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PAPER

The Effect of Problem Based Learning Approach in Enhancing Problem Solving Skills in Chemistry Education: A Systematic Review

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ABSTRACT

Chemistry is a scientific discipline that is often considered difficult because students struggle to solve contextual and open-ended problems, mainly due to a poor understanding of scientific concepts related to the problem. To fully grasp the concepts in chemistry, students must develop the ability to solve real-life problems. Problem-solving skills are applied in many aspects of life, making them crucial for the 21st century. Problem-based learning (PBL) is an effective method for improving students' problem-solving skills. This study aims to outline how the PBL approach enhances students' problem-solving skills, specifically in the context of chemistry education. The sixteen research articles reviewed in this paper were collected from well-known databases such as ERIC, SCOPUS, and Google Scholar. Systematic literature review (SLR) is the method used in this review. This review provides evidence that PBL can enhance problem-solving skills in chemistry education. All research articles have shown that PBL has a significantly positive effect on the problem-solving skills of students. Seven out of sixteen articles have provided insights into the design and framework of PBL implementation. The researcher recommends conducting more studies in all areas of chemistry to provide clear guidance on incorporating PBL. The researcher also recommends using mobile technologies to integrate PBL in a stimulating manner, such as by developing a mobile application to aid in the instructional process. Proper insights into the effectiveness of implementing PBL to enhance problem-solving skills in chemistry, as well as the integration of PBL into the instructional process, are necessary. This will aid teachers and lecturers in planning their lessons, which is why this systematic review is needed.

KEYWORDS

problem-solving, problem-solving skills, problem-based learning, chemistry education, STEM education, systematic literature review

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1 INTRODUCTION

Chemistry is a complex scientific discipline that is often considered difficult because students struggle to solve problems, primarily due to a poor understanding of the scientific concepts related to the problem [1]. Students often encounter challenges when solving authentic problems in chemistry due to the multifaceted nature of the process, which involves algorithms, conceptual understanding, and open-ended problems. An algorithmic problem is one in which the required formula, values, and goal of the solution are specifically stated in the problem, guiding the problem-solving process. Conceptual problems, on the other hand, involve students using their conceptual knowledge to solve unfamiliar problems, which requires them to relate several concepts, explain a process, and not rely on a memorized procedure. Conceptual problems necessitate students possessing a strong conceptual understanding of the topics involved. In contrast, open-ended problems are ill-structured and have multiple possible solutions. The open-ended problems serve to access the underlying key scientific concepts rather than relying on rote memory [1]. In order to solve algorithmic, conceptual, and open-ended problems, students must possess problem-solving skills. Research provides evidence that some students can solve algorithmic problems but struggle with conceptual and open-ended problems due to a lack of conceptual knowledge. To master the concepts in chemistry, learners must develop the ability to solve real-life problems [2]. Problem-solving skills can be defined as a series of cognitive-behavioral actions through which a person attempts to solve real-life problems [3].

In this era, equipping students with excellent problem-solving skills in chemistry is considered the epitome of success in the education sector [4]. Problem-solving skills are applied in many aspects of life, making them crucial for the 21st century [5]. The problem-solving skills of students can be enhanced only when they are exposed to them in the instructional process with an appropriate learning approach [6]. The main idea discussed in all the chosen articles in this review revolves around the significance of students' problem-solving skills in mastering scientific concepts in chemistry. Students can master scientific concepts in chemistry by effectively solving problems. According to Polya's problem-solving strategy, successful problem-solving involves a four-step process. The first step is to understand the problem, followed by constructing a plan, carrying out the plan, and finally reflecting on the entire process [7].

The selected studies provide scientific evidence that students at the secondary and tertiary education levels generally have poor problem-solving skills in chemistry. According to [8], enhancing students' problem-solving skills has resulted in improved academic performance in chemistry. According to [9], students may face difficulties in solving problems due to a poor understanding of the scientific knowledge underlying the problem, the presence of alternative frameworks in the scientific concept, and a lack of exposure to proper problem-solving approaches and strategies in the instructional process. One instructional approach that contributes to poor problem-solving skills in the classroom is the traditional learning method [8]. In this traditional approach, learners were not encouraged to construct their knowledge meaningfully but instead learned through memorization, also known as rote learning. Learners were given facts and knowledge instead of the opportunity to discover and construct their own knowledge in their minds.

One pedagogical approach to enhancing problem-solving skills is problem-based learning (PBL) [10]. PBL is a pedagogical approach that revolves around open-ended problems [11]. The problem will address the intended learning objectives that the learners are expected to achieve. In this process, the teacher's role is to facilitate the learning process and guide the learners in the right direction of learning [12]. Learners must be exposed to ways of relating authentic real-life problems to abstract scientific concepts in order to facilitate meaningful learning.

Despite the prominent benefits that administering PBL has to offer, some researchers have stated that this approach has its disadvantages. The implementation of PBL may lead to significant time consumption and high costs, primarily due to the lack of structure in the instructional approach [13]. Proper insights into the effectiveness of implementing PBL to enhance problem-solving skills in chemistry, as well as the integration of PBL into the instructional process, are necessary. This aids teachers and lecturers in planning their lessons. This rationale necessitated a systematic review.

