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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.

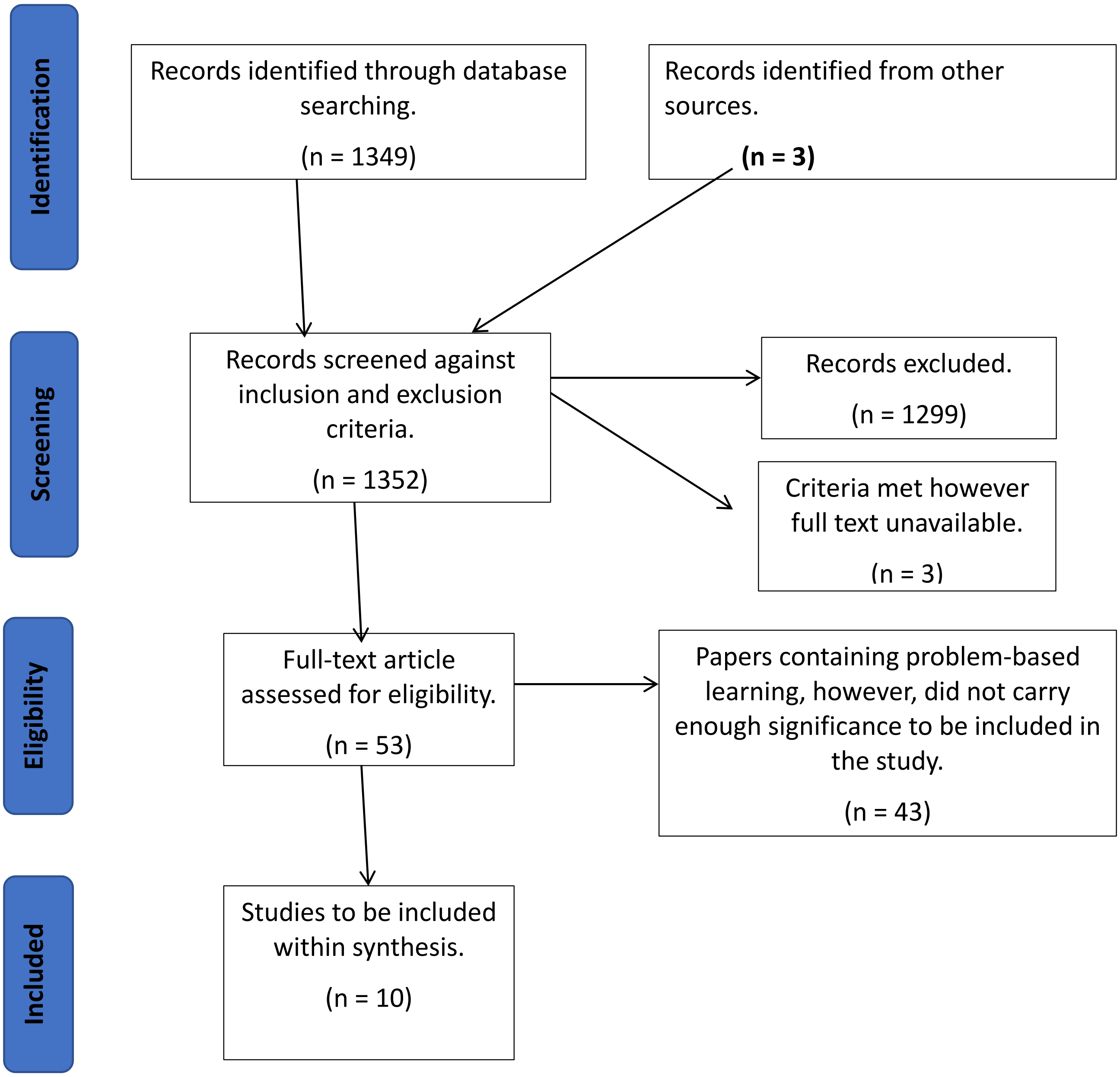

Figure 1. PRISMA flow diagram.

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 Appraisal
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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