes towards scientific investigations.	No

5. Results

5.1. Descriptive Results

Ten papers were included in this review. One used a mixed-method approach [16], four used quasi-experimental research techniques [52–55], four employed a qualitative study [36,56–58], while one utilized a quantitative research approach [59]. Most studies were from Canada (n = 3), Indonesia (n = 3), and Turkey (n = 3); only one was from the USA (n = 1). The sample sizes varied, with the combined number of participants in the qualitative studies being 80. Aryulina and Riyanto [57] did not state their sample size. The total number for the quasi-experimental study was 253, and the total sample population for the mixed-method study was 51; meanwhile, that of the study employing a quantitative research approach was 29. The earliest study was published in 2003, while the later studies were published from 2008 onwards. There were several approaches to implementing PBL, with three of the studies using a PBL model and instruction, two employing a constructivist approach, two utilizing a combined approach of PBL with another model, and three utilizing an established PBL framework.

5.2. Quality Appraisal Results

Two researchers assessed 10 articles using the Mixed-Methods Appraisal Tool (MMAT) version 2018 by Hong et al. [60]. The articles were appraised based on the criteria for each research method: qualitative, quantitative, and mixed methods (see Appendix A). To make our decisions, we considered the methodologies in each article and how they fitted the criteria for their category (Appendix A). For example, if the paper was qualitative, we rated it against the five criteria in the qualitative category [60] (see Appendix A). We used the following scoring: 'Yes' if it met all five of the criteria; 'No' if it did not meet all five criteria (but fulfilled between 1 and 4 criteria); 'Cannot tell' if it did not meet any of the criteria. The quantitative and quasi-experimental studies were appraised using the same criteria.

Overall, the quality of the studies in this review varied as seen in Table 2. The quantitative/quasi-experimental studies had the highest quality, with the mixed-methods study having the lowest quality. Drawbacks faced by qualitative studies range from a lack of coherence between the data source and interpretation to not clearly explaining how an open-ended part of a survey was used in the data-collection processes. For the mixed-methods study, the shortcomings included a lack of quotes from the surveys to justify some of the outcomes. Despite the quantitative/quasi-experimental studies having the highest quality, two of the studies had shortcomings ranging from a lack of a representative sample of preservice teachers across different institutions in one of the studies to justifying how the instrument for data collection was utilized in the PBL process.

5.3. PBL in Preservice Teachers' Training

Sumarni et al. [54] utilized a STEM–PBL–local culture learning approach that discusses three concepts: colloids, redox, and solubility. The experimental group was given STEM–PBL–local culture learning, while the control group was given problem-based learning only. The results show that the students in the experimental group who received STEM–PBL–local culture learning experienced an improvement in creative thinking and problem-solving skills in the medium category; meanwhile, the control group experienced an improvement in the low category. They concluded that an increase in students' creative thinking abilities contributed to their problem-solving abilities. This is consistent with the findings of Wahyudiati [55], that the PBL model contributed to the critical-thinking skills and scientific attitudes of students, leading to an increase in analytical skills and attitudes towards scientific investigations. However, Surmani et al.'s [54] study proposed that a combined PBL approach is more effective than PBL alone; we argue that this may not be conclusive, as other studies utilizing only the PBL approach have reported positive impacts on students' learning and preservice teachers' pedagogy.

Thomas et al. [59] adopt a different dimension to PBL, allowing preservice teachers to immerse themselves in the process by using the Science Teaching Efficacy Belief Instrument to evaluate their self-efficacy toward teaching science. This essentially provides a baseline for any learning comparability and is based on Bandura's social learning theory. Initially, the preservice teachers were undecided whether they could perform PBL but the training they received improved their understanding of PBL, their confidence, and their science teaching efficacy. Others include developing preservice teachers' pedagogical content knowledge, approaching PBL from various disciplines in science, and suggesting making links between PBL and other constructivist successful pedagogies. It concludes that preservice teachers should be provided with an opportunity to observe master teachers modeling PBL and be students of PBL to experience the impact of learning science in that way. This corresponds to the findings of Akben [61], who suggests that preservice teachers' understanding of PBL through experience can better support them in implementing it in their professional lives.

The study by De Simone [52] concluded that preservice teachers who are engaged in PBL became better at constructing the central problem, elaborating on the problem, relating their solutions to the problem, and using multiple resources to develop their pedagogical approach. The most important element of this process is that it improved preservice teachers' pedagogical problem-solving skills. This aligns with Pepper's [5] concept of an increase in preservice teachers' perceptions and confidence in teaching science investigation skills and the realization that PBL is a potential learning and teaching strategy to engage their future students in science investigations. On the other hand, promoting inquiry learning can be deduced from the findings suggested here; this is corroborated by Goodnough [36], who posits that PBL promotes an inquiry learning experience, with students exploring problems, examining their complexity, and finding practical ways to address the problems in the context of a classroom. However, Goodnough also identified challenges with carrying out PBL, such as dealing with larger class sizes that pose difficulty in facilitating collaborative working opportunities when working in groups.

In a study on preservice science teachers' environmental attitudes, Kuvac and Koc [16] (p. 78) delivered a PBL training program to the preservice science teachers based on the "Seven Jump" model by Schmidt [62]. This involved the following: "reading out the problem scenario to the preservice teachers and unknown terms and concepts were flagged; generating definitions of the problem; analyzing the problem through brainstorming and group members creating possible explanations for the problem using their prior learning; discussing the explanations; clarifying learning issues according to the information the group members thought should be known about the problem for self-directed learning; determining the task distribution and work plan and finally, investigating the task distribution and work plan". The outcome of using an established PBL framework was an increase in preservice teachers' environmental attitudes and confidence in science and technology as a means of solving environmental problems. This may also help them in developing relevant knowledge and skills to plan PBL and support learning in their classrooms.

Selcuk [53] carried out a study to promote PBL in preservice teachers' achievement, approaches and attitudes toward learning physics; they used a PBL learning scenario teaching material called the "TV Box". The PBL steps involved defining the problem, summarizing the problem, producing hypotheses related to the problem, determining the learning goals, gaining new information by researching, and undertaking numerical analyses of the problem if necessary. The outcome shows that the PBL method encouraged a deep approach to learning, and improved interest in and attitudes of the physics course and students' achievements. An interesting aspect of this study is not only that the PBL steps were explained but that the scenario was included as an appendix to guide novice teachers who may want to design and implement similar PBL approaches in their classrooms. In contrast, in a study of preservice science teachers' conceptual understanding of the colligative properties in a chemistry course, Turk and Seyhan [56] used the Walton-argument-model-supported PBL approach; the findings show an improvement in their ability to address misconceptions in the subject. However, their conceptual understanding of colligative properties did not increase to the desired level. Therefore, they concluded that the inability to fully understand the concept of the particulate nature of matter will lead to misconceptions in other chemistry topics. The authors claimed that argumentation was used to close the missing information learning gap produced by the PBL method.

Aryulina and Riyanto [57] produced a PBL model design with the following five steps: problem identification, problem-solving planning, problem-solving implementation, problem-solving result presentation, and problem-solving reflection. Expert evaluation of the model showed that it has the characteristics of problem-based teaching and is appropriate for use in developing the inquiry teaching competency of preservice teachers. In essence, this seems to be an evaluation of existing models; however, this led to the identification of areas for development in the PBL model. These included the syntax, social system, and the instructor role, the formulation of instructional effects in the syllabus, the course activity, and the assessment instruments of the preservice teachers' competency in inquiry biology teaching. We suggest that other researchers and educators of PBL should take a cue from this process by evaluating the PBL approaches in their classrooms and looking at areas that can be developed to further strengthen this pedagogy. This aligns with the views of Navy and Kaya [34] who contend that, to unify assessments and teaching in PBL, those involved in developing and implementing PBL (such as teacher educators, content experts, curriculum specialists, and teachers) should work collaboratively. However, some kind of framework [1,21] can be provided for teachers to use, because not all teachers and schools have experience with PBL or the privilege of being part of such an endeavor. This will enable them to model collaborative mindsets to ensure that the integration of content is effective for students' learning. Consequently, prospective and practicing teachers can experience integrated classes and professional development to learn more about how this approach can be implemented in schools.

Overall, the studies suggest that PBL has benefits in teaching and learning and should be considered in preparing preservice science teachers' training. Goodnough [58] concluded that PBL and other active learning strategies should be used in teacher-preparation programs. Eliciting ongoing feedback from preservice science teachers' experience is seen to be essential if PBL is to be refined and adapted for varying groups of students. This includes working collaboratively with colleagues to share, discuss, and analyze feedback.

5.4. Which PBL Frameworks Are Useful in Promoting Teachers' Pedagogical Approaches?

This systematic review has revealed that more effort is required to adopt PBL in preservice science teachers' training to enable them to understand this pedagogy and implement it in their classrooms. The complexity of the planning, variations in the PBL approach, and a lack of pedagogical knowledge can be barriers to supporting preservice science teachers, since only a few teachers may have had experience of this pedagogical approach. PBL is a complex process and requires knowledge and skills to design and implement in the classroom, especially among preservice science teachers. This view is corroborated by several studies; for example, Jerzembek and Murphy [63] and Kwan [64] suggest that PBL is difficult to implement due to the complex nature of its design; therefore, they state, it requires the development of teachers' pedagogical approaches to enable students to become accustomed to it.

This systematic review has shown a lot of discrepancies in the adoption and implementation of PBL. Some authors adopt a constructivist approach to learning to demonstrate PBL [20,65], while others use open-ended real-world problems [3,17,46]. Goodnough [36] used an established PBL framework called the Barrows [1] model and Kuvac and Koc [16] utilized the 'Seven Jump' model by Schmidt [62] (see Table 2); meanwhile, Lonergan, Cummin, and O'Neill [21] used an established PBL framework by Barrows and Tamblyn. Few studies have used a combined framework to promote PBL [34,52,66]. For example, Sumarni et al. [54] used a combined STEM–PBL–local culture learning approach; meanwhile, Turk and Seyhan [56] used a Walton-argument-model-supported PBL approach to close the missing information learning gap left by the PBL method (See Table 2).

PBL fulfills the learning requirements of constructivism; however, the discrepancies associated with it may cause pedagogical dissonance [67], leading to confusion in the way it is designed and implemented. As mentioned earlier, PBL requires time to design problems and implement them in the classroom, and teachers without prior knowledge of the process may not fully plan for its benefits. Therefore, they may promote a learning environment where students work in groups, researching information and finding answers to questions posed by the teacher, but not necessarily engaging in PBL. Contrastingly, the variations in PBL implementation gave rise to its dominance as an active learning pedagogy and one that requires attention. De Simone [52] utilized a constructivist approach, comparing PBL with a traditional form of teaching that is centered on causal-comparison design to address the basic issues of the effectiveness of problem-based learning and the degree to which it is effective. Steps to carry out PBL were itemized to guide the novice teacher in designing and implementing PBL. Based on the outcomes, participants were scored on the following abilities: "generate questions that they would like to ask the teacher; identify the problem; state the problem definition; relate the solution to the problem; evaluate the solution; provide a solution; use the literature to support that solution and use other resources to support that solution" (p. 182). Navy and Kaya [34] utilized PBL with integrated instruction to develop PBL units that integrated STEM subjects. The preservice teachers involved in the study learned about PBL unit planning through Virginia Initiative for Science Teaching and Achievement (VISTA) materials. It contained components such as problems, student roles, scenarios, and culminating projects and assessments [45]. This allowed the integration of PBL into content areas that are assessed separately, thereby promoting collaboration and an active learning process.

6. Discussion

This study shows that PBL is not fully utilized in preservice science teachers' training; the outcome is consistent with the findings of Peterson and Treagust [44], who contend that PBL has not been extensively used in science teachers' education. Few relevant articles have been published in this area. This gives an indication that more effort is required if this pedagogy is to be adopted in preservice science teachers' education. This study has shown that PBL is an effective pedagogy in teaching and learning; preservice science teachers should be engaged in the process of learning by taking part in the PBL design process and experiencing it in the classroom as students of instructors, to learn from the process. The evidence given in the present study has shown that there are a lot of benefits associated with PBL, such as the promotion of critical-thinking skills, creativity, and problem-solving abilities [13,24], the development of pedagogical content knowledge and scientific investigations, and an increase in the quality of preservice teachers' research skills and inquiry-based methodologies [33]. Others include the benefits of improvement in interests and attitudes towards subjects, the formulation of problems and dealing with real-life situations. Therefore, PBL training can be provided to preservice science teachers through continuing professional development in their universities, as well as their school placement experience (practicum).

In terms of approaches to develop preservice science teachers' pedagogical approaches in PBL, the studies included in this review had varying views. For example, McPhee [15] suggests that PBL-centered courses in teachers' initial education would require the issue of specified competencies to be addressed and the assessment materials and their certification to be critically examined. In the same vein, Thomas et al. [59] suggest that preservice science teachers should be given a baseline assessment of their self-efficacy toward teaching science to allow educators to assess their understanding of PBL and provide relevant training. This includes allowing them to take part in the learning process, just like the students they will eventually teach in their classrooms. Learning in this form can be a more promising approach in helping preservice science teachers to understand PBL and its processes and implement it in their classrooms. However, most of the studies we explored, except a few, discuss how educators carry out the PBL process among preservice teachers without considering how the preservice science teachers might take part in the PBL learning process as students. Therefore, engaging preservice science teachers as students of PBL would be an area that may require further attention among PBL educators.

Only two of the studies reviewed here attempted to find out what preservice science teachers understand about PBL and its implementation in the classroom. This involves seeking their perceptions of delivering problem-based learning and determining how it is integrated into content disciplines and how they differ in their science teaching efficacy beliefs. One of the studies further described how the preservice teachers were undecided on whether they could undertake PBL, given its complex nature and how it was introduced to them. However, this changed when the preservice teachers were trained in PBL, as it improved their understanding, confidence, and how they would implement it in their classrooms. An important element in the move towards understanding and implementing PBL involves preservice teachers observing experienced teachers and taking part in the process. The literature reports that a lack of experience with PBL is a hindrance in carrying it out, especially when planning the problems; going through the sequence of learning could deter other teachers from implementing it in their classrooms, consequently limiting them from being able to help the preservice science teachers.

As mentioned earlier, PBL is a complex process that involves a lot of planning, knowledge, and skills to implement. We have pointed out several approaches to carrying out PBL, with three of the studies explored using a PBL model and instruction, two employing a constructivist approach, two utilizing a combined PBL approach with another model, and three utilizing an established framework of PBL. One of the studies that utilized the PBL model and instruction provided steps for carrying out PBL in the classroom to guide preservice and novice teachers; meanwhile, others did not. Another study further provided a guide for carrying out PBL, but this was in an effort to evaluate and improve the existing model. However, comparing this to studies that have utilized established models of PBL, such as the Barrows [1] model and the 'Seven Jump' model by Schmidt [62], we realized that adopting an established model can form a basis for helping preservice science teachers to understand PBL and design and implement it in the classroom. Therefore, a consensus lies in utilizing an established framework for carrying out PBL and helping preservice teachers to learn from this process; this can create an opportunity to evaluate the model and improve upon it. Furthermore, the combined framework also demonstrated potential; however, several studies utilizing a PBL-only instruction model or an established PBL framework have proven more effective and reliable in promoting the benefits associated with the pedagogy. Presumably, a combined framework may address the specific intentions with which the researcher wishes to add to the benefits associated with the PBL approach. One of the studies suggests that, when introducing PBL in preservice science teacher training, educators should endeavor to link PBL and other successful constructivist methodologies in science education. However, this would involve a different level of knowledge and skills in planning the PBL problem and implementing it.

7. Conclusions

This study has shown that PBL, an effective pedagogy in teaching and learning, has not been extensively utilized in preservice science teachers training. We believe that some of the studies explored need to go beyond what is presented as a PBL approach and guide preservice science teachers and educators on the steps that they can use to promote it in their classrooms. For example, we mentioned studies that have used established PBL frameworks with examples and steps to signpost preservice science teachers and educators on how to plan and implement PBL in the classrooms. McPhee [15] suggests that PBL-centered courses in initial teacher education would require the issue of specified competencies to be addressed and assessment materials and their certification to be critically examined. Other studies have embraced a culture of identifying what preservice science teachers know about PBL and carrying out a baseline assessment to provide the relevant interventions; we envisage that this may be a welcome approach.

The science curriculum promotes inquiry learning and it is content-driven; hence, it requires relevant knowledge and skills development among students. Therefore, the PBL approach becomes even more relevant to fulfilling the learning requirements of science students, and teachers should embrace this pedagogy. In developing PBL approaches, one of the studies suggests that teacher educators, content experts, curriculum specialists, and teachers must model their mindsets of collaboration to ensure that the integration of content is effective for students' learning. The conclusion that prospective and practicing teachers can experience integrated classes and professional development to learn how the PBL approach can be implemented in schools is consistent with our findings; we suggest that a framework be provided to guide teachers and schools who are novices to PBL to develop the skills and knowledge required.

A limitation of this research is that not enough studies have been carried out in the focus area; despite extending our search to cover science education to give us a whole array of studies in the field, this has proven difficult. Therefore, our conclusion may not be generalizable, but there is scope to reconsider how PBL is portrayed; we suggest that educators utilize established PBL frameworks to evaluate the learning process and carry out further research in this area, especially involving preservice science teachers in designing and implementing PBL.

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Appendix A. Categories of Study Designs and Their Criteria

Qualitative

1. Is the qualitative approach appropriate to answer the research question?
2. Are the qualitative data collection methods adequate to address the research question?
3. Are the findings adequately derived from the data?
4. Is the interpretation of results sufficiently substantiated by data?
5. Is there coherence between qualitative data sources, collection, analysis and interpretation?

Quantitative

1. Is the sampling strategy relevant to addressing the research question?
2. Is the sample representative of the target population?
3. Are the measurements appropriate?
4. Is the risk of nonresponse bias low?
5. Is the statistical analysis appropriate to answer the research question?

Mixed Methods

1. Is there an adequate rationale for using a mixed methods design to address the research question?
2. Are the different components of the study effectively integrated to answer the research question?