2 PURPOSE OF THE REVIEW

This systematic review aims to examine the effectiveness of PBL in improving students' problem-solving skills, particularly in the context of chemistry education. The review also explores the PBL designs or frameworks utilized in the selected papers. I have included PBL implementation in research papers involving students from secondary and tertiary education levels in this review. Thus, this paper could provide guidance to those who are in the process of designing and integrating PBL into the instructional process rather than only referring to the theory. Furthermore, this paper could offer guidance on PBL designs for other researchers interested in studying PBL implementation in chemistry or other disciplines.

These research questions guided the writing of this review paper:

1. What are the effects of the problem-based learning pedagogical approach on the problem-solving skills of respondents in chemistry education?
2. What is the PBL design (model, framework) used in the research papers?

3 METHOD

Systematic literature review (SLR) is the method used in this review. A systematic review serves as a means to identify, evaluate, and summarize all relevant studies involving the problem-based learning approach and problem-solving skills in chemistry education. According to [14], a systematic literature review involves identifying and synthesizing relevant research articles selected based on specific inclusion criteria to provide insights into a particular issue. The review is conducted systematically, beginning with planning, followed by the review process, and concluding with the reporting of the findings. The research articles were obtained by searching the Internet, primarily using the ERIC, Google Scholar, and Scopus databases. The literature search and screening for inclusion were conducted from January 3rd, 2023, to April 23rd, 2023. The keywords used for the selection of research articles are 'problem solving skills in chemistry,' 'enhancing problem solving skills in chemistry,' 'PBL in chemistry education,' and 'effect of PBL in improving problem-solving skills in chemistry.' The research articles was screened based on their titles, followed by a review of the abstracts, and finally an examination of the full content of the articles. The inclusion criteria for the selected research articles were as follows: (1) Involvement of a PBL approach to enhance problem-solving skills in chemistry education. (2) Articles involving participants from secondary to tertiary education, including college and university students, were included. (3) The research articles were published between 2007 and 2021. The publication range spanned 14 years because there was one relevant article published in 2007 that needed to be included in the review. (4) Articles published in reputable journals. The research articles selected were not limited to experimental studies but also included mixed-method or qualitative studies, such as students' perceptions of problem-solving skills.

Based on the article search results, 48 articles with titles that met the inclusion criteria were obtained. Upon reviewing the abstracts of the research articles, 21 were excluded, leaving 27 articles for further analysis. The articles were mainly excluded because they did not adhere to the inclusion criteria, which focused on the impact of a problem-based approach on enhancing problem-solving skills. Most articles were excluded because they did not measure problem-solving skills or any other related learning skills. All other disciplines, such as physics and biology, were excluded. Research articles related to the field of science, specifically those investigating chemistry, are included in the review. The remaining 27 research articles were analyzed for their content, and 16 articles met the inclusion criteria, which required studies to be conducted using quantitative or mixed method designs. After the screening process, 16 articles were chosen because they met all the inclusion criteria and contained all the relevant findings discussed in this review paper. The literature search and screening process is depicted in Figure 1.

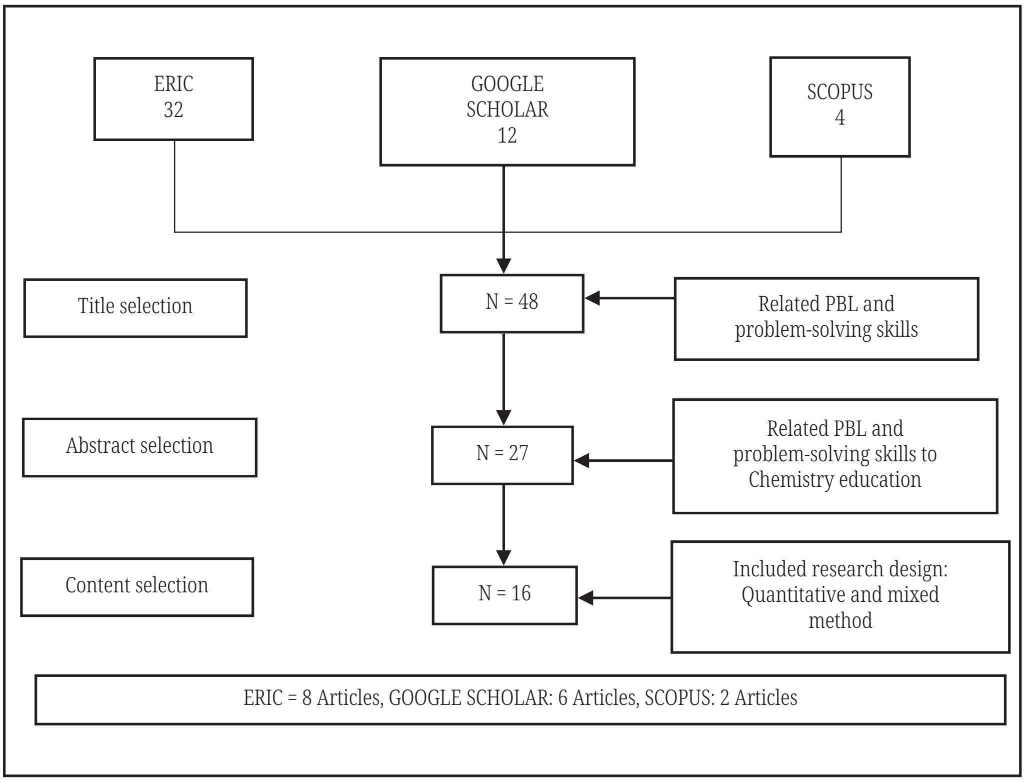

Fig. 1. Literature search and screening for inclusion

4 FINDINGS

4.1 Research question 1

What are the effects of problem-based learning pedagogical approach on problem solving skills of respondents in chemistry education?

In this section, the impact of the PBL approach on problem-solving skills in chemistry education is specifically discussed. Out of 16 papers reviewed, 100% of the research articles selected reported that implementing problem-based learning as a pedagogical approach in chemistry education has significantly promoted students' problem-solving skills. The post-test scores in all the papers reviewed showed a significant difference between the PBL, or experimental group, and the non-PBL, traditional, or control group. This indicates that the PBL intervention, as an instructional approach, has enhanced the problem-solving skills and abilities of the study participants. Although all studies have reported that the PBL pedagogical approach can improve problem-solving skills, there are differences identified in the implementation of PBL and the parameters measured. Most of the papers differ in terms of what is being measured in the study, and this will be discussed thoroughly in this review. Although problem-solving skills are the main variable measured after treatment, some papers included in this review measured other parallel learning skills, of which problem-solving skills are a subset.

Table 1. Summary of the research articles

Author/Year	Title	Participants	Dependant Variables	Research Design and Instruments	Findings
[1] Joseph E. Valdez, Melfei E. Bungihan 2018	Problem-Based Learning Approach Enhances the Problem Solving Skills in Chemistry of High School Students	96 high school students	Level of problem-solving skills in chemistry	Quantitative Descriptive-comparative research Pre- and post-tests experimental designs Instrument: Problem Solving Skill Test (PSST)	**1.** PBL approach blended in teaching chemistry concept used in the study has effectively enhanced the problem-solving skills of the students.
[2] R.E Dibyantini, R D Suyanti and R Silaban 2021	The Effectiveness of Problem Based Learning Model Through Providing Generic Science Skill in Organic Chemistry Reaction Subject.	80 teacher candidates	Level of generic science skills in chemistry.	Quantitative Pre- and post-tests design with a quasi-experimental method Instrument: Multiple choice test	**1.** MPBM-PKGK model has improved the generic ability of chemistry teacher candidate students compared to direct instruction.
[3] R Andriani and YL I Supiah 2021	Effect of problem-based learning models on students' analytical thinking abilities and scientific attitudes in chemistry.	63 senior high school students	Abilities of analytical thinking and scientific attitudes of students.	Quantitative Quasi-experimental post-test only design. Instruments: **1.** Analytical thinking skills tests **2.** Scientific attitude questionnaire.	**1.** Students' analytical thinking skills in the experimental class are higher than control group.

(Continued)

Table 1. Summary of the research articles *(Continued)*

Author/Year	Title	Participants	Dependant Variables	Research Design and Instruments	Findings
[4] Benjamin Aidoo, Sampson Kwadwo Boateng 2016	Effect of Problem-Based Learning on Students' Achievement in Chemistry	A total of 102 school students	Students' achievement in chemistry.	Quantitative Quasi-experimental design Pre- and post-tests experimental designs Instrument: Physical Science Examination test	1. The results show that PBL is an effective way for to teach chemistry so as to improve students' critical thinking and problem-solving skills.
[5] Kai-Li Teh and Nooraida Yakob 2013	Problem-Based Learning as an Approach to Teach Cell Potential in Matriculation College, Malaysia	65 matriculation students.	Student achievement in Cell Potential	Quantitative Pre-test and post-test control group design. The quasi-experimental design with non-equivalent groups was used. Instrument: Paper and pencil test.	1. PBL is effective in improving students' performance in electrochemistry. 2. PBL instruction could encourage students to use their critical thinking to solve the problems
[6] Modupe M. Osokoya and Chinwe C. Nwazota 2018	Problem-Based And School-Type As Contributory Factors To The Senior Secondary School Students' Practical Skills In Chemistry.	A total of 124 students 54 from coeducational 70 from single-sex of federal government	Chemistry manipulative skills	Quantitative pre-test, post-test, control group quasi experimental setting. Instrument: Chemistry Manipulative Skill Scale	1. PBL approach in chemistry practical lessons improves the students' practical skills significantly 2. Students from single-sex colleges are better in chemistry practical skills than single sex colleges.
[7] Hatice Gungor Seyhan 2016	The Efficacy of Problem-Based Learning in an Instrumental Analyse Laboratory	36 prospective chemistry teacher candidates.	Perception level of problem-solving ability and self-regulatory learning strategies of teachers.	Quantitative True experimental with pre- and post-tests control group design. Instrument: 1. Problem Solving Inventory (PSI). 2. Self-Regulatory Strategies Scale (SRSS)	1. The perception levels of prospective teachers about problem solving ability increased, suggesting respondents' problem-solving skills as being at a satisfactory level. 2. Respondents were able to improve perception levels of problem-solving ability and self-regulatory learning strategies better than control group.
[8] Santiago Sandi-Urena, Melanie Cooper, and Ron Stevens 2012	Effect of Cooperative Problem-Based Lab Instruction on Metacognition and Problem-Solving Skills	A total of 904 participants	Problem-solving ability and regulatory metacognitive activity.	Quantitative: Mixed method. Pre-lab and post-lab group. Qualitative: Not discussed in this paper. Instrument: Interactive Multi-Media Exercises software (IMMEX)	1. Study reports positive effect of the cooperative problem-based project laboratory instruction on problem solving strategy and ability.