3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?
4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?
5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?

Source: [60]

References

1. Barrows, H.S. Problem-based learning in medicine and beyond A brief overview. In *New Directions in Teaching and Learning: Bringing Problem-Based Learning to Higher Education: Theory and Practice*; Wilkerson, L., Gijselaers, W.H., Eds.; Jossey-Bass: Hoboken, NJ, USA, 1996; Issue 68; pp. 3–12.
2. Servant-Miklos, V.F.C. Fifty Years on: A retrospective on the world's first Problem-based learning programme at McMaster University Medical School. *Health Prof. Educ.* **2019**, *5*, 3–12. [CrossRef]
3. Hallinger, P. Mapping continuity and change in the intellectual structure of the knowledge base on problem-based learning, 1974–2019: A systematic review. *Br. Educ. Res. J.* **2020**, *46*, 1423–1444. [CrossRef]
4. Barrows, H.S. A taxonomy of problem-based learning methods. *Med. Educ.* **1986**, *20*, 481–486. [CrossRef] [PubMed]
5. Pepper, C. Pre-service teacher perceptions of using problem-based learning in science investigations. *Teach. Sci.* **2013**, *59*, 23–27.
6. Loyens, S.M.M.; Rikers, R.M.J.P. Instruction based on inquiry. In *Handbook of Research on Learning and Instruction*, 2nd ed.; Mayer, R.E., Alexander, P.A., Eds.; Routledge: New York, NY, USA, 2017; pp. 405–431.
7. Barrows, H.S.; Tamblyn, R.M. *Problem-Based Learning: An Approach to Medical Education*; Springer: New York, NY, USA, 1980.
8. Hmelo-Silver, C.E. Problem-based learning: What and how do students learn? *Educ. Psychol. Rev.* **2004**, *16*, 235–266. [CrossRef]
9. Yew, E.H.J.; Goh, K. Problem-based learning: An overview of its process and impact on learning. *Health Prof. Educ.* **2016**, *2*, 75–79. [CrossRef]
10. Nurkhin, A.; Kardoyo, K.; Pramusinto, H.; Setiyani, R.; Widhiastuti, R. Applying blended problem-based learning to accounting studies in higher education; optimizing the utilization of social media for learning. *Int. J. Emerg. Technol. Learn.* **2020**, *15*, 22–39. [CrossRef]
11. Ungaretti, T.; Thompson, K.R.; Miller, A.; Peterson, T.O. Problem-based learning: Lessons from medical education and challenges for management education. *Acad. Manag. Learn. Educ.* **2015**, *14*, 173–186. [CrossRef]
12. Aidoo, B. Teacher educators experience adopting problem-based learning in science education. *Educ. Sci.* **2023**, *13*, 1113. [CrossRef]
13. Irwanto, I.; Saputro, A.D.; Rohaeti, E.; Prodjosantoso, A.K. Promoting critical thinking and problem-solving skills of preservice elementary teachers through process-oriented guided-inquiry learning (POGIL). *Int. J. Instr.* **2018**, *11*, 777–794. [CrossRef]
14. DeSimone, C. Problem-based learning in teacher education: Trajectories of change. *Int. J. Humanit. Soc. Sci.* **2014**, *4*, 2.
15. McPhee, A.D. Problem-based learning in initial teacher education: Taking the agenda forward. *J. Educ. Enq.* **2002**, *3*, 60–78.
16. Kuvac, M.; Koc, I. The effect of problem-based learning on the environmental attitudes of preservice science teachers. *Educ. Stud.* **2019**, *45*, 72–94. [CrossRef]
17. Suwono, H.; Permana, T.; Saefi, M.; Fachrunnisa, R. The problem-based learning (PBL) of biology for promoting health literacy in secondary school students. *J. Biol. Educ.* **2023**, *57*, 230–244. [CrossRef]
18. Vasconcelos, C. Teaching environmental education through PBL: Evaluation of a teaching intervention program. *Res. Sci. Educ.* **2012**, *42*, 219–232. [CrossRef]
19. Sutton, P.S.; Knuth, R. A schoolwide investment in problem-based learning. *Phi Delta Kappan* **2017**, *99*, 65–71. [CrossRef]
20. De Witte, K.; Rogge, N. Problem-based learning in secondary education: Evaluation by an experiment. *Educ. Econ.* **2016**, *24*, 58–82. [CrossRef]
21. Lonergan, R.; Cumming, T.M.; O'Neill, S.C. Exploring the efficacy of problem-based learning in diverse secondary school classrooms: Characteristics and goals of problem-based learning. *Int. J. Educ. Res.* **2022**, *112*, 101945. [CrossRef]
22. Wang, C. The process of implementing problem-based learning in a teacher education programme: An exploratory case study. *Cogent Educ.* **2021**, *8*, 1. [CrossRef]
23. Blackbourn, J.M.; Bunch, D.; Fillingim, J.; Thomas, C.; Schillinger, D.; Dupree, J. Challenging orthodoxy: Problem-based learning in preservice teacher training. *J. Instr. Psychol.* **2011**, *38*, 140–153.
24. Brears, L.; MacIntyre, B.; O'Sullivan, G. Preparing teachers for the 21st century using PBL as an integrating strategy in science and technology education. *Des. Technol. Educ. Int. J.* **2011**, *16*, 36–46.
25. Cavadas, B.; Rezio, S.; Nogueira, J.R.; Branco, N.A. Framework and a research design proposal to identify preservice teachers' integration performance of science and mathematics. *Can. J. Sci. Math. Technol. Educ.* **2022**, *22*, 101–129. [CrossRef]
26. Altunisik, S.; Uzun, S.; Ekici, D.I. The effect of problem-based STEM practices on pre-service science teachers' conceptual understanding. *J. Pedagog. Res.* **2023**, *7*, 344–358.

27. Syring, M.; Kleinknecht, M.; BohL, T.; Kuntze, S.; Rehm, M.; Jürgen Schneider, M.A. How problem-based or direct instructional case-based learning environments influence secondary school pre-service teachers' cognitive load, motivation and emotions: A quasi-experimental intervention study in teacher education. *J. Educ. Hum. Dev.* **2015**, *4*, 115–129.
28. Caukin, N.; Dillard, H.; Goodin, T.A. problem-based learning approach to teacher training: Findings after program redesign. *SRATE J.* **2016**, *25*, 26–32.
29. Smith, K.; Maynard, N.; Berry, A.; Stephenson, T.; Spiteri, T.; Corrigan, D.; Mansfield, J.; Ellerton, P.; Smith, T. Principles of problem-based learning (PBL) in STEM education: Using expert Wisdom and research to frame educational practice. *Educ. Sci.* **2022**, *12*, 728. [CrossRef]
30. Hung, W. The 9-step problem design process for problem-based learning: Application of the 3C3R model. *Educ. Res. Rev.* **2009**, *4*, 118–141. [CrossRef]
31. Loyens, S.M.M.; van Meerten, J.E.; Schaap, L.; Winjnia, L. Situating Higher-Order, Critical, and Critical-Analytic Thinking in Problem- and Project-Based Learning Environments: A Systematic Review. *Educ. Psychol. Rev.* **2023**, *35*, 39. [CrossRef]
32. Tapilouw, M.C.; Firman, H.; Redjeki, S.; Chandra, D.T. The importance of training needs questionnaire to arrange science teacher training program. *JPII* **2017**, *6*, 110–115. [CrossRef]
33. Connolly, C.; Logue, P.A.; Calderon, A. Teaching about curriculum and assessment through inquiry and problem-based learning methodologies: An initial teacher education cross-institutional study. *Ir. Educ. Stud.* **2023**, *42*, 443–460. [CrossRef]
34. Navy, S.L.; Kaya, F. PBL as a pedagogical approach for integrated STEM: Evidence from prospective teachers. *Sch. Sci. Math.* **2020**, *120*, 221–232. [CrossRef]
35. Ruiz-Gallardo, J.; Gonzalez-Geraldo, J.L.; Castano, S. What are our students doing? Workload, time allocation and time Management in PBL instruction. A case study in Science Education. *Teach. Teach. Educ.* **2016**, *53*, 51–62. [CrossRef]
36. Goodnough, K. *Issues in Modified Problem-Based Learning: A Study in Preservice Teacher Education*; ERIC: Chicago, IL, USA, 2003. Available online: https://files.eric.ed.gov/fulltext/ED477797.pdf (accessed on 8 March 2024).
37. Bledsoe, E.; Flick, L. Concept development and meaningful learning among electrical engineering students engaged in a Problem-Based Laboratory experience. *J. Sci. Educ. Technol.* **2011**, *21*, 226–245. [CrossRef]
38. Magaji, A. Promoting problem-solving skills among secondary science students through problem-based learning. *Int. J. Instr.* **2021**, *14*, 549–566. [CrossRef]
39. Ertmer, P.A.; Simons, K.D. Jumping the PBL implementation hurdle: Supporting the efforts of K-12 teachers. *Interdiscip. J. Probl-Based Learn.* **2006**, *1*, 40–54. [CrossRef]
40. Hmelo-Silver, C.E.; Barrows, H.S. Goals and strategies of a problem-based learning facilitator. *Interdiscip. J. Probl-Based Learn.* **2006**, *1*, 21–39. [CrossRef]
41. Major, T.; Mulvihill, T.M. Problem-based learning pedagogies in teacher education: The case of Botswana. *Interdiscip. J. Probl-Based Learn.* **2018**, *12*, 1. [CrossRef]
42. Wilder, S. Impact of problem-based learning on academic achievement in high school: A systematic review. *Educ. Rev.* **2015**, *67*, 414–435. [CrossRef]
43. Merritt, J.; Lee, M.; Rillero, P.; Kinach, B.M. Problem-based learning in K–8 mathematics and science education: A literature review. *Interdiscip. J. Probl-Based Learn.* **2017**, *11*, 2. [CrossRef]
44. Peterson, R.F.; Treagust, D.F. A problem-based learning approach to science teacher preparation. In *Models of Science Teacher Preparation*; Lavoie, D.R., Roth, W.M., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2001; pp. 49–66.
45. Sterling, D.R. Methods and strategies: Modeling problem-based instruction. *Sci. Child.* **2007**, *45*, 50–53.
46. McConnell, T.J.; Parker, J.M.; Eberhardt, J. Problem-based learning as an effective strategy for science teacher professional development. *Clear. House* **2013**, *86*, 216–223. [CrossRef]
47. Selçuk, G.S. A problem-based Learning scenario that can be used in science teacher education. *Asia-Pac. Forum Sci. Learn. Teach.* **2015**, *16*, 11.
48. Arksey, H.; O'Malley, L. Scoping studies: Towards a methodological framework. *Int. J. Soc. Res. Methodol.* **2005**, *8*, 19–32. [CrossRef]
49. Rodgers, M.; Sowden, A.; Petticrew, M.; Arai, L.; Roberts, H.; Britten, N.; Popay, J. Testing methodological guidance on the conduct of narrative synthesis in systematic reviews: Effectiveness of interventions to promote smoke alarm ownership and function. *Evaluation* **2009**, *15*, 49–73. [CrossRef]
50. Lucas, P.J.; Baird, J.; Arai, L.; Law, C.; Roberts, H. Worked examples of alternative methods for the synthesis of qualitative and quantitative research in systematic reviews. *BMC Med. Res. Methodol.* **2007**, *7*, 4. [CrossRef]
51. Page, M.J.; McKenzie, J.E.; Bossuyt, P.M.; Boutron, I.; Hoffmann, T.C.; Mulrow, C.D.; Shamseer, L.; Tetzlaff, J.M.; Akl, E.A.; Brennan, S.E.; et al. The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *Syst. Rev.* **2021**, *10*, 89. [CrossRef]
52. DeSimone, C. Problem-Based Learning: A framework for prospective teachers' pedagogical problem-solving. *Teach. Dev.* **2008**, *12*, 179–191. [CrossRef]
53. Selcuk, G.S. The effects of problem-based learning on pre-service teachers' achievement, approaches and attitudes towards learning physics. *Int. J. Phys. Sci.* **2010**, *5*, 711–723.
54. Sumarni, W.; Rumpaka, D.S.; Wardani, S.; Sumarti, S.S. STEM-PBL-Local culture: Can it improve prospective teachers' problem-solving and creative thinking skills? *J. Innov. Educ. Cult. Res.* **2022**, *3*, 70–79. [CrossRef]

55. Wahyudiati, D. The critical thinking skills and scientific attitudes of pre-service chemistry teachers through the implementation of a problem-based learning model. *J. Penelit. Pendidik. IPA* **2022**, *8*, 216–221. [CrossRef]
56. Türk, G.E.; Seyhan, H.G. Evaluation of pre-service science teachers' conceptual understandings on the topic of "colligative properties" according to Walton's Argument Model components. *Int. Online J. Educ. Teach. (IOJET)* **2022**, *9*, 241–262.
57. Aryulina, D.; Riyanto, R. A problem-based learning model in biology education courses to develop inquiry teaching competency of preservice teachers. *J. Cakrawala Pendidik.* **2016**, *35*, 1. [CrossRef]
58. Goodnough, K. *Preparing Pre-Service Science Teachers: Can Problem-Based Learning Help?* ERIC: Chicago, IL, USA, 2003. Available online: https://files.eric.ed.gov/fulltext/ED477805.pdf (accessed on 8 March 2024).
59. Thomas, K.R.; Horne, P.L.; Donnelly, S.M.; Berube, C.T. Infusing problem-based learning (PBL) into science methods courses across Virginia. *J. Math. Sci. Collab. Explor.* **2013**, *13*, 93–110.
60. Hong, Q.N.; Pluye, P.; Fabregues, S.; Bartlett, G.; Boardman, F.; Cargo, M.; Dagenais, P.; Gagnon, M.; Griffiths, F.; Nicolau, B.; et al. *Mixed Methods Appraisal Tool (MMAT) Version 2018 User Guide*; McGill: Montreal, QC, Canada, 2018.
61. Akben, N. Suitability of problem scenarios developed by pre-service teacher candidates to problem-based learning approach. *Eurasian J. Educ. Res.* **2019**, *83*, 231–252. [CrossRef]
62. Schmidt, H.G. Problem-based learning: Rationale and description. *Med. Educ.* **1983**, *17*, 11–16. [CrossRef]
63. Jerzembek, G.; Murphy, S. A narrative review of problem-based learning with school-aged children: Implementation and outcomes. *Educ. Rev.* **2013**, *65*, 206–218. [CrossRef]
64. Kwan, T.Y.L. Student-teachers' evaluation on the use of different modes of problem-based learning in teacher education. *Asia-Pac. J. Teach. Educ.* **2008**, *36*, 323–343. [CrossRef]
65. Tarhan, T.; Acar, B. Problem-based learning in an eleventh-grade chemistry class: Factors affecting cell potential. *Res. Sci. Technol. Educ.* **2007**, *25*, 351–369. [CrossRef]
66. Santos Meneses, L.F.; Pashchenko, T.; Mikhailova, A. Critical thinking in the context of adult learning through PBL and e-learning: A course framework. *Think. Ski. Creat.* **2023**, *49*, 101358. [CrossRef]
67. Bradbury, B. The impact of pedagogical dissonance and associated resilience within a foreign sociocultural context of teaching abroad. *Int. J. Inf. Educ. Technol.* **2018**, *8*, 161–165. [CrossRef]

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Article

Understanding Science Teachers' Integration of Active Methodologies in Club Settings: An Exploratory Study

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Abstract: This study analyses if school science clubs may serve as a resource to facilitate the introduction of active methodologies into science classrooms. Focusing on science clubs in Portuguese schools, this study aims to determine whether the teachers who coordinate and direct these clubs promote activities that incorporate aspects of problem-based learning and project-based learning methodologies. In order to do so, a series of semi-structured interviews were conducted with 20 teachers, and their responses were analysed using content analysis strategies. The results show that although they do not explicitly refer to the use of these methodologies, teachers do propose the implementation of projects within clubs, and they incorporate aspects of these strategies in the activities they conduct. In this sense, teachers appreciate the role of clubs in promoting these types of strategies (PBL y PjBL) and the facilities they offer for their implementation. Additionally, teachers believe that one can only learn how to do projects through practise, i.e., doing projects with their students, and they think that clubs offer an opportunity to develop PBL and PjBL methodologies in a context free from the responsibilities and constraints of the classroom.

Keywords: science clubs; active methodologies; project-based learning; problem-based learning; qualitative research; interviews; teachers' perspectives

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1. Introduction

Adapting educational systems to the scientific and cultural changes that occur in society, and improving their quality and effectiveness constitute two fundamental objectives of modern communities.

In this context, one of the crucial tasks of education must be to provide students with knowledge, as well as the competencies and attitudes they will need to navigate a changing and complex world, where traditional solutions are becoming less useful each day [1]. Therefore, over the last decade, numerous institutions have addressed the skills and dispositions that are expected to be vital for schooling in the 21st century [2]. Some of these skills are critical thinking, communication, autonomy, collaboration, and creativity, and adaptability, flexibility, interdisciplinary communication, and complex problem-solving are examples of competencies that will be required for the future [3].

Scientific education must also take responsibility for fostering the development of these skills in future generations of citizens. In this regard, as stated by Domènech-Casal et al. [4], science education advocates for a more contextualised and competency-based approach to science education [5], where student participation promotes their ability to apply, transfer, and create scientific knowledge.

This same perspective is also evident in works such as those of Lee et al. [6], and it translates into an educational approach in which the essential focus is no longer on having "specific knowledge" of mathematics, science, or technology, but on being able to confront specific situations or problems in real contexts, thinking and acting as scientists, mathematicians, or engineers would [4]. Furthermore, some of these 21st-century skills, such as critical thinking and problem solving, effective communication, collaboration and team building, creativity, and innovation, have been identified as important skills that enable students to improve their understanding of science [7].

In light of these circumstances, active methodologies such as inquiry [7], problem-based learning (PbBL), and project-based learning (PjBL) are regarded as strategies that facilitate learning and the development of 21st-century competencies and skills [2,8–11]. These methodologies support the cultivation of critical thinking [12] by encouraging problem solving and the integration and application of knowledge in authentic contexts and tasks [13].