(Continued)

Table 1. Summary of the research articles *(Continued)*

Author/Year	Title	Participants	Dependant Variables	Research Design and Instruments	Findings
[9] Ratu Evina Dibyantini, Retno Dwi Suyanti, and Ramlan Silaban 2020	Teacher Candidate's Generic Science Skills on Organic Chemistry Reactions Through Problem-Based Learning Model	48 teacher candidates	The generic skills in Chemistry	Quantitative This study was one group pre-test-pos-test design with the quasi-experimental method Instrument: Multiple choice test	**1.** PBL model can improve generic science skills of chemistry teacher candidates. **2.** PBL has improved students' problem-solving skills and high order thinking skills.
[10] Abbas Babayi Abubakar & Mohammad Yusof Arshad 2015	Self-Directed Learning and Skills of Problem-Based Learning: A Case of Nigerian Secondary Schools Chemistry Students	15 Chemistry students and one teacher.	Students' self-directed learning.	Qualitative approach and explanatory design. Instrument: Observation and interview protocols	**1.** PBL improves students' self-directed learning, where they learn better with minimal teacher support. **2.** PBL aids students to develop their problem-solving skills.
[11] Cemal Tosun and Yavuz Taskesenligil 2013	The effect of problem-based learning on undergraduate students' learning about solutions and their physical Properties and scientific processing skills.	84 freshmen	The academic achievement on solutions and their physical properties	Mixed method Quasi experimental Instrument: **1.** Solutions and their Physical Properties Academic Achievement Test (SPPAAT) **2.** Interview	**1.** PBL is more effective to teach the subject of solutions and their physical properties **2.** More than 70% of the students stated that PBL contributes positively to students' problem-solving skills, critical thinking skills, communication skills, self-learning ability, scientific process skills, ability to work in a group cooperatively, and research skills.
[12] Abanikannda, M.O. (Ph.D) 2016	Influence Of Problem-Based Learning in Chemistry On Academic Achievement Of High School Students In Osun State, Nigeria	300 seniors secondary science students	Academic achievement in Chemistry	Quantitative Descriptive survey design Instrument: PBL in Chemistry Education Students Academic Achievement in Questionnaire. (PBLCEQ)	**1.** PBL approach improves the students' achievement towards chemistry. **2.** PBL improves problem solving skills like cooperating, communicating, and researching skills.
[13] Ahmet Gurses, Metin Açıkyıldız, Çetin Do and Mustafa Sozbilir 2007	An investigation into the effectiveness of problem-based learning in a physical chemistry laboratory course	40 undergraduate students	Students' attitudes towards a chemistry laboratory course, scientific process skills of students and their academic achievement	Quantitative: One group pre-test and post-test Instruments: **1.** Physical Chemistry Laboratory Concept Test (PCLCT), **2.** Attitudes towards Chemistry Laboratory (ATCL) questionnaire **3.** Science Process Skills Test (SPST).	**1.** PBL approach promoted critical thinking and problem-solving skills; self-direction, identification of own learning needs, teamwork, creative discussion and learning from peers.

(Continued)

Table 1. Summary of the research articles *(Continued)*

Author/Year	Title	Participants	Dependant Variables	Research Design and Instruments	Findings
[14] Festus, C. and O. A. Ekpete 2012	Improving Students' Performance and Attitude towards Chemistry through Problem-Based-Solving Techniques (PBST).	98 senior secondary school students	The performance and attitude toward chemistry of respondents	Quantitative: Correlational and survey research designs Pre- and post-tests Instrument: Test	**1.** This study reports that the problem-solving ability was more positive after treatment. **2.** PBST should be incorporated in Chemistry instruction to reduce the number of students opting out of this discipline.
[15] Maria M. Ferreira and Anthony R. Trudel. 2012	The Impact of Problem-Based Learning (PBL) on Student Attitudes Toward Science, Problem-Solving Skills, and Sense of Community in the Classroom.	48 high school students	Students attitudes toward science, problem-solving skills and their perceptions of the learning environment.	Mixed method design. Instruments: Survey questionnaire, journal entries	**1.** The research indicate significant increase in student attitudes toward science, problem-solving skills and positive views of the learning environment. **2.** The use of PBL also facilitated the development of a sense of community in the classroom.
[16] Shuang Gao, Yuxin Wang, Bin Jiang and Ying Fu 2018	Application of problem-based learning in instrumental analysis teaching at Northeast Agricultural University.	258 university students	Student achievement in instrumental analysis course.	Quantitative design Instrument: Test	**1.** PBL is a new teaching approach that has proven to be suitable for the instrumental analysis course in this study.

In the papers reviewed, four papers [15–18] have reported the use of a problem-based learning approach in laboratory instruction. All the other papers, except one, have focused on classroom instruction, involving the teaching of chemistry concepts in their research. In contrast, the research by [8] has included scientific concept teaching and experimental procedures with PBL intervention, which will be discussed in this review. All four studies have utilized different instruments, including the manipulative skills scale, problem-solving inventory, multimedia exercise software, and laboratory concept tests. This is in contrast to the papers on classroom instruction, which primarily relied on paper-and-pencil tests to assess the problem-solving abilities of the participants.