However, the inherent characteristics of these methodologies sometimes make it challenging for teachers to introduce them into the classroom. As a result, a potential alternative that arises is the use of non-formal spaces. The main objective of this study was to examine whether teachers who coordinate science clubs proactively implement active methodologies in these clubs.

This study aims to explore the voluntary adoption and integration of active instructional strategies by teachers within the club context. By investigating teachers' practises and approaches, this study seeks to gain insights into the extent to which active methodologies are employed in club activities and the factors that influence their implementation.

2. Theoretical Framework

2.1. Shifting Gears: Introducing Active Methodologies in Science Education

As can be inferred, the response to contemporary educational and social demands involves a revision of how science is taught in schools. This revision should lead to the design of suitable strategies for today's society and redefine the teaching model so that the development of skills is linked to the acquisition of scientific, technical skills. According to many experts, although traditional methods of direct instruction and recitation may be effective for acquiring factual knowledge, 21st-century skills require new pedagogical approaches [2].

Therefore, the history of education is filled with calls to make student learning more active and shift the focus from the memorisation of information to the utilisation of information [9]. The landscape of teaching and learning in schools is rapidly evolving, as educators continue to seek innovative approaches that adapt to the characteristics of 21st-century societies, life, and students [14]. This is evidenced by the paradigm shift observed over the past decades, where education professionals have re-evaluated the approaches that should be adopted in schools. In particular, there is now a recognition of the role that informal or non-formal learning opportunities can play, and there is a transition from a teacher-centred pedagogy, characteristic of traditional models of teaching and learning [15], which views the process as a transmission of knowledge, to a student-centred pedagogy built upon the constructivist principles of learning, where students "learn by doing and reflecting on what they have done and what it means" [16].

These calls have attracted significant interest since the beginning of the 21st century [17]. Initiatives developed throughout Europe actively pursue the renewal of science education and the implementation of active learning methodologies. Examples of such active methodologies include inquiry-based pedagogical strategies like project-based learning (PjBL) [8,18–20].

Implementing active methodologies is a complex process that requires a paradigm shift, necessitating schools to review their vision and mission, and teachers and students to change their perspectives on science education [21]. For instance, in contrast to traditional lecture-based education, active learning significantly reduces teacher-centred instruction, and students are expected to actively seek knowledge from various sources [21].

Despite the challenges in implementing active methodologies, it is recognised that the types of activities typically implemented when students engage in active methodologies (e.g., students formulating their own questions following a reading assignment, students participating in peer discussion, or students working collaboratively/individually on complex problems) are the most effective in promoting student learning and addressing student affect (i.e., learning attitudes and motivation) in the subject domain [22].

Indeed, there is ample evidence that active learning is an effective way to improve learning and student performance in subjects such as science and mathematics compared to passive lectures. For example, the meta-analysis conducted by Freeman et al. [23], in which the authors reviewed 225 different studies focused on various STEM subjects (biology, chemistry, computer science, engineering, geology, maths, and physics), showed the benefits of active learning approaches in outcomes such as exam performance, even when the studies were conducted in different contexts, classes, educational levels, and so on [24]. Furthermore, both these studies and others indicate that active methodologies support the effectiveness of active learning for student engagement and performance in STEM fields.

Freeman et al.'s [23] meta-analysis provides strong evidence supporting the adoption of active learning strategies, as opposed to traditional lectures, in order to enhance the academic performance of undergraduate STEM students [22]. However, for these benefits to occur, it is essential to make students aware of their role in active learning as opposed to the teacher's role, because students, who may be new to this way of learning, might not even perceive such learning as normal [25].

In general, most methodologies grouped under the umbrella term "active methodologies" are based on a conceptual framework developed around concepts such as constructivism, which proposes that knowledge is actively constructed by the learner. For example, constructivism considers that learning is deeper and easier to transfer to new situations when it is contextualised [4]. Similarly, Beier et al. [24] proposed that students "learn and apply important ideas in a discipline" while engaged in a driving question (p. 318). The most common and prevalent active methodologies in science education are problem-based learning (PbBL) and project-based learning (PjBL). These methodologies, frequently situated within the framework of inquiry-based teaching strategies (IBL), offer valuable opportunities for students to actively engage in their learning processes. PbBL and PjBL foster a student-centred approach, allowing learners to delve into real-world problems and projects, encouraging critical thinking, collaboration, and the integration of knowledge across disciplines. By embracing these active methodologies, educators can cultivate a deeper understanding of scientific concepts and nurture the development of the essential skills needed for success in the modern world.

2.2. Problem-Based Learning (PbBL): An Overview

The concept of PbBL has gained international recognition and evolved to a point where there is no single consistent and universally agreed definition [8]. Instead, multiple, and sometimes contradictory, conceptualisations exist [26]. Merritt et al. [9] conducted a systematic literature review and concluded that there are multiple theoretical sources for researchers' definitions of PbBL. Nevertheless, following these authors, PbBL can be defined as the art of problem solving, a learning approach that challenges students with ill-structured problems that serve as stimuli for learning [12]. Therefore, it is an instructional approach that places students at the centre of the learning process by presenting them with real-world, complex problems or scenarios that reflect authentic challenges within the subject domain, but also require going beyond disciplinary knowledge to integrate and apply it in the resolution of specific problems [12].

In brief, PbBL is a student-centred pedagogy that stimulates students with authentic, ill-structured problems through which they can acquire new knowledge, while teachers act as facilitators. However, when the literature is reviewed, it has been found that PbBL is not perfectly characterised and structured. Specifically, as stated by Sukackė et al. [21], depending on the sources consulted, it can be concluded that the implementation includes six stages [27], five stages, or sometimes three stages [12]. The complete process can be summarised as follows: (1) identifying and understanding the problem, (2) collecting potentially useful information to solve it, (3) agreeing on a possible solution, and (4) reviewing the proposed solution. Once again, following Sukackė et al. [21], this general framework is reflected in a series of specific characteristics, including:

1. Ill-structured, open, real, and unstructured problems are drivers, motivations, and frameworks for learning.
2. Problem identification and resolution serve as a vehicle to acquire knowledge, develop different types of skills, and consequently achieve (learning) goals. Thus, the learning process is self-directed and collaborative, but also exemplary, contextual, experiential, and reflective.
3. Teachers become facilitators and "scaffolders".

Therefore, the distinct essence of an effective problem-based learning process lies in its reiterative and reflective characteristics, which allow for the creation of a knowledge-building environment. Reiteration enables students to review their prior thought processes about a problem and discuss how they would modify their ideas and possible solutions based on the new knowledge they obtained through self-directed learning [11]. In summary, an effective PbBL process is composed of a sequence of learning activities that are reiterative and reflective, involving far more than acquiring the facts and concepts to be recalled.

These distinctive characteristics translate into a series of benefits for students when introduced into the classroom. For instance, PbBL is often associated with positive student learning experiences [28]. Specifically, by using real-world applications, students tend to have a higher level of motivation to participate and engage with the material [29]. A critical point highlighted in the literature is that students engaged in PbBL sequences are motivated by finding a solution rather than gaining a clear understanding of the task, and they tend to adhere to relatively rigid structures and minimise effort when facing unfamiliar and ill-defined problems [21].

Furthermore, when working with methodologies such as PbBL, students show similar or better conceptual gains compared to traditional lecture courses [28]. In this regard, studies indicate that PbBL also increases knowledge retention, conceptual development, and academic achievement [9], and facilitates interdisciplinary thinking towards an integrative perspective and a holistic approach to scientific and practical solutions [30].

Finally, students learn to work in professional teams, with each member bringing different skills to solve the problem [28]. Additionally, PbBL can support the development of "soft" skills [30], such as research skills, negotiation, teamwork, reading, and writing, and contributes to the improvement of communication skills [31]. In conclusion, the problem-based learning approach facilitates the teaching of both essential knowledge and transferable skills beyond the classroom [12].

2.3. Project-Based Learning (PjBL): Definition and Overview

As with PbBL, there are also multiple definitions of project-based learning (PjBL), as researchers have defined it in various ways over the years [24]. However, most of these definitions agree that it is a student-centred teaching methodology that organises learning around the development of projects contextualised in real-world problems that are meaningful to students. The most notable characteristic of project-based learning is the requirement for the development of a product intended for an audience [20,32].

In this regard, PjBL is an inquiry-based [33], active, and experiential learning approach [23], in which the central element of the process is the development of a project. Thus, PjBL engages students in activities such as design, problem-solving, decision-making, and research [34], enabling them to integrate, apply, and construct knowledge as they work together [8,20]. Furthermore, it is described as a teaching method that is open-ended and provides limited guidance from the teacher, offering ample opportunities for acquiring higher-order thinking skills [2].

PjBL finds its pedagogical foundation and starting point in constructivist premises, based on the transformation and construction of knowledge. Specifically, projects focus on issues that lead students to confront and deal with the key concepts and principles of a certain discipline [34], mobilising their theoretical and technical knowledge to find solutions [21].

As previously indicated, PjBL is a learner-centred learning process in which students investigate a question through enquiry, with benchmark lessons and milestones along the way [35]. Project-based learning is a system developed to encourage students to take more responsibility for their education and learning, as they need to solve problems by defining them, discussing ideas, designing enquiries, collecting and analysing data, and sharing findings with their peers [32]. Therefore, students have a high degree of responsibility, autonomy, and unsupervised work time when engaging in projects [33].

However, ambiguity remains among researchers regarding the exact key characteristics or core features of PjBL [8]. The essential elements of PjBL may vary, but there are substantial overlaps among several of those elements [8,11,20,24,36], which normally include the following:

1. PjBL projects are authentic in terms of topics and contextualised in such a way that the learner is working on authentic or real-world problems. As Daddysman et al. [28] indicate, "a key tenet of PjBL is that the project must be real and important and something that a professional would actually do or consider".
2. Everything begins with challenging scientific problems and questions, which act as driving questions that anchor student learning. Thus, as Aksela and Haatainen [13] pointed out, the distinctive feature of project-based learning is problem orientation, that is, the idea that a problem or question drives learning activities.
3. Learners control the learning process, which allows decisions regarding pacing, sequencing, and the actual learning content. In other words, they have voices and choices.
4. Students are engaged in scientific and disciplinary practises, such as investigations in which they can conduct sustained enquiries. They also participate in benchmark lessons and activities.
5. There is a focus on defining appropriate learning goals that lead to deep understanding [9].
6. There are ample opportunities for student reflection, critiques, and revisions. Additionally, it is common to provide feedback and various types of scaffolding to the students throughout the process.
7. Social structures are developed that promote participation and collaboration among students.
8. The project results in the students developing a final product or artefact.

Of these characteristics, the two most distinctive are (1) the fact that projects require a driving question or problem that serves to organise the project activities [32], and (2) that the activities should result in artefacts that culminate in a final product that addresses the driving question [12].

Regarding the driving question, according to Krajcik and Czerniak [37] and Wilhelm et al. [18], it should be feasible (i.e., an investigable question) and sufficiently open-ended that the results are not predetermined and allow for student choice and variability [35] so that they can develop their own approaches to develop the product or artefact.

On the other hand, the construction of the artefact is critical; through this process, students construct their knowledge [13], as it helps learners integrate and reconstruct their knowledge, discover and improve their professional skills, and increase their interest in the discipline and their ability to work with others [20]. Thus, the final products are concentrated expressions of various competencies that students may develop during PjBL. These artefacts are representations of students' solutions resulting from the activities used to address the driving question [32], and can take the form of physical objects, models, documents, such as reports, and multimedia, such as videotapes and computer programmes.

Although this study did not intend to focus on the impact of PjBL on student learning, a small number of studies have demonstrated that PjBL brings benefits in terms of students' content knowledge, learning strategies, skills, and motivation (see, for example, Guo et al.'s meta-analysis [20]). However, more evidence is needed regarding how and when PjBL is the most suitable. In general, it is recognised that PjBL provides student-centred, culturally relevant, and contextualised learning opportunities [19], enabling teachers to tailor instruction to their students and promote students' ability for self-directed learning [36].

Similarly, different studies [24,35,38] have indicated that the introduction of PjBL in the classroom positively affects students' interest, enthusiasm, and motivation. In this regard, PjBL creates opportunities for students to take initiative in the learning process and tackle relevant real-world problems independently and in teams, contributing to increased student engagement, commitment, and self-efficacy.

The involvement in these projects offers a suitable occasion for building bridges between phenomena studied in the classroom and experiences in the real world [12], allowing students to employ their existing knowledge and combine it with the learning acquired throughout project development [21]. Therefore, researchers agree that PjBL contributes to a deeper understanding of key concepts and principles in disciplines, and an increase in students' content knowledge [22,26,37,39].

Within this framework, other studies have detailed how the introduction of PjBL methodologies can contribute to improving academic performance [8,32,39], specifically in STEM subjects [2].

Regarding students' skills, as mentioned, PjBL plays a relevant role in developing 21st-century skills such as communication, negotiation, collaboration, and teamwork [13,31]. Studies have also highlighted the contribution of PjBL to the development of "soft skills" and other skills, such as problem-solving [17], critical thinking [31], autonomy [4], and self-efficacy [33]. Finally, PjBL enables the development of science process skills such as the ability to organise work, plan, and manage time [34].

Entering the realm of affective aspects, the literature details how PjBL improves students' attitudes (see meta-analysis conducted by Guo et al. [19]) and their personal involvement and commitment in the learning process [4,33]. However, the most common results [32,36] focus on the effects of methodology on student motivation. In this regard, PjBL allows students to make certain decisions throughout the process, and to focus on aspects of the project that capture their attention and interest them most. Additionally, the problems they face in PjBL are usually relevant to the real world, which further enhances student motivation.

In summary, when thoughtfully designed and implemented, the evidence suggests that project-based learning can be more effective than traditional educational approaches and can provide various benefits for the students involved, both at cognitive, conceptual, and procedural levels, as well as at affective, personal, social, emotional, and motivational levels.

2.4. PbBL versus PjBL: Exploring the Shared Grounds and Distinctive Aspects

PbBL and PjBL share a series of characteristics and similarities [2,28] that often make it difficult to distinguish them from each other or clearly define their key characteristics [2]. As a result, both terms are often confused [24] and even used interchangeably by researchers and teachers [40].

However, it is true that there may be some overlap between the two strategies [21], as they are closely related, share a central goal, and are designed around complex and contextualised problems that allow students to operate relatively autonomously in order to construct solutions [24]. In this framework, both are described as active and student-centred educational methods that promote group work and knowledge construction, with teachers acting as facilitators of the learning process [40]. Similarly, both PbBL and PjBL employ open-ended problems that promote students' critical thinking and facilitate their understanding of scientific knowledge [28].

However, it is also true that PbBL and PjBL have some significant differences [2], such as the implementation time. While PbBL uses semi-structured problems that can last only a few class periods, projects in PjBL can last from a few weeks to a whole term or year, depending on the course and programme structure [28]. Although studies [28,30] have pointed out certain differences between the two methods, such as the different types of tasks, the key lies in the way knowledge is used [20].

The focus of PjBL is more on the mobilisation of knowledge to produce a final product [26], whereas PbBL is more oriented towards knowledge acquisition [21], emphasising the role of students in defining the problem and developing a solution [2]. Therefore, the main difference between the two methods is that in PbBL, the solution to the problem is merely suggested, whereas in PjBL, it must be executed. Thus, a significant difference lies in the fact that PjBL focuses on creating a "product" or constructing a concrete artefact [13,36].

However, since both strategies resemble each other in the pedagogical foundations, objectives, and rationale behind them, despite their differences in specific aspects of their implementation, this work has chosen to follow the steps of authors like English and Kitsantas [41], Merritt et al. [9], and Beier et al. [24], among others, and consider that PjBL constitutes a specific type of PbBL focused on a problem that involves the development of a product and culminates in the construction of an artefact.

2.5. Not a Walk in the Park: Challenges to Face When Introducing Active Methodologies

While active methodologies bring numerous benefits to the learning process, their implementation is not without its challenges, despite the widely recognised advantages and growing popularity they are gaining [12] and the enthusiasm shown by educators [11,42]. However, these challenges must also be considered:

1. First, active methodologies generally require more resources and can be costlier than traditional teaching methods [30]. For instance, they may require access to specific resources, spaces, or tools that are not readily available in all educational settings.
2. Second, a common criticism of these methodologies is that they require significant effort and substantial time investment from both teachers and students [43]. In this regard, the study by [32] illustrates how some teachers or parents might perceive that project-based methodologies consume large amounts of instructional time, with these extended time blocks covering only a small portion of curriculum content. Methodologies such as PjBL and PbBL require more time for planning and implementing activities than traditional methods. However, as demonstrated by previous studies [21], it is crucial for students to have this dedicated time to ensure positive learning outcomes.
3. Third, specific methodologies, such as PbBL and PjBL, require a deep understanding of the pedagogical foundations on which they are based. This poses a challenge for teachers, who may unintentionally use problem-based learning without realising that their teaching practises have essentially remained unchanged [12]. In fact, arguments from Mentzer et al. [44], Hasni et al. [45], and Wieselmann et al. [11] emphasise that teachers often mistakenly equate PjBL with hands-on activities that lack genuine purpose.
4. Finally, active methodologies often involve increased student engagement and collaboration. As mentioned previously, their implementation requires students to take responsibility for the learning process while receiving appropriate the support and tools to develop their projects. Therefore, the learning environment and teaching practises must be intentionally designed to support students' self-regulated learning. These two factors determine that managing group dynamics may differ from traditional classroom settings, which often require additional classroom management strategies and skills.

Within this scenario, a space is created that can be leveraged by non-formal scientific activities that, when appropriately integrated as a complement to the formal system, can offer clear opportunities to address this issue. Non-formal scientific activities provide valuable opportunities for the development of active methodologies, as they may not be subject to some of the typical limitations encountered in formal education, such as time constraints or curriculum restrictions. Therefore, by leveraging non-formal activities, educators can provide students with more enriching experiences that are often difficult to replicate within the confines of the classroom [46]. For that reason, the integration of non-formal contexts in learning and teaching has gained recognition as a vital component in science education, as evidenced by a wide range of studies [47–51]. These studies emphasise the significance of non-formal activities in fostering a holistic approach to science education and promoting deeper engagement with the subject matter. By acknowledging the role of non-formal contexts, educators can effectively leverage these opportunities in order to provide students with a well-rounded and impactful science education [47,48].

Building on these ideas, this study seeks to examine whether science club coordinators encounter the conducive conditions necessary for implementing active methodologies in science education.

3. The Study: Research Methods and Data Collection Procedures

This study is part of a larger research project focused on exploring the educational possibilities offered by the "Clubes de Ciência Viva na Escola" (The Alive Science Club at School) programme in contributing to science education from the perspectives of coordinating teachers. In this regard, the project aims to gather teachers' evaluations of the clubs themselves, their experiences participating in them, the benefits they provide to students, and, ultimately, their role in the teaching and learning processes of science.

Consequently, a qualitative approach was employed because it seeks to give voice to the participants and understand how they interpret their experiences [52]. Thus, this article reports a descriptive qualitative study in line with its intention to present, analyse, and provide a rich description of science teachers' subjective perceptions and experiences regarding school science clubs. The focus was on capturing the lived experiences of science teachers within the specific context of running a science club in their school.

This study emerged within the context of the broader project. In this regard, the findings described represent specific aspects that arose during the project's development and data analysis, and were not initially considered in the original design. Therefore, this study has an exploratory nature and it aims to investigate whether teachers overseeing science clubs proactively incorporate active methodologies in club activities.

3.1. Exploring the Context: Setting the Stage for the Study

This study involved science teachers and was conducted in the context of school science clubs. These clubs are part of the "Rede Nacional de Clubes Ciência Viva na Escola" (The Alive Science Club at School Network (https://clubes.cienciaviva.pt/, (accessed on 7 January 2024)). The primary objective of this network is to promote science literacy among students, integrate and connect different learning spaces in school (namely the classroom and the clubs), and foster innovative approaches to teaching science that provide students with widespread access to scientific practises through hands-on and minds-on methodologies.

The network encompasses a diverse range of schools across the country, with 897 clubs in 718 schools collaborating with various institutions such as universities, museums, and research centres. These partner institutions organise activities, present challenges, and offer resources. School science clubs operate as extracurricular projects within schools and are coordinated by science teachers affiliated with these institutions.

3.1.1. Participants

The participants were 20 teachers who are responsible for coordinating or running science clubs in their schools. They were selected based on their availability and interest in this study. This group of teachers was chosen because they were deemed best suited to provide insights, experiences, and reflections [53] on their roles as coordinators of the club. All participants were experienced science teachers with teaching experience ranging from 21 to 40 years and had at least one year of experience in running a science club. They were informed about this study's conditions and objectives, and were asked to sign an informed consent form.

3.1.2. Data Collection and Analysis

The data collection process involved conducting semi-structured interviews with the participants. The interview script was designed with open-ended questions to encourage participants to express their thoughts and experiences freely, allowing for detailed and comprehensive responses that would provide a deeper understanding of their perspectives and experiences.

Following ethical approval from the Comissão de Ética para a Investigação em Ciências Sociais e Humanas da Universidade do Minho (nº 101/2022) and the Ministry of Education (code 0843600001), the interviews were conducted face-to-face, enabling personal and interactive exchanges between the researcher and participants. Each interview was conducted separately for each teacher in the school. With the participants' consent, the interviews were audio-recorded and transcribed verbatim, in order to ensure the accurate representation of the data. The textual information collected from the transcriptions was then analysed using the basic principles of Content Analysis [54], employing a combination of strategies from Qualitative Content Analysis (QCA) [55,56] and Thematic Content Analysis (TCA) [57]. Content analysis was chosen to preserve the richness of the teachers' responses and to gain a deeper understanding of the diverse perspectives held by the participants.

The analysis was conducted inductively, with codes emerging directly from the data rather than being pre-established. The responses provided by the interviewed teachers were coded using semantic criteria based on the meanings of the participants' statements. Throughout the Results section, interview excerpts are presented to illustrate and exemplify the types of responses provided by the teachers. A code was attributed to each teacher to maintain anonymity.

For this reason, instead of sorting the teachers' perspectives into fixed categories, we opted for a storytelling approach. We aim to seamlessly blend various excerpts that genuinely represent the diverse viewpoints of educators. This method allows us to thoroughly explore the many aspects of teachers' perspectives, offering a deeper and more nuanced understanding of the challenges and successes in implementing active methodologies within science club coordination, thus providing a deeper and more authentic portrayal of the complex landscape surrounding teachers' experiences.

4. Results

Insights from Science Teachers in School Science Clubs

First, the interviews revealed how teachers value the role of active methodologies in science learning. Specifically, while acknowledging the existence of various types of active methodologies, the vast majority of teachers primarily associate them with project-based learning. This preference stems from the belief that project-based learning aligns with the ideal classroom approach (T15).

> *"In my point of view, the school should be like this. Students should learn through projects, not by subjects. Because we could connect several disciplines, right? And they would still learn the same content, but in a different way. However, there should be fewer students, right? And therefore, I would be satisfied if by the end of their schooling, students acquire the competencies outlined in the student profile, right?"* (T15)

In this regard, when teachers reflect on their vision of an ideal school, a key aspect that emerges from their responses is their ability to engage in interdisciplinary and cross-curricular activities that address complex real-world problems in contemporary societies (T1 and T7). The implementation of projects is seen by teachers as a fundamental element in promoting interdisciplinarity in schools.

> *"The school increasingly needs to be... it can't be just the classroom. In other words, in my understanding, maybe in the near future, the student enters the school and becomes a student at the school, and all of us teachers have to organize ourselves so that they are in the school space and learn in an interdisciplinary manner. That is, the problems we need to solve in our society regarding sustainability or whatever may be, they are complex*

problems. They can't be solved through physics, chemistry, or mathematics alone; they require an interdisciplinary approach. So, we need to work in a different way, breaking down the walls of the classroom, and students become students at the school." (T7)

"The school should close itself less and open itself more to the outside, and classes should be less confined and more cross-curricular, encompassing more disciplines and having more joint projects. Therefore, it doesn't make sense that it does not exist. I think it should be indispensable." (T1)

However, teachers are also aware of the challenges they face when introducing active methodologies into their classrooms. For instance, they point out that school culture itself often reinforces a certain way of working, making it difficult to promote alternative approaches among both students and teachers (T16). Additionally, challenges may arise from the classroom context and circumstances that hinder the implementation of broader activities such as projects (T15).

"Sometimes in the classroom, we can't carry out these types of projects, right? And we know that they are enriching for the students, and I think it's a valuable opportunity for us, right? [...] because we know that students develop other skills that are impossible to develop in the classroom. [...]. Last year, I couldn't do this experience [PjBL] when there were thirty students in the classroom, only twenty-seven, right? But now, with this small group of only twelve, we were able to do this project, right?" (T15)

"I think it's a bit difficult to involve and engage the students because they are very accustomed to traditional approaches, and they are also busy students, always with an extreme concern to prepare their school subjects, and sometimes they are not very available. It's not only the students; it's also the parents of the students and, of course, the teachers. But teachers, despite everything, despite being a class where making changes is difficult, I think they are the easiest to convince because they are people used to deal with the unexpected, with new situations." (T16)

In this regard, teachers perceive science clubs as tools to engage in activities that are often challenging to implement in a regular classroom setting (T7). In some cases, the science club has provided a common framework to integrate various small-scale projects and science-related activities initiated by teachers in the school (T2, T19).

"Of course, we always try to do projects that allow us to do different things with our students, but sometimes there is not enough time in the classroom. Therefore, I end up using the club's time as a complement. That is, my students are also in the club, most of them. It's almost inherent... and I complement the work in the classroom with the work in the club, and vice versa. That's the added value for me." (T7)

"Our application was to take all the science projects developed in the school and compete with all those projects in an agglutinating project that we called 'Desafíos'" (T2)

"We try to somehow articulate with existing projects in the school and provide support. Therefore, the science club aims to give relevance to all the existing projects in the school and help them articulate with each other and with various disciplines." (T19)

Aligned with their vision of teaching in schools, one aspect highly valued by teachers is the opportunity to design interdisciplinary projects that integrate different disciplines, in order to provide students with a holistic understanding of scientific knowledge (T18). The theme of interdisciplinary work consistently emerged in the interviews (e.g., T1, T2, T6, and T11). Additionally, teachers appreciate the opportunities created by these interdisciplinary projects to collaborate with colleagues from different fields of knowledge, allowing them to learn from one another (T7), gain better insight into their colleagues' expertise, and establish closer bonds (T14).

"Doing activities that can bring together various disciplines is difficult. We work in isolation in our daily lives, and even with these projects, we try to create a different idea because

today, society does not match compartmentalized knowledge. Everyone needs to have a little knowledge of various aspects to be able to control their specific area, right?" (T18)

"I think that a large part of my preparation as a teacher has come through this, through my involvement in projects with other teachers, even from other schools (...), my participation in these communities of practice." (T7)

"Firstly, I believe that it greatly helps the relationship within the school because what I say to the students also reflects on us. There is a close relationship between the teachers. [...] Having these colleagues collaborating helps us in other areas within the school. I quickly know that I have someone who is good at this or that, and I ask them for their help. And since I recently joined the school, if it weren't for the club, I wouldn't have discovered t my colleagues' skills so easily." (T14)

Throughout the interviews, the teachers provided various examples of projects undertaken with students within the science club context. These projects typically arise from different sources; however, three main origins can be identified.

(1) Teachers themselves decide to propose a project as a means to address specific curriculum content for a particular course (T1).

"A couple of years ago, we conducted a survey of the trees in the school park, and then we proposed it to the seventh-grade students. They saw the trees, where they came from, whether they were native or not. [...] This activity also emerged from the ideas of the seventh-class council. [...] Therefore, we have focused on this issue" (T1)

(2) Students who demonstrate curiosity and a desire to work on or delve deeper into a specific topic of interest (T2 and T7). In this sense, the club, through its projects, allows students to work according to their interests.

"So, if they want to learn how to make a bioplastic because they saw it on the Internet and we have the materials, then let's make a bioplastic. If they want to make conductive clay or a science challenge, they usually bring their own challenges because they watch YouTube or TikTok and come with their own interests. Through their own interests, they become involved. Therefore, we do not focus solely on teachers [proposals]. We also focused on the students' [suggestions]. What do they want to do? They actively participate in the activities." (T2)

"For example, they have a lot of interest in things related to astronomy at the moment, and maybe there is a competition in Portugal called CanSat. It exists in Portugal and in other countries. [In this competition] they [are challenged to] make a satellite of the size of a can and then we take temperature measurements, for example, using sensors. They are interested in doing something in the space field, so I engage in a brainstorm with them to explore what they want to do." (T7)

(3) The context in which projects may spontaneously emerge owing to diverse circumstances, such as commemorative dates of science landmarks or other events, providing the necessary context for project development (T1).

"Three years ago, we did a... It was a celebration of the first landing on the Moon. At that time, we organized an activity that involved the entire seventh grade. The kids created an exhibition and had a rocket competition that they launched at school. That was three years ago." (T1)

Furthermore, teachers view these projects as opportunities for students to engage in more comprehensive scientific research (T1, T7), resembling the actual practises employed in scientific fields, including aspects such as the communication of information and results through tools such as posters or videos (T2, T9, and T15). In these cases, as highlighted by T6, the benefits for students go beyond the specific content they learn but rather focus on the process of acquiring that knowledge, which is considered the most significant aspect.

"When it comes to secondary school, we try to implement a research project, a mini project, a small activity within the project, two years ago." (T1)

"At the beginning of 2018, we worked extensively on the topic of nutrition. Coincidentally, it was also the International Year of the Periodic Table. We conducted a research project focused on bread, in which the students incorporated different flours rich in various chemical elements, such as chromium and iron. They used alternative flours and conducted the study with the help of Science Alive. This collaboration allowed us to establish a partnership with an university, specifically a Faculty of Sciences, where the students had the opportunity to visit the laboratory, analyse the bread, and compare it with regular bread—experiences that we couldn't have provided at school." (T7)

"We also try to participate in other projects where students are required to work on more scientific tasks, such as creating posters, making videos, or giving presentations. It varies depending on the level of education we are working with." (T2)

"In the first cycle, throughout the school year, students work on projects and create posters to showcase the work they have been doing. They present and communicate their projects at the end of the school year during the Science Fair, where we gather all the projects completed by the students." (T9)

"For example, last year we worked on a project that connected science with art. We focused on cyanotype photography throughout the year, and the students created several cyanotype artworks. At the end of the year, we exhibited their works. It was displayed at the entrance of the school, and parents came to see it." (T15)

"No, I don't see a project as having specific contents. I believe that a project should be interdisciplinary, with the goal of exposing students to different areas and allowing them to learn in different ways. It's not like a traditional classroom setting; otherwise, it would just be a regular classroom. Instead, it's about engaging with the content, whether through emotions or cognitive aspects." (T6)

Conversely, in other cases, the final outcome of the project is not a presentation, poster, or video, but a tangible artefact that can be manipulated and utilised, as indicated by teachers T9, T15, T16, and T17. In the latter case, teacher T17 further noted that the artefacts constructed in club projects can also be employed in regular classroom settings to illustrate specific content.

"We don't just want the students to create a solar collector. No way. They must communicate all the steps involved in their research work, leading up to their proposed solar collector. All the solar collectors will be tested for their efficiency. Additionally, they will be required to create a poster where they report on all the steps and stages of their investigation in developing the solar collector." (T9)

"In our other workshops, we work on projects as well. For example, in the 'Science Splashes' workshop, during the last term, we worked on creating carts powered by elastic potential energy. The students used reusable materials to build the carts. Now, in this term, they are transitioning to carts powered by solar energy. They are beginning to think about the types of materials they need and what needs to be acquired. They are even looking for old carts from which they can remove the motors and wheels for reuse." (T15)

"Furthermore, the chemistry department will also collaborate with us by either hosting our students or working with us to create a prototype of a water treatment station. This way, the students can see and understand the processes involved in water treatment." (T16)

"For example, we can create an interdisciplinary project involving physics from the ninth grade. This involves engineering, technological education, design, and printing. We have the printers here [so we can print small 3D cars that use a balloon as a 'motor'] and we can then [use them to] study Newton's third law, which is about action and reaction, from the ninth-grade physics curriculum. This can be connected to different subjects. The objective is to develop activities that reinforce learning and that are not disconnected from the curriculum. When I'm talking about sound, for example, when I'm discussing sound, we have an ultrasonic sensor here [on the rover's head]. Its function is to measure

distance. These are things that I bring into the classroom. Sometimes, I bring these gadgets to the classroom when we're studying sound." (T17)

In some instances, these projects address current complex issues, such as sustainability, with microplastics being a recurring theme in several interviews (T1, T2, and T9). In other cases, projects developed within the club aimed to connect the school with the community, for example, by providing a service to the community (T19).

"Then, two years ago, we conducted an activity on microplastics. We performed statistical analysis of the quantity and chemical composition of plastics and their effects on living organisms. That was another project we worked on." (T1)

"In 2018 and 2019, we had a major project in partnership with the Faculty of Chemistry in Porto, focusing on microplastics. It was a well-structured project in which seventh-, eighth-, and ninth-grade students participated. Water samples were collected from beaches near their homes, analysed for microplastics, and observed under a microscope. It was a year-long project centered around microplastics, but we always try to involve all students in the school cluster." (T2)

"In the case of the subject I teach, CSAV (Science, Society, and Environment), one of the research topics is related to water, [namely] the presence of microplastics or water quality. Landscape laboratories conduct research in this area. So, what we have planned is to have the students monitor and observe the presence of microplastics in water and document it through photography." (T9)

"Many of the club projects are related to the daily life of the community... For example, a few years ago, we had a project in which we cleaned a small stream that ran near a school. It is often polluted by plastics and other debris. What did we do? We cleaned the river, and the project focused on the ecosystem and importance of cleaning rivers. It was a very interesting project, and the students actively participated in the cleanup." (T19)

"For instance, electronics. Students have a community support centre for repairing household appliances, computers, smartphones, and anything related to electronics. During this week and the next, they will be available at the local council office with specific hours for community assistance." (T19)

Ultimately, as reflected in the response of T16, teachers demonstrate a genuine interest in learning to work with these methodologies, to the extent that they actively seek specific training opportunities to expand their knowledge and incorporate these methodologies into their practises. Teachers like T7 acknowledge the indispensable role of training, since the project-based approach differs from usual classroom practises.

"Actually, in this second semester, or rather in the first semester of 2023, we are going to have a training session conducted by our partners from the University on active learning. In particular, the twelfth-grade teachers will try to apply the project-based methodology to involve more and more students... because it's challenging to work with project-based methodology, for example, right? Several other active methodologies have been proposed. But it's necessary to talk about how to teach or at least read, experiment, and apply it to our students, and that's what we're going to do." (T16)

"The role of the teacher, in the club, is that of a mediator, a privileged interlocutor, someone who has quicker access to objects of knowledge. But who doesn't possess knowledge about everything because we are working in unknown territory... It's a bit about deconstructing the traditional role of the teacher, right?... Not so much as a transmitter or someone who is there just to teach. In the club, I don't feel like I'm teaching. In the club, I feel like I'm creating opportunities, providing resources, and trying to facilitate their access to what they neede." (T7)

However, others, like T6, indicate that "*You do not learn this [conducting projects with the students] in university. You learn this day by day*", because, as T17 mentioned: "*There are things* *that can only be acquired through experience*" (T17). Therefore, they value the opportunity that the club provides to develop these projects with students and to learn along the way.