Research by [15], which is a quantitative quasi-experimental study with pre- and post-test measurements was conducted over in period of five weeks. In addition to the PBL intervention, the study also manipulated the variable of school type. The instrument used, the chemistry manipulative skill scale (CHEMMSS), was developed by the researcher to measure students' manipulative abilities in chemistry. The research has included data from both Nigerian single-sex schools and coeducational schools, which were selected through purposive sampling. This study reported that PBL intervention resulted in a higher post-test mean score in practical skills, indicating improved learning with PBL. This paper also reported that the mean score for practical skills after the implementation of PBL in laboratory instruction is higher in single-sex schools than in coeducational schools. The researcher suggested that the reason for lower practical ability could be due to less interaction between male and female respondents in coeducational schools during practical work, which affects problem-solving skills [15]. This is a particularly intriguing discovery that can be further explored to improve problem-solving skills among learners, particularly in the field of chemistry.

Similarly, in the research conducted by [16], PBL design was adapted in an instrumental analysis laboratory course as an alternative to traditional laboratory practices. In this study, teacher candidates who were exposed to PBL design in their laboratory practices showed a positive increase in future teachers' problem-solving skills, understanding levels, and self-regulatory learning strategy levels. This study concluded that PBL will be an effective approach for teaching chemical laboratory practices. The research by [17] is also aligned with the studies discussed above, as the researchers explored the effects of a modified version of a problem-based approach, which is a cooperative PBL-based project, on metacognition and problem-solving ability in laboratory instruction. This study aims to contribute to the understanding of the role of laboratory instruction in science concept learning. The researchers have supported their hypothesis by identifying a positive correlation between PBL-based laboratory instruction and the development of problem-solving skills in college students. In this mixed-methods research design, this paper discusses only the findings of the quantitative data, while the qualitative findings are reported in a separate paper [17]. Meanwhile, a study by [18] also reported similar findings, stating that including PBL in the laboratory promoted problem-solving skills and facilitated an active learning environment. In this environment, respondents took control of their own learning process and successfully worked in groups.

The four papers that investigated problem-based learning in chemistry laboratory practices reported that problem-solving skills were significantly enhanced in response to the intervention. In addition, the PBL approach is also reported to enhance cooperative skills, communication skills, creativity, teamwork, and self-directed learning among learners [18]. This finding suggests that educators should actively engage students in a constructivist approach during chemistry practical lessons to help them become effective problem solvers in real life. Speaking of research design, all four papers have utilized quantitative research design. However, one paper, authored by [17], employed a mixed-method design. All four papers have adopted a pre-test, and a post-test control group design. In my opinion, this research design is appropriate for addressing the research questions posed in the respective studies. The pre-test provides insight into what the learners must have learned, while the post-test indicates what the learners have mastered.

Unlike [15–18] discussed above, the following papers have adopted a PBL pedagogical approach in classroom instruction to enhance problem-solving skills and conceptual knowledge in chemistry. [19] investigated the effect of PBL on the problem-solving skills of Grade 9 chemistry students in the Philippines. This research utilized descriptive-comparative and pre-test-post-test experimental designs and was conducted during the years 2015–2016, although the exact duration of the treatment was not clearly specified. The respondents were divided into two groups: PBL and non-PBL, with 50 and 46 respondents, respectively. The research tools, including the PBL instructional material and the problem-solving skills test used as an instrument, were precisely developed by the researchers and validated by experts.

Therefore, they are not similar to those discussed in any other papers. In fact, there are fewer similarities among the PBL instructional frameworks and tools used across all the reviewed papers. This could be because each PBL instruction administered in each paper is tailored to the specific topic or concept the researcher has included in their prospective research. Research by [19], for instance, has included topics such as the electronic structure of the atom, chemical bonding, carbon compounds, and the mole concept in their PBL learning matrix and instrument. The problem-solving skills test has covered these concepts. [19] reports, along with all the other reviewed papers, that the PBL approach was proven to be more effective than the non-PBL approach in promoting problem-solving skills among Grade 9 chemistry students.

Six papers [8], [20], [21], [22], [2], and [23] included in this review have measured the effect of a PBL pedagogical approach on students' achievement, specifically in developing problem-solving skills in chemistry. Studies by [8] and [20] have both measured students' achievement in chemistry using quantitative quasi-experimental designs with pre-test-post-test experimental designs. The study conducted by [8], which examined the impact of PBL on students' achievement in chemistry, was motivated by the low academic performance of students in South Africa. A total of 102 students with similar levels of academic achievement were selected for the pre-test in this research. In this study, PBL lessons are provided for both conceptual teaching and experimental procedures, which sets it apart from the other papers in this review. The findings indicate that PBL is an effective method for developing problem-solving skills among students in the field of chemistry. This paper also documented some challenges encountered during the experimental procedures as a result of faulty equipment, which may have impacted the results of the study.

Similarly, research conducted by [20] in Malaysia measured student achievement in chemistry among biology students who were taking a chemistry course. The treatment lasted for one year. This study reported that the backgrounds of the respondents in the PBL and non-PBL groups were similar, contributing to effective control. Unlike all the other papers, this research used an instrument adapted from a study by Tarhan and Acar (2007), which involved a written test specifically on cell potential. The findings were consistent with those of other studies, showing that the treatment has produced positive results in students' problem-solving skills and cell potential. This paper has made a significant contribution to the Malaysian preparatory program, Matriculation, by proposing that curriculum designers consider integrating full PBL instruction into the chemistry curriculum.