> *"It's not necessary to spend a semester learning this. You don't learn this at university. You learn this daily. [...] I don't think you can learn to do projects at university. You learn by doing. It's like that saying goes, 'Learn by doing. Find someone who is willing to teach and is truly willing to guide a new person. That's when a person learns."* (T6)

5. Discussion

Exploring the Potential of Active Methodologies in Science Clubs

The analysis of the interviews revealed that teachers who coordinate school science clubs are aware of the significant role that active methodologies can play in science education. In this regard, their perceptions of education in the 21st century stem from the premise that the traditional transmissive model of teaching should be drastically different, advocating for student-centred approaches and more frequent interdisciplinary project-based learning.

However, educators also recognise the difficulties and challenges associated with this transformation. Similar to findings in other studies [7,58], teachers acknowledged that the implementation of methodologies such as projects is constrained by school-related factors, including limited time, lack of suitable spaces, and insufficient financial resources. They are also aware that resistance to change may arise within the educational community, including students, parents, schools, and even some members of the teaching staff. Furthermore, they mentioned the lack of training as another challenge that needs to be addressed in order to achieve the proper integration of active methodologies.

In this context, teachers are acutely aware of the need for professional development to effectively employ these methodologies in their classrooms. They demonstrated a willingness to actively seek and engage in training activities that focus on practical applications involving both themselves and their students in project-based learning.

This is where the importance of science clubs lies, because they provide an environment conducive to tackling these projects. Considering the results of studies such as Martín-García et al. [59–61], it appears that clubs can help mitigate the resistance and issues often pointed out to the implementation of active methodologies in the classroom. Clubs, namely those working in partnership with external institutions, offer more time and resources to teachers, providing a safe space to carry out these activities with support from other organisations, serving as a platform for ongoing learning and development through experiential learning.

Thus, as highlighted in the preceding section, science clubs act as escape valves, enabling the implementation of activities or projects that are typically challenging to conduct in the classroom. Simultaneously, they serve as testing grounds where teachers can innovate and introduce new methodologies (T3), allowing them to experiment, practise, and familiarise themselves with these approaches in a more comfortable and less pressured environment.

> *"[...] we are trying different things and, therefore, we know that there are things that already work and maybe it gives us some confidence, more than trying it for the first time, because at the end of the day our experiences were in the club, isn't it?"* (T3)

Another crucial aspect for understanding why teachers find opportunities to develop projects in science clubs that they do not have in formal classes is funding. As highlighted by T10, many projects often cannot be realised because of a lack of funding or equipment. The integration of clubs into the Ciência Viva network addresses this issue by providing the necessary financial support demanded by teachers, as well as additional equipment and resources offered by the entities collaborating with the network and the clubs in each school (T9, T15). The possibility of accessing additional funding through the club significantly expands the possibilities and options available to educators.

> *"Many times, projects don't happen because there is no funding. So, the first step was to show colleagues the opportunity that existed when there was a budget. With the available*

funds, if possible, they can invite the speaker or organise the initiative. So, the club served as a framework for what already existed." (T10)

"Well, we have partners sometimes just for specific projects, right? We try to reconcile and find partnerships to provide us with new materials. [...] This year, for example, in the first semester, we had a partnership with Texas Instruments. They provided us with the materials and kits to create an automatic irrigation system, right? So, we do have partners sometimes just for specific projects, right? We try to reconcile and find partnerships to provide us with some materials that we don't have." (T15)

"So, we have several partnerships with the company that provided us with the aquariums" (T9)

One interesting aspect that stood out from the collected responses was that the teachers seemed to associate the idea of active methodologies with the implementation of projects. They did not mention other approaches such as problem-based learning, flipped classrooms, or design thinking. Previous studies [61] have highlighted that teachers coordinating science clubs value the opportunities they provide for the development of extensive and long-term activities and projects beyond the school curriculum.

Specifically, teachers believe that these types of projects offer a highly enriching experience for students, as they allow for interdisciplinary work across different areas of knowledge and the development of competencies and skills that would be challenging or nearly impossible to achieve solely in the classroom. This may explain why the teachers primarily focused their responses on this type of active methodology.

These results reflect how teachers value interdisciplinary work and consider it one of the major advantages of science clubs, aligning with their vision of how classroom work should be conducted. In this sense, club projects also contribute to students' learning about wicked problems [62] and socioscientific issues [63], the complex challenges that contemporary societies face at the social and scientific levels. These problems can only be addressed from a holistic and integrated perspective, considering them from different viewpoints and with the knowledge of various areas of expertise.

However, the development of projects within clubs also appeared to have beneficial effects on teachers. The fact that the teacher's role in these activities differs from what they typically perform in the classroom makes the club a valuable learning tool. Moreover, it provides realistic and practical training that takes place within the work environment [64].

Being in charge of a club requires teachers to step out of their comfort zones and engage in tasks that are not typically performed in science classrooms. Teachers such as T7 and T15 acknowledge that clubs promote professional development by encouraging teachers to seek ways to expand their knowledge to bring new projects and topics to the club. It seems that in order to work on a specific theme in the club, teachers have had to research and learn about that topic and how to approach it. Evolution at the professional level implies not only self-directed and autonomous learning [65]; teachers also mentioned engaging in professional training courses to seek support, as shown in the extract from T16 at the beginning of the previous section:

"For example, there are certain activities where I want to participate with the students, like the ones I mentioned earlier. If they really want to participate in CanSat this year, as a teacher, I am obliged to guide them to undergo training, which also contributes to my professional development. It's a process of self-learning where, as I mentioned earlier, I have the ability to work with the students as a facilitator of their learning." (T7)

This personal development is expressed with positive feelings towards teaching, as stated by teacher T7: "*deep down, I started to adhere to this kind [of projects]... to motivate myself because, sometimes, the work of the classroom alone is a little routine, demotivating*".

Nevertheless, the results described in the previous section indicate that teachers consider different motivations when planning and developing projects in science clubs. For example, in some cases, projects are designed to address a specific part of the curriculum during a particular academic year. In other cases, the choice of theme stems directly from students' interests, providing them with the opportunity to learn and delve deeper into topics that fascinate them.

The promotion of scientific culture and the connection between scientific development and social well-being appear to be additional motivations for initiating projects in science clubs. Some teachers emphasise the development of specific projects to commemorate notable events (such as the Moon landing) or significant dates in the history of scientific advancement. Lastly, the possibility of opening the school to the community and engaging in social services is also present in some responses, particularly those provided by T19, aligning with the goals set for the creation of the Rede de Clubes Ciência Viva [66].

However, there is an aspect of the results that requires further discussion. Teachers' responses did not clearly indicate the extent to which the described activities fit within the parameters or basic characteristics of PjBL. Specifically, the teachers refer to the "implementation of projects", but there may be doubts as to whether the way these projects are approached aligns with the described framework of PjBL. For instance, when examining the different definitions of PjBL proposed by various authors [11,13], it becomes evident that a fundamental element is absent from the interviews: the guiding question that drives the project.

Indeed, the transcripts of the interviews did not show teachers referring to a question that structured the project or presented a problem that required a solution. It is true that in specific cases, such as T9 (efficient solar collector) or T7 (CanSat—building a satellite in a can), the question or problem can be inferred from the responses, but it is not explicitly stated. Based on the collected testimonies, it seems that the projects are driven more by the chosen theme or the content to be promoted, rather than by a guiding question or problem that needs to be addressed.

Moreover, another element of these definitions that did not fully emerge from the respondents' answers was the notion of artefacts. Some teachers' responses (for example, T2, T9, and T15) suggest that they conceive of the project's culmination as the presentation of a poster or video documenting its development, which indicates that PjBL demands the creation of an artefact that serves as the final product of the learning process. This was evident in specific cases (e.g., T9, T7, and T17). Therefore, it is uncertain whether the interviewed teachers truly comprehended the significance and implications of PjBL. This highlights the need to emphasise teacher training as a driving force for promoting the incorporation of active methodologies in the classroom.

In conclusion, the presented results allow us to conclude that while some of the surveyed teachers may not have a clear understanding of what Project-Based Learning entails as an active methodology, they recognise that school science clubs are a good option for the development of extensive and enriching projects for students. These clubs are not subject to the same limitations as formal education, thus providing better characteristics and conditions for the implementation of these types of activities.

6. Conclusions

This study focuses on the voluntary adoption of active instructional strategies by science teachers within the context of science clubs. The findings reveal that participants in this study are aware of the need and importance of promoting educational changes towards a student-centred approach in which students play a more active role.

Furthermore, it has been observed that teachers often associate active methodologies with project-based learning (PjBL). However, it is important to note that the teachers' interpretation of "carrying out projects" does not necessarily encompass all the characteristics described in the literature for PjBL.

Therefore, while teachers acknowledge the need for practical, real-world project-based learning experiences for students to acquire project skills, this study emphasises the importance of creating academically oriented training programmes for teachers. These programmes should provide a solid conceptual foundation for understanding the principles of PjBL, including the essential features of instructional sequences, the necessary conditions, and effective implementation strategies. Such programmes would enhance teachers' understanding of what PjBL entails and bridge the gap between teachers' perceptions and theoretical conceptualisations.

Moreover, in line with teacher insights, the results highlight the need for more opportunities and situations that allow teachers to practise and implement active teaching and learning strategies before introducing them into conventional classrooms. Science clubs, as examples of long-term scientific activities, have been identified as suitable environments for this purpose. The conditions provided by science clubs, including time, resources, funding, and collaboration possibilities with peers and professionals from different fields (university researchers and other research centres), allow projects to reach a new dimension and overcome the limitations and constraints often encountered in traditional school settings.

The relaxed and informal atmosphere, the student–teacher relationship, the trust built between teachers and students, fluid communication, and the distinct role of teachers in science clubs all contribute to overcoming initial hesitations from both teachers and students, facilitating the successful incorporation of PjBL in science clubs.

Finally, teachers express various reasons supporting the importance of carrying out projects in science clubs and highlight the value they place on the opportunities created by these clubs. Although they recognise the additional effort and work involved, they experience personal satisfaction in making a positive and beneficial impact on their students' development. Projects enable students to acquire knowledge and develop skills and attitudes that may not be fully attainable in a regular classroom setting. This personal satisfaction becomes the driving force that motivates teachers to continue improving and striving for science education that aligns with their ideals and convictions.

This study provides a glimpse into the adoption of active methodologies by science teachers in science clubs. The results emphasise the importance of providing science teachers with professional development opportunities in active methodologies and combining academically oriented training programmes with opportunities for practise and experimentation in real-world situations. Within this framework, science clubs are identified as key facilitators for the successful implementation of PjBL because of their characteristics and non-formal nature.

In conclusion, this study has educational implications for the implementation of PjBL and highlights the importance of further exploring and promoting active instructional approaches such as PjBL in order to enhance science learning and to foster student engagement in their own learning process. From the perspective of science education research, this work provides a solid foundation for future research on the design and evaluation of educational programmes that integrate the PjBL approach and the role of non-formal contexts in improving science education. However, further investigation is essential to promote greater integration and to better understand how to incorporate these contexts into formal teaching.

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References

1. *OECD Education 2030: The Future of Education and Skills*; OECD: París, France, 2018.
2. Ferrero, M.; Vadillo, M.A.; León, S.P. Is Project-Based Learning Effective among Kindergarten and Elementary Students? A Systematic Review. *PLoS ONE* **2021**, *16*, e0249627. [CrossRef]
3. Wiek, A.; Withycombe, L.; Redman, C.L. Key Competencies in Sustainability: A Reference Framework for Academic Program Development. *Sustain. Sci.* **2011**, *6*, 203–218. [CrossRef]
4. Domènech-Casal, J.; Lope, S.; Mora, L. Qué proyectos STEM diseña y qué dificultades expresa el profesorado de secundaria sobre Aprendizaje Basado en Proyectos. *Rev. Eureka Sobre Enseñanza Divulg. Cienc.* **2019**, *16*, 2203. [CrossRef]
5. Couso, D.; Jiménez-Aleixandre, M.P.; López-Ruiz, J.; Mans, C.; Rodríguez, C.; Rodríguez, J.M.; Sanmartí, N. *Informe ENCIENDE: Enseñanza de las Ciencias en la Didáctica Escolar para Edades Tempranas en España*; Confederación de Sociedades Científicas de España (COSCE): Madrid, Spain, 2011.
6. Lee, M.; Larkin, C.J.K.; Hoekstra, S. Impacts of Problem-Based Instruction on Students' Beliefs about Physics and Learning Physics. *Educ. Sci.* **2023**, *13*, 321. [CrossRef]
7. Martins-Loução, M.A.; Gaio-Oliveira, G.; Barata, R.; Carvalho, N. Inquiry-Based Science Learning in the Context of a Continuing Professional Development Programme for Biology Teachers. *J. Biol. Educ.* **2020**, *54*, 497–513. [CrossRef]
8. Markula, A.; Aksela, M. The Key Characteristics of Project-Based Learning: How Teachers Implement Projects in K-12 Science Education. *Discip. Interdiscip. Sci. Educ. Res.* **2022**, *4*, 2. [CrossRef]
9. Merritt, J.; Lee, M.Y.; Rillero, P.; Kinach, B. Problem-Based Learning in K–8 Mathematics and Science Education: A Literature Review. *Interdiscip. J. Probl. Based Learn.* **2017**, *11*. [CrossRef]
10. Kanter, D.E.; Konstantopoulos, S. The Impact of a Project-Based Science Curriculum on Minority Student Achievement, Attitudes, and Careers: The Effects of Teacher Content and Pedagogical Content Knowledge and Inquiry-Based Practices. *Sci. Educ.* **2010**, *94*, 855–887. [CrossRef]
11. Wieselmann, J.R.; Sager, M.T.; Price, B.C. STEM Project-Based Instruction: An Analysis of Teacher-Developed Integrated STEM PBI Curriculum Units. *Educ. Sci.* **2022**, *12*, 626. [CrossRef]
12. Kek, M.Y.C.A.; Huijser, H. The Power of Problem-based Learning in Developing Critical Thinking Skills: Preparing Students for Tomorrow's Digital Futures in Today's Classrooms. *High. Educ. Res. Dev.* **2011**, *30*, 329–341. [CrossRef]
13. Aksela, M.; Haatainen, O. *Project-Based Learning (PBL) in Practise: Active Teachers' Views of Its' Advantages and Challenges*; Queensland University of Technolog: Brisbane, Australia, 2018; pp. 9–16.
14. Kariippanon, K.E.; Cliff, D.P.; Lancaster, S.L.; Okely, A.D.; Parrish, A.-M. Perceived Interplay between Flexible Learning Spaces and Teaching, Learning and Student Wellbeing. *Learn. Environ. Res* **2018**, *21*, 301–320. [CrossRef]
15. Dovey, K.; Fisher, K. Designing for Adaptation: The School as Socio-Spatial Assemblage. *J. Archit.* **2014**, *19*, 43–63. [CrossRef]
16. Kolb, D.A. *Experiential Learning: Experience as the Source of Learning and Development*, 2nd ed.; Pearson Education, Inc.: Upper Saddle River, NJ, USA, 2015; ISBN 978-0-13-389240-6.
17. Han, S.; Yalvac, B.; Capraro, M.M.; Capraro, R.M. In-Service Teachers' Implementation and Understanding of STEM Project Based Learning. *EURASIA J. Math. Sci. Technol. Educ.* **2015**, *11*, 63–76. [CrossRef]
18. Blumenfeld, P.C.; Soloway, E.; Marx, R.W.; Krajcik, J.S.; Guzdial, M.; Palincsar, A. Motivating Project-Based Learning: Sustaining the Doing, Supporting the Learning. *Educ. Psychol.* **1991**, *26*, 369–398. [CrossRef]
19. Wilhelm, J.; Wilhelm, R.; Cole, M. *Creating Project-Based STEM Environments: The REAL Way*; Springer International Publishing: Cham, Switzerland, 2019; ISBN 978-3-030-04951-5.
20. Guo, P.; Saab, N.; Post, L.S.; Admiraal, W. A Review of Project-Based Learning in Higher Education: Student Outcomes and Measures. *Int. J. Educ. Res.* **2020**, *102*, 101586. [CrossRef]
21. Sukackė, V.; Guerra, A.O.P.d.C.; Ellinger, D.; Carlos, V.; Petronienė, S.; Gaižiūnienė, L.; Blanch, S.; Marbà-Tallada, A.; Brose, A. towards Active Evidence-Based Learning in Engineering Education: A Systematic Literature Review of PBL, PjBL, and CBL. *Sustainability* **2022**, *14*, 13955. [CrossRef]
22. Cleveland, L.M.; Olimpo, J.T.; DeChenne-Peters, S.E. Investigating the Relationship between Instructors' Use of Active-Learning Strategies and Students' Conceptual Understanding and Affective Changes in Introductory Biology: A Comparison of Two Active-Learning Environments. *Life Sci. Educ.* **2017**, *16*, ar19. [CrossRef]
23. Freeman, S.; Eddy, S.L.; McDonough, M.; Smith, M.K.; Okoroafor, N.; Jordt, H.; Wenderoth, M.P. Active Learning Increases Student Performance in Science, Engineering, and Mathematics. *Proc. Natl. Acad. Sci. USA* **2014**, *111*, 8410–8415. [CrossRef]
24. Beier, M.E.; Kim, M.H.; Saterbak, A.; Leautaud, V.; Bishnoi, S.; Gilberto, J.M. The Effect of Authentic Project-Based Learning on Attitudes and Career Aspirations in STEM. *J. Res. Sci. Teach.* **2019**, *56*, 3–23. [CrossRef]

25. Martinez-Rodrigo, F.; Herrero-De Lucas, L.C.; de Pablo, S.; Rey-Boue, A.B. Using PBL to Improve Educational Outcomes and Student Satisfaction in the Teaching of DC/DC and DC/AC Converters. *IEEE Trans. Educ.* **2017**, *60*, 229–237. [CrossRef]
26. Mann, L.; Chang, R.; Chandrasekaran, S.; Coddington, A.; Daniel, S.; Cook, E.; Crossin, E.; Cosson, B.; Turner, J.; Mazzurco, A.; et al. From Problem-Based Learning to Practice-Based Education: A Framework for Shaping Future Engineers. *Eur. J. Eng. Educ.* **2021**, *46*, 27–47. [CrossRef]
27. Yağcı, M. Web-Mediated Problem-Based Learning and Computer Programming: Effects of Study Approach on Academic Achievement and Attitude. *J. Educ. Comput. Res.* **2018**, *56*, 272–292. [CrossRef]
28. Daddysman, J.A.; Wilhelm, J.A.; Taghaddosi, F. Is It Problem or Project-Based Instruction: Implementing PBI for the First Time in an Engineering Mechanics College Course. *Educ. Sci.* **2023**, *13*, 175. [CrossRef]
29. Perrenet, J.C.; Bouhuijs, P.A.J.; Smits, J.G.M.M. The Suitability of Problem-Based Learning for Engineering Education: Theory and Practice. *Teach. High. Educ.* **2000**, *5*, 345–358. [CrossRef]
30. Braßler, M. Interdisciplinary Problem-Based Learning—A Student-Centered Pedagogy to Teach Social Sustainable Development in Higher Education. In *Teaching Education for Sustainable Development at University Level*; Leal Filho, W., Pace, P., Eds.; World Sustainability Series; Springer International Publishing: Cham, Switzerland, 2016; pp. 245–257; ISBN 978-3-319-32928-4.
31. Vogler, J.S.; Thompson, P.; Davis, D.W.; Mayfield, B.E.; Finley, P.M.; Yasseri, D. The Hard Work of Soft Skills: Augmenting the Project-Based Learning Experience with Interdisciplinary Teamwork. *Instr. Sci.* **2018**, *46*, 457–488. [CrossRef]
32. Chen, C.-H.; Yang, Y.-C. Revisiting the Effects of Project-Based Learning on Students' Academic Achievement: A Meta-Analysis Investigating Moderators. *Educ. Res. Rev.* **2019**, *26*, 71–81. [CrossRef]
33. Santos, C.; Rybska, E.; Klichowski, M.; Jankowiak, B.; Jaskulska, S.; Domingues, N.; Carvalho, D.; Rocha, T.; Paredes, H.; Martins, P.; et al. Science Education through Project-Based Learning: A Case Study. *Procedia Comput. Sci.* **2023**, *219*, 1713–1720. [CrossRef]
34. Oguz-Unver, A. A Comparison of Inquiry-Based Learning (IBL), Problem-Based Learning (PBL) and Project-Based Learning (PJBL) in Science Education. *Acad. J. Educ. Res.* **2014**, *2*, 120–128.
35. Krall, R.M.; Wilhelm, J.A.; LeVaughn, J.M. Project-Based Unit Development by Middle School Science Teachers: Investigations on Watershed Water Quality. *Educ. Sci.* **2023**, *13*, 11. [CrossRef]
36. Helle, L.; Tynjälä, P.; Olkinuora, E. Project-Based Learning in Post-Secondary Education—Theory, Practice and Rubber Sling Shots. *High Educ.* **2006**, *51*, 287–314. [CrossRef]
37. Krajcik, J.S.; Blumenfeld, P.C.; Marx, R.W.; Soloway, E. A Collaborative Model for Helping Middle Grade Science Teachers Learn Project-Based Instruction. *Elem. Sch. J.* **1994**, *94*, 483–497. [CrossRef]
38. Bilgin, I.; Karakuyu, Y.; Ay, Y. The Effects of Project Based Learning on Undergraduate Students' Achievement and Self-Efficacy Beliefs Towards Science Teaching. *EURASIA J. Math. Sci. Technol. Educ.* **2015**, *11*, 469–477. [CrossRef]
39. Schneider, R.M.; Krajcik, J.; Marx, R.W.; Soloway, E. Performance of Students in Project-Based Science Classrooms on a National Measure of Science Achievement. *J. Res. Sci. Teach.* **2002**, *39*, 410–422. [CrossRef]
40. Jensen, K. A Meta-Analysis of the Effects of Problem- and Project-Based Learning on Academic Achievement in Grades 6–12 Populations. Master's Thesis, Seattle Pacific University, Seattle, WA, USA, 2015.
41. English, M.; Kitsantas, A. Supporting Student Self-Regulated Learning in Problem- and Project-Based Learning. *Interdiscip. J. Probl. Based Learn.* **2013**, *7*, 6. [CrossRef]
42. Tamim, S.; Grant, M. Definitions and Uses: Case Study of Teachers Implementing Project-Based Learning. *Interdiscip. J. Probl. Based Learn.* **2013**, *7*, 3. [CrossRef]
43. Zhang, Z.; Hansen, C.T.; Andersen, M.A.E. Teaching Power Electronics with a Design-Oriented, Project-Based Learning Method at the Technical University of Denmark. *IEEE Trans. Educ.* **2016**, *59*, 32–38. [CrossRef]
44. Mentzer, G.A.; Czerniak, C.M.; Brooks, L. An Examination of Teacher Understanding of Project Based Science as a Result of Participating in an Extended Professional Development Program: Implications for Implementation. *Sch. Sci. Math.* **2017**, *117*, 76–86. [CrossRef]
45. Hasni, A.; Bousadra, F.; Belletête, V.; Benabdallah, A.; Nicole, M.-C.; Dumais, N. Trends in Research on Project-Based Science and Technology Teaching and Learning at K–12 Levels: A Systematic Review. *Stud. Sci. Educ.* **2016**, *52*, 199–231. [CrossRef]
46. Jarvis, T.; Pell, A. Factors Influencing Elementary School Children's Attitudes toward Science before, during, and after a Visit to the UK National Space Centre. *J. Res. Sci. Teach.* **2005**, *42*, 53–83. [CrossRef]
47. Affeldt, F.; Tolppanen, S.; Aksela, M.; Eilks, I. The Potential of the Non-Formal Educational Sector for Supporting Chemistry Learning and Sustainability Education for All Students—A Joint Perspective from Two Cases in Finland and Germany. *Chem. Educ. Res. Pract.* **2017**, *18*, 13–25. [CrossRef]
48. Garner, N.; Siol, A.; Eilks, I. The Potential of Non-Formal Laboratory Environments for Innovating the Chemistry Curriculum and Promoting Secondary School Level Students Education for Sustainability. *Sustainability* **2015**, *7*, 1798–1818. [CrossRef]
49. Halonen, J.; Aksela, M. Non-Formal Science Education: The Relevance of Science Camps. *LUMAT Int. J. Math. Sci. Technol. Educ.* **2018**, *6*, 64–85. [CrossRef]
50. Eshach, H. Bridging In-School and Out-of-School Learning: Formal, Non-Formal, and Informal Education. *J. Sci. Educ. Technol.* **2007**, *16*, 171–190. [CrossRef]
51. Fernández-Limón, C.; Fernández-Cárdenas, J.M.; Gómez-Galindo, A.A. The Role of Non-Formal Contexts in Teacher Education for STEM: The Case of Horno3 Science and Technology Interactive Centre. *J. Educ. Teach.* **2018**, *44*, 71–89. [CrossRef]

52. Merriam, S.B.; Tisdell, E.J. *Qualitative Research: A Guide to Design and Implementation*, 4th ed.; John Wiley & Sons: San Francisco, CA, USA, 2015; ISBN 978-1-119-00361-8.
53. Bauer, M.; Gaskell, G. *Qualitative Researching with Text, Image and Sound*; SAGE Publications Ltd.: London, UK, 2000; ISBN 978-0-7619-6481-0.
54. Fraenkel, J.R.; Wallen, N.E.; Hyun, H.H. *How to Design and Evaluate Research in Education*, 8th ed.; McGraw-Hill: New York, NY, USA, 2012; ISBN 978-0-07-809785-0.
55. Mayring, P. Qualitative Content Analysis. *Forum Qual. Soc. Res.* **2000**, *1*, 159–176. [CrossRef]
56. Mayring, P. *Qualitative Content Analysis: Theoretical Foundation, Basic Procedures and Software Solution*; GESIS Leibniz Institute for the Social Sciences: Klagenfurt, Austria, 2014.
57. Braun, V.; Clarke, V. Using Thematic Analysis in Psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [CrossRef]
58. Martín-García, J.; Dies Álvarez, M.E. An Examination of Teacher's Goals for a School Crystal Growing Competition: More than Having Fun. *Int. J. Sci. Educ.* **2022**, *44*, 962–979. [CrossRef]
59. Martín-García, J.; Afonso, A.S.; Dies Álvarez, M.E. School Science Clubs: A Glance of Teachers' Perceived Professional Development. In Proceedings of the 15th Conference of the European Science Education Research Association (ESERA), Cappadocia, Türkiye, 28 August–1 September 2023.
60. Martín-García, J.; Afonso, A.S.; Dies Álvarez, M.E. Un club de ciencias en la escuela ¿Para qué? In *Investigación En Contextos Educativos Formales, No Formales E Informales: Descubriendo Nuevos Horizontes En La Educación*; Victoria Maldonado, J.J., Berral Ortiz, B., Martínez Domingo, J.A., Camuñas García, D., Eds.; Dykinson: Madrid, Spain, 2023; pp. 543–553.
61. Martín-García, J.; Afonso, A.S.; Dies Álvarez, M.E. School Science Clubs: What Is Their Value for Teachers? In Proceedings of the 15th Conference of the European Science Education Research Association (ESERA), Cappadocia, Türkiye, 28 August–1 September 2023.
62. Achiam, M.; Glackin, M.; Dillon, J. Wicked Problems and Out-of-School Science Education: Implications for Practice and Research. In *Addressing Wicked Problems through Science Education: The Role of Out-of-School Experiences*; Achiam, M., Dillon, J., Glackin, M., Eds.; Contributions from Science Education Research; Springer International Publishing: Cham, Switzerland, 2021; pp. 229–237; ISBN 978-3-030-74266-9.
63. Alcaraz-Dominguez, S.; Barajas, M. Conceptualization of socioscientific issues in educational practice from a review of research in science education. *IJIET* **2021**, *11*, 297-203. [CrossRef]
64. Tynjälä, P. Perspectives into Learning at the Workplace. *Educ. Res. Rev.* **2008**, *3*, 130–154. [CrossRef]
65. Agonács, N.; Matos, J.F. Heutagogy and Self-Determined Learning: A Review of the Published Literature on the Application and Implementation of the Theory. *Open Learn. J. Open Distance e-Learn.* **2019**, *34*, 223–240. [CrossRef]
66. Reis, E.; Colaço, A.; Miguel, C.; Dias, F.; Oliveira, J.; Gonçalves, L.; Rodrigues, M.; Gomes, T.; Veiga-Pires, C. Introducing Portable Digital Devices into Science Museum Outreach Activities: How Diverse Can It Be? In Proceedings of the 11th International Conference on Education and New Learning Technologies, Palma, Spain, 1–3 July 2019; pp. 6589–6597.

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Article

Teacher Educators Experience Adopting Problem-Based Learning in Science Education

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Abstract: Higher educational institutions have utilized problem-based learning (PBL) approaches over the last two decades. The approach has been found to enable educators to adopt different teaching and learning strategies. This study examined how teacher educators have adopted technology integrated PBL in teacher education. The study aimed to understand teacher educators perceptions of adopting the approach in their classrooms. Interviews were conducted with three teacher educators in Ghana. A thematic analysis was used to analyse the data from the interviews. The teacher educators believed integrating PBL into the curriculum emphasizes students learning roles to support their independent and self-directed learning. They also perceived that the PBL approach enabled them to create collaborative learning activities to interact and communicate with students, which can lead to conceptual knowledge development. The educators also indicated challenges such as a lack of beliefs and competence, inadequate resources, and limited time allocation for school inquiry-based lessons.

Keywords: problem-based learning; technology; teacher education; engagement; collaborative learning; professional development

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1. Introduction

Over the past two decades, educators in higher education have relied on different teaching methods, including lectures and demonstrations. Many researchers have suggested that educators should design their instructions to meet the needs, challenges, and opportunities of 21st-century students learning [1–3]. New emerging insights and evidence of science teaching suggest that learning sciences with traditional approaches emphasizing students recall abilities of disconnected facts should be replaced with learning that enables them to "critically think, solve a problem and transfer ideas, knowledge, and skills in new situations" [4]. In this context, Perkins and Perkins [2] suggested providing opportunities for students to "play the whole game" and experience how knowledge is constructed rather than learning about facts and definitions or procedures and rules (p. 25). One approach that has been found to foster students engagement to apply knowledge in new situations is problem-based learning.

According to Barron and Darling-Hammond [5], "inquiry-based learning constitutes a group of teaching approaches including problem-based learning, project-based learning, designed-based learning which are classified under one umbrella due to their similarities in characteristics" (p. 201). Problem-based learning (PBL) is a pedagogical and learning approach in which students are actively engaged in learning activities that are facilitated by an instructor [6], allowing them to make some level of decisions in the learning process [7,8]. Other researchers define PBL as activities that guide students inquiries, generate meaningful questions, and find answers to discovering new knowledge [9–11]. PBL is a student-centred instructional approach that helps students working on real-case scenarios to interpret data, construct models, and develop ideas through integrated scientific knowledge activities [12–14]. In exploring PBL, seven indicators exist to follow in solving problems. These indicators include problem identification, formulating, analysing, determining solutions, drawing conclusions, evaluating, and solving the problem [15].

According to Pedaste et al. [16], PBL allows students to explore questions or problems by experimenting, predicting, and drawing conclusions.

Recent curricula have emphasized the concept of inquiry as a teaching approach and advocated for integrating technology into inquiry learning practices in science education [14]. It has been established that technology-infused PBL helps educators to encourage students to develop skills actively learning on their own [17–19], build learning communities for students to collaborate and communicate [5], and foster creativity for their understanding of conceptual knowledge [19,20]. Therefore, there is a need to emphasize using PBL in science education. This study examines how chemistry teacher educators have experienced integrating technology to adopt problem-based teaching in a college of education in Ghana. The following research questions guided the study:

1. In adopting the new curriculum, what are teacher educators perceptions on including PBL in the curriculum?
2. What are the perceptions of teacher educators on the advantages and challenges of PBL as an instructional approach?

Problem-Based Learning in Chemistry and Teacher Education

In the literature, several studies have investigated the effects of PBL on student teachers learning attitudes, thinking skills, and academic performance. Studies on PBL have shown that the approach positively affects students learning, especially student teachers. For instance, researchers have contended that including a problem-based curriculum in teacher education programs has supported student teachers in acquiring theoretical concepts for future practice [20,21]. Research has shown that PBL activities improve student teachers learning gains in attitudes and beliefs, helping them to develop knowledge for future teaching [21–23]. For instance, Laursen et al. [21] concluded that PBL is an effective instructional approach for supporting student teachers attitudes towards group work to discover ideas for understanding mathematics concepts. Some studies have indicated that PBL improves student teachers critical thinking skills [24–26]. For instance, Aidoo et al. [24] showed that PBL enhances student teachers motivation to develop critical thinking skills to understand and apply their knowledge into practice. In other research, many studies have reported that PBL improves student teachers academic performance [24,27,28]. For instance, Owusu [27] investigated the effects of PBL on student teachers academic performance in trigonometry. The results showed that the post-test mean scores of students instructed with problem-based learning were higher than those in the conventional instruction class.

Furthermore, PBL is an effective instructional approach in chemistry classrooms. For instance, research has shown the approach improves students attitudes toward chemistry concepts [29–31]. For instance, Ni'mah et al. [31] reported that PBL helps to improve students attitudes towards learning solubility and buffer solution concepts. Other studies have shown that PBL helps to improve students academic performance [32–34]. Similar results have been found in other studies [34–36], which have examined the effect of PBL activities on student critical thinking skills. These studies findings indicate that PBL is an effective instructional approach that facilitates students attitudes, conceptual understanding, thinking skills, and academic achievement, and could contribute to the development of student teachers learning. Many studies have raised concerns about the use of PBL. For instance, Settlage [37] argued that open inquiry is an impracticable mythology for science education. Research has revealed that teachers are not adopting PBL due to their low pedagogical content knowledge [38–40], lack of good resources [38,39,41], and lack of time [42,43]. These issues have affected teachers adoption and implementation of PBL in schools.

In Ghana, the current National Council for Curriculum and Assessment (NaCCA, 2019) statement focuses on using appropriate strategies, such as inquiry learning, to help learners to develop knowledge construction skills to solve problems rather than memorizing knowledge. Adopting the appropriate pedagogical strategies is essential to developing 21st-century core skills such as creativity, critical thinking, innovation, problem solving, and communication skills. Students are then tested on scientific knowledge related to remembering and understanding, the application of knowledge, and experimental and process skills dimensions [44]. There are concerns about students knowledge ability at these three organizational levels which affects their performance in national tests [44,45]. Regardless of the concerns, Ghanaian teachers are mandated to adopt PBL in their classrooms, as done in the USA's Next Generation Science Standards [46]. Some studies on PBL have been conducted in the country targeting K-12 levels [39,40] and pre-service teachers [22,24,27,28]. Despite the mandatory utilization of PBL, limited studies have been conducted on teacher educators views and experiences, especially at colleges of education. Meanwhile, in the colleges of education, teachers are required to adopt pedagogical approaches that ensure creativity, innovation, critical thinking skills, and problem-solving skills in student teachers. Effective pedagogical approaches and classroom management practices in science education have gained space in the current curricula to achieve instructional competence and career readiness beyond teacher training.

Studies have shown that teachers usually practice how they are taught as students because they lack experience of PBL [38,40]. Thus, as teachers are required to use PBL, they need to experience and use it during their teacher training and practice the approach [47]. This suggests that effective instructional strategies during teacher training and professional development are critical to students learning outcomes. Recommendations for teacher professional development on using PBL are ongoing [48–50]. Researchers have indicated that professional development helps to build teachers knowledge and dispositions. Given this, policies have focused on changes towards the curriculum, assessment, and effective pedagogies in science teacher education, including PBL [43,51], which is yet to come to pass. This study explores teacher educators perceptions of the benefits and challenges of implementing PBL in science education.