The research by [21] and [22] has some similarities; both studies measured student achievement in chemistry in terms of students' perceptions of academic achievement in chemistry. The theory behind the PBL-based approach is constructivism, which is also discussed in both research papers. In the study [22] conducted in Nigerian schools, it was reported that students had a positive perception of PBL. They felt comfortable learning using PBL, which contradicts previous research stating that students accustomed to traditional lectures would not adapt well to PBL. This research also concludes that PBL enhances other problem-solving skills, such as cooperation, communication, and research skills. On the other hand, the research design by [21] was mixed-mode. Quantitative data were collected through scientific processing skill tests, a specific test, and scales developed for PBL. Interviews were also conducted to collect qualitative data. This study reports that PBL intervention was more effective than conventional instruction. Additionally, more than 70% of the students stated that PBL positively contributed to their problem-solving skills and other learning abilities. This indicates that the intervention has boosted respondents' confidence in learning. The report indicates that respondents have expressed the idea that the PBL intervention enabled them to remember the learned scientific knowledge in a proper manner. This study also reported that the PBL intervention in the experimental group led to a lower use of alternative frameworks in understanding the scientific concepts taught. This clearly indicates a significant need for more research to investigate the impact of PBL on reducing learners' alternative frameworks and promoting meaningful learning. The paper also reported that the biggest obstacle faced during PBL implementations is the limited time. It also pointed out that this instructional approach is not limited to classroom activities, thus concluding that the success of PBL intervention could be greatly influenced by the time factor.

Meanwhile, [2] investigated the effect of PBL intervention, specifically the problem-based solving technique (PBST), on student perception and achievement in chemistry. This research is motivated by the identified research gap, which is the absence of empirical studies on students' changes in attitude towards chemistry. This study reported that administering PBST in chemistry learning improved students' problem-solving ability, as reflected in their achievement. The significance of this study lies in its contribution to the empirically proven fact that PBL in chemistry could help reduce the number of students opting out of the subject. This calls for further research to change the perception of chemistry as a difficult and abstract discipline among learners. The findings are consistent with those of other papers discussed in this review, indicating that problem-solving skills are significantly enhanced by the PBL approach.

Similar to the five papers discussed above [8], [20], [21], [22], [2], the research by [23] also measured student achievement in relation to PBL instruction. The difference from other papers that measured student achievement is that [23] introduced PBL in an instrumental laboratory course involving third-semester students at a university in China. According to this research, the instrumental analysis course has always been taught in a traditional manner; therefore, the researchers emphasized the need to investigate the PBL approach in this area of learning. The study reports that PBL has improved students' problem-solving skills and self-directed learning, thereby significantly enhancing the students' overall comprehensive ability. The transition from traditional learning to a problem-based approach involves significant changes, as discussed in this study. The study reported evaluations given by students on PBL, such as it being time-consuming, some students facing difficulties in understanding the main point, concerns about the outcome of the lesson, and an inability to communicate effectively in groups. These were some of the negative evaluations provided by the students. The inability of teachers to fulfill their role as facilitators in PBL was also identified as a limitation to the successful implementation of this learner-centered approach, as reported by [23]. This paper provides valuable insights into the problem-based learning approach, which can be adapted in other research studies. More research conducted on PBL can provide a better understanding of the learning approach, which facilitates a successful transition from traditional methods to active learning in education overall and in chemistry education specifically.

Two papers included in this research were written by the same authors but published in different years. They discuss the effect of problem-based learning on the generic science skills of teacher candidates in chemistry. Research by [24] aimed to determine the effect of PBL instruction on the generic science skills of respondents in organic chemistry, specifically addition, substitution, and elimination. The study reported that PBL has improved students' problem-solving skills and higher-order thinking skills. The author has conducted additional research on the impact of PBL on general science skills by incorporating a specific model into their study. Research by [25] has assessed the effectiveness of the PBL model in developing generic chemistry skills (MPBM-PKGK) to enhance students' generic science skills in organic chemistry. The research design is quasi-experimental, employing a one-group pre- and post-tests. Multiple-choice tests and questionnaires were used to collect data. According to the researcher, generic science skills are of utmost importance for chemistry students to excel in their studies and to thrive in the real world. The study reported that the PBL intervention significantly enhanced students' problem-solving and higher-order thinking skills. The respondents expressed satisfaction with the PBL model. This study recommends conducting further research using MPBM-PKGK in other areas of chemistry to gain a better understanding of the proposed model.

Research by [16], [17], and [26], on the other hand, evaluated self-directed learning among participants in response to PBL intervention. The first two papers mentioned were discussed earlier in this review. The study by [26] was conducted in a Nigerian secondary school with a qualitative approach and an explanatory design. This research is the only qualitative paper included in this review, providing valuable insights into the qualitative data collection methods used. The intervention process lasted for six weeks, during which data was collected through observation and interviews. The collected protocol and data were analyzed using content analysis. In this study, self-directed learning is strongly linked to the success of PBL interventions. The study reports that PBL instruction enhanced respondents' self-directed learning with minimal guidance from the teacher. This research highlights that taking control of one's learning process inevitably leads to improved problem-solving skills among students. In my opinion, the report vaguely describes the role of the teacher, especially the extent to which the teacher contributes to the success of the self-directed learning process. This exposure could provide direction and serve as guidance for teachers to become successful facilitators in the transition from traditional teaching to active learning.