2. Materials and Methods

This study involves a longitudinal case study [52] to generate in-depth and rich information on the studied phenomenon. This study aimed to complement the conception of how teacher educators experience problem-based learning and the benefits and challenges of adopting the approach in their classroom. For this reason, a case study was appropriate for the researcher to understand the relations between contexts and practice and provide a contextual understanding of the benefits of problem-based learning in teacher education [53]. In case study designs, an inductive approach is used to generate theories to hypothesize and build theory by drawing findings from the cases stated [52].

2.1. Participants and Data Collection

Three teacher educators from three colleges of education across southern Ghana were identified to participate in the study. These educators were selected based on their experience in implementing PBL and their availability to participate in the study during the pandemic. A semi-structured online interview using the Zoom App and WhatsApp was conducted, and questions were asked to explain their experiences of integrating the approach in their classrooms.

Some studies have utilized multiple data sources to assess and evaluate the extent to which problem-based instructions are used in classrooms to make informed decisions [54,55]. Brief teacher interviews are a unique source of classroom data that are easy to obtain and do not consume instructional time. Although teacher interviews are typically lengthy and analysed using complex qualitative methods, they are flexible and provide detailed information from respondents [56], allowing a greater depth and rich information of judgement, unlike questionnaires. Further, Oppong-Nuako et al. [57] noted that brief teacher interviews with a straightforward coding system are effective in assessing the extent of teachers inquiry experience. In this research, brief teacher interviews were used to assess the teachers descriptions of their typical instruction, classroom practices, and anticipated student learning outcomes.

Each interview lasted between 45 and 60 min and was recorded and stored on the Microsoft stream App. The educators were asked their views on the rationale for including PBL and their experiences using PBL. Similarly, the teacher educators were asked about any benefits and challenges faced when integrating the approach into their chemistry classes. The research took place between August 2020 and April 2021. The first set of interviews was conducted in September 2020 to explore the teacher educators experiences integrating student-centred strategies, including PBL. All colleges and universities were closed during this period, and educators shifted to online learning. I was interested to know how the teacher educators adopted the learning. After the first interview, we (the author and the three participants) collaborated to design and develop teaching and learning materials that followed the principles of PBL from the national teacher education curriculum. The second set of interviews was conducted in December 2020, when full classroom sessions (i.e., no restrictions with entire teaching and activities in place) existed. Examples of the questions used to explore the teacher educators experiences with PBL are:

i. What teaching styles do you use in your classroom, and how do you use them to organize or prepare your class for teaching and learning?
ii. What is your definition of a student-centred learning approach?
iii. What teaching method(s) do you consider as student-centred learning approaches?
iv. Have you been using them in your classroom, and why do you use them?
v. How do you describe your role, or what role do you play in the traditional face-to-face classroom compared to the PBL classroom, can you summarize your roles?
vi. What are your views on including PBL in the curriculum and whether it is necessary to adopt it?
vii. Describe your experiences in using PBL in teaching.
viii. Describe how you use ICT and implement the PBL approach in your classroom.
ix. Can you explain some advantages of using PBL as a teaching and learning approach?
x. What challenges or barriers can limit the use of the PBL approach?

2.2. Data Analysis

The video and audio data files from the interviews were saved in Microsoft stream. The data files were transcribed using Microsoft stream and approximately 10,529 words and 730 sentences were identified from the transcripts. The transcripts were then printed out and analysed using paper and pencil methods to categorise them into themes by identifying patterns for analysis within the data. The patterns in the data were analysed using a thematic analysis [58]. The teacher educators were identified using pseudonyms such as Albert, Frank, and George.

2.3. Ethical Considerations

The teacher educators were reached through contacts in the various colleges. Prior to the research, the purpose was explained to the teacher educator and an informed consent form was sent to them for approval. On the consent form, information about their voluntary participation, anonymity about themselves and their institutions, and voluntary withdrawal at any point in time was clearly stated. In addition, a request for the recording and transcribing of the interviews with hidden identities during a presentation of the results was also included. The teachers welcomed the idea and responded that they understood the purpose of the research and that the publication of the results, including anonymity and other consent forms, was explained to them. The research was conducted in accordance with the Constitution of the Ghana Association of Administrators of Research Ethics Committees (GHAAREC, 2015). In ensuring the trustworthiness of the data collection, the transcripts were sent to the participants for member checking and approval before the final draft was drafted for publication. Three experts from both the University of Iceland and University of Helsinki reviewed the interview protocol, transcriptions, and provided feedback for review.

3. Results

The data from the interviews with the teacher educators revealed that they perceived the approach as a pedagogical approach aimed at transforming classroom practices to impact their work and students learning. These benefits are elaborated in the next session.

3.1. Views on the Rationale for PBL Inclusion

The teacher educators were asked to explain their views and acceptance of including PBL in the curriculum. The identified themes regarding the teacher educators perceived views on the rationale for adopting PBL were categorized, students learning roles and learning responsibilities, and independent and self-directed learning.

3.1.1. Students Learning Roles and Responsibilities

The recent curriculum has focused on transforming classroom practices to adopt innovative teaching approaches. There is a focus on integrating learning approaches that emphasize students learning roles and responsibilities. The PBL approach focuses on the principle that students actively participate in their learning. The educators believed the approach was introduced in the curriculum to change their roles to facilitators and for students to take responsibility for their learning. According to Albert, the inclusion of the PBL approach in the curriculum is geared towards changing their classroom practices from a teacher-centred approach to a more student-centred learning approach. He believed adopting PBL was meant to emphasize students active learning. He indicated that they often use approaches allowing students to take on much more learning responsibilities than in the traditional classroom. For instance, he narrated his teaching experiences and said,

> *"Integrating PBL is one of the many teaching strategies in my courses. I believe that the PBL is an approach that emphasizes students active role in the learning process; through PBL, students can explore learning materials, ask questions, and share ideas when working on group tasks."*

In addition, Frank also expressed similar views as Albert on integrating PBL to focus on students active participation in the learning process. To him, the approach enables teachers to shift their instructions to place students as the lesson's focus, with teachers facilitating such a process. He added,

> *"The PBL creates a student-centred learning environment that allows students to take ownership of their learning through experience because they do most of the activities, unlike in the lecture-based method, in which students become passive learners."*

As stipulated in the new curriculum, teachers acceptance of PBL and ICT integration is essential to innovative teaching. George also believed the intent of blending these two key ideas was to strengthen and improve their pedagogical practices, which could lead to improving students learning outcomes. He reflected on his views and experience in the interview that,

> *"We are required to adopt PBL and integrate ICT in our classroom activities. These practices are familiar, and I have experienced using ICT in my classroom activities. In the past 5 years, I have incorporated their use to promote students interactions, communication, innovation, and scaffolding toward creativity, critical thinking, and problem-solving as essential curriculum components."*

3.1.2. Independent and Self-Directed Learning

Teaching with an inquiry is an independent strategy where students are engaged in an active learning process that reflects scientific inquiry. The educators understood the requirement for the transition to develop and integrate active learning strategies to improve students learning outcomes. They believed that active learning approaches focus on students independent learning and that students become active learners when they learn independently. Frank further indicated the approach, *"Allow students to explore information independently, discover, and develop new ideas."*

This indicates that the educators guided students to learn independently through their facilitation. Other educators emphasized the need for students to learn by themselves. For example, Albert also pointed out that,

"In PBL settings, it is required that students become independent learners so they can find information by themselves."

These findings showed that the educators were aware of the requirement for students independent learning approaches, such as the PBL approach, as stipulated in the curriculum document.

3.2. Benefits and Challenges of Implementing PBL

The teacher educators perceived that adopting PBL was beneficial to their classroom practices. These benefits included "classroom interactions", "collaborating learning", and "conceptual knowledge."

3.2.1. Classroom Interactions

Problem-based learning is an avenue for teachers to interact and communicate with students. In this study, the teacher educators emphasized their facilitating role in helping students to construct their ideas. George believed the approach created an opportunity to interact with the students to motivate and provide feedback constantly. According to him, these interactions enhanced students learning progress in performing tasks. He noted that,

"The approach creates opportunities for deeper interaction between teachers and students."

Frank also highlighted the benefits of using ICT tools to create a social learning channel where he could have weekly interaction and discussions with students. According to him, regular interactions with students allowed his students to ask questions about their misconceptions and other learning difficulties. He added that the interactions helped to build confidence in some weaker students to participate in the discussion forum. For example, Frank explained that,

"Engaging and interacting with students brings cordial relationships to the extent that they don't feel reluctant to answer and ask questions in class."

3.2.2. Collaborative Learning

The use of technology contributes to the emergence of collaborative learning during PBL lessons. PBL is a constructivist pedagogy focusing on active and collaborative learning that helps students to solve real-life problems. Albert believed PBL can help instructors to develop avenues to plan lessons that enhance students collaboration in the online learning environment. He felt the integration of technology enabled him to create an enabling environment for students to collaborate. He noted that,

"Through the online applications, creating a collaborative learning platform that allows students to work with their peers and share their ideas and learning experiences is possible."

3.2.3. Conceptual Knowledge

Problem-based learning emphasizes skills and effective practices such as collaboration and problem solving for knowledge acquisition. Active engagement in collaborative and problem-solving activities challenges students to acquire more information for knowledge construction. The teacher educators perceived that the PBL approach made it easy for the students to actively participate in the lesson, as most students participated in the activities. According to George, students used the instructional videos as a guide to engage and work on challenging tasks. Active participation enables students to work on tasks that can enable them to apply ideas learned in real-life situations. He mentioned that:

> *"Students can make connections about what they are learning, which allows them to understand the topic better."*

Apart from the benefits of using PBL, the educators perceived they faced challenges adopting it. They felt that their beliefs and competencies were low. They also did not have the adequate materials and resources, and there was limited time allocation for science lessons. These issues were identified themes from the data.

3.2.4. Beliefs and Competences

Problem-based learning practices demands teacher knowledge, skills, and competence including designing and managing the learning activities. Although educators chose relevant and appropriate type of inquiry activities based on the available learning facilities. However, the educators had difficulty to effectively manage the classroom activities. Some of them could not create the online learning communities and monitor students activities simultaneously. According to the teacher educators, planning activities, managing group work, and assessing students were difficult, and it took more time to provide an effective lesson on content. For instance, Albert indicated he lacked the understanding and competence to manage students online group work. He commented in his reflection on the teaching experience that:

> *"Managing the design, preparation, delivery, and assessment of students inquiry learning group tasks is complex. Teachers should have adequate knowledge and competence to adopt that approach."*

Frank also acknowledged the importance of his skills and competence in engaging and monitoring students learning progress continuously. He added,

> *"Creating online learning groups monitoring students activities within the shortest time available to provide immediate feedback to students is more challenging."*

3.2.5. Materials and Resources

Implementing PBL demands an adequate preparation and planning of the activities and resources available. Due to the hands-on and practical nature of the learning activities, more resources are required. The educators indicated that, due to the large class size, the resources were inadequate for them, especially during group work and experiments. According to Frank, one challenge he encountered adopting inquiry instructions was the lack of adequate science equipment and apparatus for engaging the students during group tasks and practical work. He pointed out that,

> *"I had a challenge with the classroom resources, like learning materials, that will enable us to deliver instructions efficiently without any difficulties."*

George also added that there were inadequate concrete learning materials to explain the models, such as the ball and sticks. He explained that,

> *"The lack of concrete chemistry materials, tools, and equipment for some practical works to help facilitate instruction to the students was inadequate."*

3.2.6. Time Allocation

Implementing problem-based learning activities, planning activities, and designing experiments require time. In guided inquiry, instructors must guide students to design their activities, which requires a lengthy and well-planned process. George explained that PBL implementation planning and implementing was lengthy and time-consuming; therefore, adequate time is needed. He said he felt more time was required to plan and design the activities and handle the materials. Due to the lack of time, he could not perform many of the activities. He further complained about the demands of the curriculum, student accountability, types of assessments, and the rigid nature of the timetable. To him, the rigid timetable provided limited flexibility for conducting extra activities like experiments, especially with large class sizes. He explained that, *"Due to inadequate time allocation for practical activities, problem-based learning is challenging, especially when many students are in the class."*

4. Discussion

This research examined teacher educators views and experiences of using PBL in their classrooms during the pandemic. The findings highlighted the views held by the participants on the inclusion, advantages, and barriers of adopting PBL in teacher education.

Curriculum revision, adoption, and inclusion of student-centred approaches aim to improve educators classroom practices. Inquiry learning is a student-centred approach that allows for students to participate actively in their learning [12–14]. The teachers believed that the inclusion of PBL reveals the relevance of the principles of students independent learning, where the central focus is how learners can experience and gain knowledge. According to the teacher educators, PBL can help students to understand how to acquire knowledge through their desires and ways to initiate, manage, and perform tasks to gain knowledge independently [2]. These suggest that the teacher educators role was to guide students to enact a more significant part of the learning by themselves, where the instructor becomes a facilitator. Slavich and Zimbardo [3] pointed out that inquiry-based learning emphasizes teachers role of facilitating students active participation and responsibility for discovering new knowledge. Through experience, students develop the skill of becoming active learners as they engage in activities. Some researchers have pointed out that, with technology, educators can support students to take on an active role and become responsible for their learning [17–19,59,60]. Kuhn et al. [60] argued that inquiry learning can be effective when integrated with technology and materials to support students' learning experiences. The educators believed that, when students are introduced to the concept by explaining, they can find relevant information themselves. Such an opportunity can help students to develop the relevant learning experiences related to synthesizing, analysing, and applying knowledge [15]. This suggests that PBL, as a learning procedure, emphasizes students roles and usually places them at the centre of learning and interacting with their colleagues on a topic.

It has been established that technology infused PBL helps educators to encourage students to develop skills in actively and independently learning [18,60] and be better prepared to engage with other students during group learning. Through developing self-confidence, students can collaborate and communicate with their peers to build a learning community. Regular classroom interactions between teachers and students have an impact on students learning. The participants in this study believed PBL promotes effective classrooms among instructors and students to promote their communication skills. In this study, the educators led the students to engage in group tasks, write reports, and make presentations to the whole class. Such an opportunity improved the students confidence to communicate and discuss their results. This finding confirms other results reported in earlier studies [14,17,19] that integrating technology to implement PBL helps educators to communicate with students and enhance students communication skills.

Research has indicated that the effective use of a technology-infused curriculum helps students to move beyond relying on teachers information to develop deeper learning efficacies [59,61]. In this study, the educators felt that allowing students to take on learning responsibilities enabled them to become active learners to construct their knowledge that boosted their understanding of the concepts. According to Panjaitan and Siagian [15], PBL includes learning processes involving checking facts and observations through identifying a problem and generating ideas to resolve the problem. In the online PBL environment, teachers use different instructional strategies to provide students with opportunities for open-inquiry learning activities that enhance their higher-order thinking experiences, leading to a better understanding of content knowledge and how to create their knowledge. This finding aligns with other studies showing that PBL is a valuable technique that allows students to relate classroom learning to the real world and understand concepts better [18–20,24,34]. These findings suggest that students can retain information that improves their conceptual knowledge development when actively involved in learning.

According to Tondeur et al. [59], using technology can help educators to scaffold and design inquiry learning activities that facilitate the development of cognitive tasks in the classroom. This study found that the educators valued the PBL activities and provided an understanding of integrating in-class and out-of-class activities. The educators perceived that technology integration effectively supported students collaborative learning, enabling them to develop deeper learning. The results indicate that teachers can use the approach to engage students in a collaborative learning environment involving hands-on practices that promote scientific concepts [5]. In this research, students were engaged in tasks that allowed them to ask questions and explain their scientific knowledge through collaborative work with peers. In the PBL environment, instructors guide and facilitate groups for collaborative learning communities where students can learn how to design and generate new ideas and solutions to problems under investigation [1,21]. This suggests that a technology-infused learning environment effectively supports teachers professional growth in creating online learning communities for students.

Educators competence is a critical factor in implementing PBL activities. Educators must provide effective inquiry learning and opportunities to students to improve their learning outcomes. However, this is not the case, as most educators lack the requisite skills to design and implement problem-based instructions. Researchers have reported that educators lack of understanding of the inquiry instructional approach and their competencies in using PBL make it challenging to work with it in their classrooms [36,38]. As argued by McKeown et al. [62], many educators are narrow-minded about using inquiry instructions in their classroom practices. Educators lack the desired background knowledge, pedagogy, classroom management, and curriculum design to adopt PBL effectively [37]. Dai et al. [63] pointed out that teachers always focus on using PBL to guide students to gain the skills of measuring data recording as the essential requirement of the PBL curriculum. There is less focus on the conceptual and epistemic aspects of inquiry design, and the data analysis processes, evidence interpretation, explanations reasoning, relationships, and casual effects for conclusion are often left out. As indicated by Sjöberg [64], teachers adopt a teaching approach based on their experience during their teacher training. Therefore, it is essential to include PBL in the teacher education curriculum. These findings suggest that educators gain much confidence and experience in PBL when they develop an understanding of and motivation to practice it.

Studies have shown that adequate resources facilitate educators adoption of PBL activities. The educators recognized the benefit of teaching and learning materials such as models and equipment. According to the educators, the teaching and learning materials facilitated students understanding of conceptual knowledge because of the pictorial representation of the concepts learned. However, the educators indicated they lacked the excellent learning models and other resources that could bring about the needed change in their teaching to adopt PBL [38,39,41,65]. The educators further indicated that the large class made supporting individual or small groups of students impossible during experimental lessons. Similar findings have been reported in previous works [34,63,66,67], that implementing PBL in large classes makes it difficult for teachers to provide feedback and support to individual or small groups of students. According to [68], the risk of performing problem-based experiments makes it difficult to reduce the risk of accidents, particularly in chemistry, where safety issues relating to the use of chemicals are involved. In such situations, teachers fear controlling the huge class in performing actual experiments and instead rely on YouTube videos.

Finally, the teachers believed time was an essential factor when implementing PBL. Teacher educators classroom practices focus mainly on guiding students to learn facts, concepts, and theories, without adequate opportunities to practice what is learned due to the limited time available. They found it frustrating, and despite their zeal to adopt PBL, stated it was challenging to adopt the approach due to the complexity of other school activities, limiting the time to design and develop inquiry learning activities effectively. Similar findings have been reported in other studies, where educators felt they had limited time to prepare and implement PBL [34,42,43,67]. According to Romero-Ariza et al. [42], teachers are usually confronted with challenges relating to lack of time, a high demand in the curriculum and assessments usually frustrate them from adopting PBL. This finding indicates that inflexibility, inadequate time allocation, and curriculum demands limit educators zeal to implement problem-based instructions.