In this review, two papers are included that have examined students' perceptions and attitudes towards chemistry with PBL intervention. The study by [18] and [27] has shown that improved problem-solving skills among respondents are related to improved students' perceptions and attitudes towards chemistry. [18] is discussed in the earlier section of this review. [27] utilized an adapted mixed-method research design, employing pre- and post-survey questionnaires to measure changes in student attitudes after the PBL intervention. Additionally, we analyzed student journals to understand how the PBL process was perceived and experienced by the students. This is indeed an appropriate way to understand the effects of PBL intervention on students' attitudes toward science learning, problem-solving skills, and gaining insights into the learning process from the students' perspective. This research reports a significant increase in student attitudes towards problem-solving skills among respondents, and the usage of PBL stimulated a sense of community in the classroom. In other words, the study's participants expressed confidence in their ability to learn science concepts through the PBL approach, as it empowers students to take control of their own learning process. The findings of this research add value to the existing literature on the understanding and influence of PBL on learners' problem-solving skills.

On the other hand, the research by [4] is the only paper that has measured the analytical thinking and scientific attitudes of students in relation to PBL intervention in chemistry. This research was conducted in an Indonesian senior high school and utilized a quasi-experimental design with a post-test-only research design. According to the researcher, this study is motivated by the observation that Indonesian students lack analytical thinking skills in chemistry, particularly in problem-solving. Analytical thinking skills play a significant role in helping learners become successful problem-solvers [29]. The researcher suggested that the current situation could be a result of teachers' inability to instill scientific attitudes among students in the classroom. The traditional teaching approach still adhered to in schools does not allow students to be active learners [4]. This study reports significant differences in the analytical thinking abilities and scientific attitudes of students in the experimental group, indicating that PBL intervention enhanced the students' analytical thinking abilities and scientific attitudes. I agree with the researcher's emphasis on the idea that students cannot achieve scientific conceptual understanding without simultaneously instilling a scientific attitude. The researcher has identified an important criterion for successful scientific concept learning and, consequently, for developing efficient problem solvers.

As a conclusion, providing students with excellent problem-solving skills in chemistry is considered the pinnacle of success in the education sector [4]. Problem-solving skills are applied in many aspects of life, making them crucial for the new generation. Problem-solving skills can be enhanced among students only when they are exposed to them in the teaching and learning process. All the studies included in this review have incorporated a PBL approach to enhance problem-solving skills and have provided evidence that PBL is able to promote problem-solving skills in chemistry education. Students must be exposed to ways of relating authentic real-life problems to abstract scientific concepts in order to pave the way for meaningful learning to take place. This provides evidence that there is a pressing need for more research to be conducted on ways to integrate PBL into teaching and learning chemistry in Malaysia.

4.2 Research question 2

What is the PBL design? Is there any supporting framework used in the research papers?

4.3 PBL design: framework used in the reviewed papers

The integration of PBL as a pedagogical approach is well-received among educators, especially in the field of chemistry education. Research has shown that integrating PBL into chemistry education has a positive correlation with achieving learning goals and acquiring learning skills. Despite the positive effects, there are some discrepancies in the implementation of PBL as a pedagogical approach. In this review, I have also included an analysis of how PBL is implemented in prospective research to provide valuable insights into its application in the instructional process.

Table 2. Summary for PBL framework used

	Study	Framework to Design PBL	Instrument	Treatment/Study Length
1.	Joseph E. Valdez, Melfei E. Bungihan 2018	Only explained, no framework	Problem Solving Skill Test (PSST)	2015–2016 Not clearly mentioned 4 sessions (60 minutes) per week
2.	R.E Dibyantini, R D Suyanti and R Silaban 2021	No framework, PBL model mentioned	Multiple choice test	2018–2019 Not clearly mentioned
3.	R Andriani and YL I Supiah 2021	Only mentioned PBL model, not explained, no framework	Analytical thinking skills tests.	Not clearly mentioned
4.	Benjamin Aidoo, Sampson Kwadwo Boateng (2016)	Not explained, no framework	Physical Science Examination test	Three month period. 2015
5.	Kai-Li Teh and Nooraida Yakob 2013	Not explained, no framework	Paper and pencil test	5 weeks program
6.	Modupe M. Osokoya and Chinwe C. Nwazota 2018	Not explained, no framework	Chemistry Manipulative Skill Scale (CHEMMSS)	Period of 5 weeks
7.	Hatice Gungor Seyhan 2016	Stages of PBL explained: Understand the problem Explore the problem Generate possible solution Determine the best fit solution Solve the problem by performing an experiment Evaluate (Yoon *et al.*, 2014)	Problem Solving Inventory (PSI)	12 weeks
8.	Santiago Sandi-Urena, Melanie Cooper, and Ron Stevens 2012	Only explained, no framework	Online test	Period of three semesters to allow for the replication study.
9.	Ratu Evina Dibyantini, Retno Dwi Suyanti, and Ramlan Silaban 2020	PBL steps explained: Orientation of problem Organization in learning Individual or group investigation Developing and presenting works Evaluation Arends, 2012.	Multiple choices test	10 meetings, duration not clearly mentioned.
10.	Abbas Babayi Abubakar & Mohammad Yusof Arshad 2015	Only mentioned Barrows (1996) PBL model, not explained.	Interview protocol	6 weeks
11.	Cemal Tosun and Yavuz Taskesenligil 2013	4 stages to develop PBL module: Stage 1 Generation of ideas Stage 2 Identifying learning needs Stage 3 Working process outside classroom Stage 4 Reporting the findings (Gallagher *et al.*, 1995; Senocak *et al.*, 2007)	Solutions and their Physical Properties Academic Achievement Test (SPPAAT)	5 weeks