5. Conclusions and Implications for Practice

This research examined teachers views and experiences using PBL in their classrooms. The results showed that the educators had positive beliefs about including the PBL approach in the curriculum. They believed the adoption of PBL is geared towards changing learning roles to allow students to play actively and take responsibility for their learning. The educators felt it would allow the student teachers to learn independently to construct knowledge. The educators also perceived that implementing PBL would allow the student teachers to collaborate with their peers and instructors to gain skills for communicating and learning that can enhance their conceptual understanding. Despite the positive views, the educators indicated that adopting PBL requires better understanding, attitudes, and competence. The findings of this study address teacher educators' concerns about the adoption of PBL in the curriculum. Teachers in Ghana know the rationale of the integration and benefits of using PBL. However, most teachers are not adopting the approach due to misunderstandings, teacher competence, inadequate resources, and inadequate time allocation. Most educators lack the skills to plan, design, and manage the learning activities, leading to them developing negative attitudes towards the approach. They also face challenges with large class sizes, affecting the available resources and limited time, making it challenging to utilize the approach effectively. To harness educators classroom practices to adopt PBL, it is therefore vital for institutions to make extra time available for science lessons. It is also vital to consider continuous professional development activities for science teachers to re-examine their teaching and how to use PBL to teach effectively. Addressing these issues could enable teachers to build their professional learning and focus on the need for continuous professional development to understand the ideas and strategies for implementing PBL.

6. Limitations

In the study, some limitations were identified, which can lead to improvement in future studies. For example, the research was limited to only three teacher educators from three different colleges, and, since the sample size was small, the results cannot be generalized. It is also vital to indicate that the advantages of the PBL approach for students learning, as claimed by the educators, were not measured independently in terms of grades or performance. This indicates a limitation of the method on teachers self-assessment and reflection that does not always conform to actual performance. Despite this limitation, the general information provided by the teacher educators could help them improve their professional growth and practice. Therefore, I recommend further studies to include more educators and measure students actual performances to complement the findings of this study.

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References

1. Barron, B.; Darling-Hammond, L. *Teaching for Meaningful Learning: A Review of Research on Inquiry-Based and Cooperative Learning. Book Excerpt*; George Lucas Educational Foundation: San Rafael, CA, USA, 2008.
2. Perkins, D.N.; Perkins, D.N. *The Mind's Best Work*; Harvard University Press: Cambridge, MA, USA, 2009.
3. Slavich, G.M.; Zimbardo, P.G. Transformational teaching: Theoretical underpinnings, basic principles, and core methods. *Educ. Psychol. Rev.* **2012**, *24*, 569–608. [CrossRef]
4. Darling-Hammond, L.; Burns, D.; Campbell, C.; Goodwin, A.L.; Hammerness, K.; Low, E.-L.; McIntyre, A.; Sato, M.; Zeichner, K. *Empowered Educators: How High-Performing Systems Shape Teaching Quality Around the World*; John Wiley & Sons: Hoboken, NJ, USA, 2017.
5. Barron, B.; Darling-Hammond, L. Prospects and challenges for inquiry-based approaches to learning. In *The Nature of Learning: Using Research to Inspire Practic*; OECD Publishing: Paris, France, 2010; pp. 199–225.
6. Nzomo, C.; Rugano, P.; Njoroge, J.M.; Muriithi, C.G. Inquiry-based learning and students' self-efficacy in chemistry among secondary schools in Kenya. *Heliyon* **2023**, *9*, e12672. [CrossRef]
7. Jiang, F.; McComas, W.F. The effects of inquiry teaching on student science achievement and attitudes: Evidence from propensity score analysis of PISA data. *Int. J. Sci. Educ.* **2015**, *37*, 554–576. [CrossRef]
8. Bernido, R. Assessing Students' Performance in Guided Inquiry-Based Learning Environment. *Educ. Meas. Eval. Rev.* **2020**, *11*, 25–44.
9. Ismail, N.; Elias, S.; Muthusamy, I.; Perumal, P.D. Learning to write descriptive essays in an ESL Writing Class with the aid of online i-learn web-based resources. In *INTED2014 Proceedings*; IATED: Valencia, Spain, 2014.
10. Lenkauskaitė, J.; Mažeikienė, N. Challenges of introducing problem-based learning (PBL) in higher education institutions: Selecting and using problems. *Soci. Tyr.* **2012**, *2*, 78–88.
11. Savery, J.R. Overview of problem-based learning: Definitions and distinctions. *Essent. Read. Probl. -Based Learn.* **2015**, *9*, 5–15.
12. Kaçar, T.; Terzi, R.; Arıkan, İ.; Kırıkçı, A.C. The effect of inquiry-based learning on academic success: A meta-analysis study. *Int. J. Educ. Lite. Stud.* **2021**, *9*, 15–23. [CrossRef]
13. Trullàs, J.C.; Blay, C.; Sarri, E.; Pujol, R. Effectiveness of problem-based learning methodology in undergraduate medical education: A scoping review. *BMC Med. Educ.* **2022**, *22*, 104. [CrossRef]
14. Nicolaou, S.A.; Petrou, I. Digital Redesign of Problem-Based Learning (PBL) from Face-to-Face to Synchronous Online in Biomedical Sciences MSc Courses and the Student Perspective. *Educ. Sci.* **2023**, *13*, 850. [CrossRef]
15. Panjaitan, M.B.; Siagian, A. The Effectiveness of Inquiry Based Learning Model to Improve Science Process Skills and Scientific Creativity of Junior High School Students. *J. Educ. E-Learn. Res.* **2020**, *7*, 380–386. [CrossRef]
16. Pedaste, M.; Mäeots, M.; Leijen, Ä.; Sarapuu, T. Improving students' inquiry skills through reflection and self-regulation scaffolds. *Tech. Instru. Cogn. Learn.* **2012**, *9*, 81–95.
17. Fielding-Wells, J.; Makar, K. Developing primary students' argumentation skills in inquiry-based mathematics classrooms. In The Future of Learning Proceedings of the 10th International Conference of the Learning Sciences [ICLS 2012], Sydney, Australia, 2–6 July 2012.
18. Hakverdi-Can, M.; Sonmez, D. Learning how to design a technology supported inquiry-based learning environment. *Sci. Educ. Int.* **2012**, *23*, 338–352.
19. Caswell, C.J.; LaBrie, D.J. Inquiry based learning from the learner's point of view: A teacher candidate's success story. *J. Humanist. Math.* **2017**, *7*, 161–186. [CrossRef]
20. Connolly, C.; Logue, P.A.; Calderon, A. Teaching about curriculum and assessment through inquiry and problem-based learning methodologies: An initial teacher education cross-institutional study. *Iris Educ. Stud.* **2023**, *42*, 443–460. [CrossRef]
21. Laursen, S.L.; Hassi, M.L.; Hough, S. Implementation and outcomes of inquiry-based learning in mathematics content courses for pre-service teachers. *Int. J. Math. Educ. Sci. Technol.* **2016**, *47*, 256–275. [CrossRef]
22. Boye, E.S.; Agyei, D.D. Effectiveness of problem-based learning strategy in improving teaching and learning of mathematics for pre-service teachers in Ghana. *Soc. Sci. Humanit. Open* **2023**, *7*, 100453. [CrossRef]
23. Ural, E. The Effect of Guided-Inquiry Laboratory Experiments on Science Education Students' Chemistry Laboratory Attitudes, Anxiety and Achievement. *J. Educ. Train. Stud.* **2016**, *4*, 217–227. [CrossRef]
24. Aidoo, B.; Anthony-Krueger, C.; Gyampoh, A.O.G.; Tsyawo, J.; Quansah, F. A mixed-method approach to investigate the effect of flipped inquiry-based learning on chemistry students learning. *Eur. J. Sci. Math. Educ.* **2022**, *10*, 507–518. [CrossRef] [PubMed]
25. Saputro, A.D.; Irwanto, I.; Atun, S.; Wilujeng, I. The impact of problem solving instruction on academic achievement and science process skills among prospective elementary teachers. *Ilkog. Online-Elem. Educ. Online* **2019**, *18*, 496–507.
26. Saputro, A.D.; Rohaeti, E.; Prodjosantoso, A.K. Using inquiry-based laboratory instruction to improve critical thinking and scientific process skills among preservice elementary teachers. *Eura. J. Educ. Res.* **2019**, *80*, 151–170.
27. Owusu, A. Problem Based Learning: Errors Minimization, Conceptual and Procedural Understanding in Trigonometry. *Afri. J. Educ. Stud. Math. Sci.* **2023**, *19*, 1–18.
28. Yeboah, A.; Siaw, W.N. The impact of inquiry-based method of teaching on the academic performance of primary education students of Atebubu College of Education in General chemistry. *Eur. J. Bas. Appl. Sci.* **2020**, *2020*, 7.

29. Barthlow, M.J.; Watson, S.B. The effectiveness of process-oriented guided inquiry learning to reduce alternative conceptions in secondary chemistry. *Sch. Sci. Math.* **2014**, *114*, 246–255. [CrossRef]
30. Faradilla, M.; Hasan, H. The effectiveness of guided inquiry-based student worksheets on students' generic science skills. *J. Phys. Conf. Ser.* **2018**, *1088*, 012106. [CrossRef]
31. Ni'mah, F.; Ibnu, S.; Rahayu, S. How guided inquiry and coupled inquiry influence students attitude toward chemistry in buffer solution and solubility topics. *AIP Conf. Proc.* **2018**, *2049*, 020037.
32. Uzezi, J.G.; Zainab, S. Effectiveness of guided-inquiry laboratory experiments on senior secondary schools students academic achievement in volumetric analysis. *Ameri. J. Educ. Res.* **2017**, *5*, 717–724.
33. Leonard, N.C.; Nwanekezi, A.U. Effects of guided inquiry and task hierarchy analysis model in cooperative learning strategy on chemistry students' performance in Imo State. *Eur. Sci. J.* **2018**, *14*, 54–62. [CrossRef]
34. Aidoo, B.; Boateng, S.K.; Kissi, P.S.; Ofori, I. Effect of Problem-Based Learning on Students′ Achievement in Chemistry. *J. Educ. Pract.* **2016**, *7*, 103–108.
35. Tornee, N.; Bunterm, T.; Lee, K.; Muchimapura, S. Examining the effectiveness of guided inquiry with problem-solving process and cognitive function training in a high school chemistry course. *Pedagog. Int. J.* **2019**, *14*, 126–149. [CrossRef]
36. Kadioglu-Akbulut, C.; Uzuntiryaki-Kondakci, E. Implementation of self-regulatory instruction to promote students' achievement and learning strategies in the high school chemistry classroom. *Chem. Educ. Res. Pract.* **2021**, *22*, 12–29. [CrossRef]
37. Settlage, J. Demythologizing science teacher education: Conquering the false ideal of open inquiry. *J. Sci. Teach. Educ.* **2007**, *18*, 461–467. [CrossRef]
38. Fitzgerald, M.; Danaia, L.; McKinnon, D.H. Barriers inhibiting inquiry-based science teaching and potential solutions: Perceptions of positively inclined early adopters. *Res. Sci. Educ.* **2019**, *49*, 543–566. [CrossRef]
39. Brobbey, E.W.; Baah, A.; Ampon-Wireko, S. Influencing Factors Bedevilling the Study of Science among Ghanaian Students in Senior High Schools. *J. Educ. Pract.* **2020**, *11*, 254–260.
40. Mohammed, S.M.; Amponsah, K.D. Junior high school teachers' attitudes toward inquiry-based science teaching: Enabling or disabling dispositions? *J. Educ. Train. Stud.* **2021**, *9*, 41–54. [CrossRef]
41. Crawford, B.A.; Capps, D.K. Teacher cognition of engaging children in scientific practices. In *Cognition, Metacognition, and Culture in STEM Education*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 9–32.
42. Romero-Ariza, M.; Quesada, A.; Abril, A.M.; Sorensen, P.; Oliver, M.C. Highly Recommended and Poorly Used: English and Spanish Science Teachers' Views of Inquiry-Based Learning (IBL) and Its Enactment. *Eura. J. Math., Sci. Tech. Educ.* **2020**, *16*, 1.
43. Ministry of Education. Science Curriculum for Ghanaian Basic School. National Council for Curriculum and Assessment (NaCCA), nacca.gov.gh. 2019. Available online: https://nacca.gov.gh/wp-content/uploads/2019/04/SCIENCE-UPPER-PRIMARY-B4-B6.pdf (accessed on 31 October 2023).
44. Klutse, G.Y. A Novel Approach to Integrated Science Teaching and Learning in a Selected Ghanaian Junior High School. *Eur. Educ. Res.* **2021**, *4*, 1–27. [CrossRef]
45. Buabeng, I.; Owusu, K.A.; Ntow, F.D. TIMSS 2011 science assessment results: A review of Ghana's performance. *J. Curric. Teach.* **2014**, *3*, 1–12. [CrossRef]
46. Nariman, N.; Chrispeels, J. PBL in the era of reform standards: Challenges and benefits perceived by teachers in one elementary school. *Inte. J. PBL.* **2016**, 10. [CrossRef]
47. Anderson, R.D.; Helms, J.V. The ideal of standards and the reality of schools: Needed research. *J. Res. Sci. Teach.* **2001**, *38*, 3–16. [CrossRef]
48. Du, X. Professional development for virtual environment: Designing assistive-technology infused inquiry-based learning experience for online teaching. *J. Online Learn. Res.* **2022**, *8*, 425–446.
49. Levy, S.; Bagno, E.; Berger, H.; Eylon, B.-S. Professional growth of physics teacher-leaders in a professional learning communities program: The context of inquiry-based laboratories. *Int. J. Sci. Math. Educ.* **2021**, *20*, 1813–1839. [CrossRef]
50. Marshall, J.C.; Smart, J.B.; Alston, D.M. Inquiry-based instruction: A possible solution to improving student learning of both science concepts and scientific practices. *Int. J. Sci. Math. Educ.* **2017**, *15*, 777–796. [CrossRef]
51. Windschitl, M. Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Sci. Educ.* **2003**, *87*, 112–143. [CrossRef]
52. Flyvbjerg, B. Case study. In *The Sage Handbook of Qualitative Research*; SAGE Publications: New York, NY, USA, 2011; Volume 4, pp. 301–316.
53. Bryman, A. Methods and methodology. Qualitative Research in Organizations and Management. *Int. J.* **2008**, *2*, 159–168. [CrossRef]
54. Tal, T.; Levin-Peled, R.; Levy, K.S. Teacher views on inquiry-based learning: The contribution of diverse experiences in the outdoor environment. *Innov. Educ.* **2019**, *1*, 2. [CrossRef]
55. Pozuelos, F.; González, G.T.; Cañal de León, P. Inquiry-based teaching: Teacher's conceptions, impediments, and support. *Teach. Educ.* **2010**, *21*, 131–142. [CrossRef]
56. Cohen, L.; Manion, L.; Morrison, K. *Research Methods in Education*, 8th ed.; Abingdon Oxon; Routledge: London, UK, 2018; pp. 532–533.
57. Oppong-Nuako, J.; Shore, B.M.; Saunders-Stewart, K.S.; Gyles, P.D. Using brief teacher interviews to assess the extent of inquiry in classrooms. *J. Adva. Acade.* **2015**, *26*, 197–226. [CrossRef]

58. Braun, V.; Clarke, V. Using thematic analysis in psychology. *Qual. Res. Psychol.* **2006**, *3*, 77–101. [CrossRef]
59. Tondeur, J.; Scherer, R.; Baran, E.; Siddiq, F.; Valtonen, T.; Sointu, E. Teacher educators as gatekeepers: Preparing the next generation of teachers for technology integration in education. *Br. J. Educ. Techol.* **2019**, *50*, 1189–1209. [CrossRef]
60. Kuhn, D.; Black, J.; Keselman, A.; Kaplan, D. The development of cognitive skills to support inquiry learning. *Cogn. Instr.* **2000**, *18*, 495–523. [CrossRef]
61. Brewer, R.; Movahedazarhouligh, S. Successful stories and conflicts: A literature review on the effectiveness of flipped learning in higher education. *J. Comp. Assis. Learn.* **2018**, *34*, 409–416. [CrossRef]
62. McKeown, T.R.; Abrams, L.M.; Slattum, P.W.; Kirk, S.V. Enhancing teacher beliefs through an inquiry-based professional development program. *J. Educ. Sci. Environ. Health* **2016**, *2*, 85–97. [CrossRef] [PubMed]
63. Dai, D.Y.; Gerbino, K.A.; Daley, M.J. Inquiry-based learning in China: Do teachers practice what they preach, and why? *Front. Educ. China* **2011**, *6*, 139–157. [CrossRef]
64. Sjöberg, L. The Swedish primary teacher education programme: At the crossroads between two education programme traditions. *Educ. Inq.* **2019**, *10*, 116–133. [CrossRef]
65. Okyere, G.A.; Tawiah, R.; Lamptey, R.B.; Oduro, W.; Thompson, M. An assessment of resource availability for problem-based learning in a Ghanaian University setting. *Quality Assur. Educ.* **2017**, *25*, 237–247. [CrossRef]
66. Cheung, D. Facilitating chemistry teachers to implement inquiry-based laboratory work. *Int. J. Sci. Math. Educ.* **2008**, *8*, 107–130. [CrossRef]
67. Kang, J.; Keinonen, T. Examining factors affecting implementation of inquiry-based learning in Finland and South Korea. *Probl. Educ. 21st Century* **2016**, *74*, 31–48. [CrossRef]
68. Cheung, D. Teacher beliefs about implementing guided-inquiry laboratory experiments for secondary school chemistry. *J. Chem. Educ.* **2011**, *88*, 1462–1468. [CrossRef]

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