(Continued)

Table 2. Summary for PBL framework used *(Continued)*

	Study	Framework to Design PBL	Instrument	Treatment/Study Length
12.	Abanikannda, M.O. (Ph.D) 2016	Only explained, no framework	PBL in Chemistry Education Students Academic Achievement in Questionnaire (PBLCEQ)	Not clearly mentioned
13.	Ahmet Gurses, Metin Açıkyıldız, Çetin Do and Mustafa Sozbilir 2007	PBL administered through six consecutive stages. Problem presentation Problem identification Carrying out scientific investigation Putting information together Experimenting Presenting the findings	Physical Chemistry Laboratory Concept Test (PCLCT), Attitudes towards Chemistry Laboratory (ATCL) questionnaire and Science Process Skills Test (SPST).	12 weeks period for four experiments
14.	Festus, C. and O. A. Ekpete 2012	Not described, no framework.	Test	Not clearly mentioned Six hours per week
15.	Maria M. Ferreira and Anthony R. Trudel. 2012	PBL administered in 7 steps Delisle (1997) Setting the climate, Connecting with the problem Setting up with the structure Visiting the problem Revisiting the problem Producing a product or performance Evaluation	Survey questionnaire, journal entries	Not mentioned
16.	Shuang Gao, Yuxin Wang, Bin Jiang and Ying Fu 2018	PBL procedure followed 5 steps Grouping and task assignment Analyze and clarify the problem Suggest possible methods Improvement of the details Summarize and evaluate	Test	16 weeks

Seven out of the 16 papers reviewed have designed their PBL implementation based on a framework. Out of the seven papers mentioned, one [16] has included a framework for PBL implementation as the treatment, and one research paper [25] has included a PBL model. [16] adapted the PBL framework developed by Yoon *et al.* (2014) for their research, which was conducted over a 12-week period in an instrumental laboratory analysis course. The framework includes understanding the problem, exploring the issues, generating possible solutions, determining the best-fit solution, solving the problem through experimentation, and finally evaluating the results. The researcher has included a transparent methodology in their paper, which clearly describes the implementation of PBL in an instrumental laboratory course. Researchers have mentioned that the problems presented in this approach should allow students to connect their prior knowledge with the new content they are supposed to learn. Thus, the problems presented are those that are relevant to the lives of the study's respondents. On the other hand, [25] has implemented a problem-based learning model to deliver generic chemistry skills (MPBM-PKGK). The respondents were teacher candidates in organic chemical reactions lectures. In this study, the content and MPBM-PKGK model were not clearly explained. Therefore, the exact PBL design could not be discussed in this review.

Unlike references [16] and [25], the other five papers ([24], [23], [27], [18], and [21]) have discussed PBL implementation without any specific framework. However, they included explanations of the phases, stages, and steps of the PBL implementation in their research. [24] has implemented a five-phase PBL regime to enhance the generic science skills of teacher candidate students in organic chemistry. The researchers have adapted five steps outlined by Arends (2012), which include problem orientation, learning organization, individual or group investigation, development and presentation of work, and evaluation. In my opinion, the implementation of PBL in this research has required the tutor to be closely involved in the instructional process. In the first step, the problems are illustrated by tutors. In the second step, the tutor plays a prominent role in constructing the materials for the learning process. In the third step, the task is assigned to the respondents, either in groups or individually. Then the respondents have to present their findings, followed by an evaluation of the tutor. This last step is similar to other research papers that have been reviewed. The researcher emphasized that the difficulty of the problems presented should align with the respondents' abilities, and be relevant to their life experiences. The learning environment must be conducive, and learning resources must be provided to the participants in the study to ensure successful PBL learning [24].

Similarly, [23] has also delineated five steps in their study involving non-chemistry majors in an instrumental analysis course. The steps discussed are as follows: the first step is grouping and task assignment; the second step is analyzing and clarifying the problem; the third step suggests possible methods; the fourth step is improving the details; and the fifth step is summarizing and evaluating. Although this research has followed a five-step approach, similar to [24], all the steps are distinct except for the final one, which involves evaluating the PBL process. In the study conducted by [24], the five steps were implemented over the course of one semester. At the beginning of the semester, the respondents were grouped and assigned tasks. The respondents were grouped heterogeneously based on their learning abilities, with individuals of different abilities grouped together. The researcher suggested that participants at different levels are able to assist each other during the PBL process. The second step is crucial because this is where the respondents analyze the problem, determine their next course of action, decide on methods to solve the problem, and identify the information needed. In order for PBL to be successful, teachers were included in meetings at least once a month to track the students' progress. The researchers have outlined some difficulties faced in implementing PBL as a pedagogical approach. The role of teachers in the success of PBL is of utmost importance. It is crucial for teachers to monitor the progress of the students and guide them back to the expected learning outcomes if they deviate from the correct path. In addition, the students' ability to efficiently obtain the necessary information for the learning process is also a limiting factor for the success of PBL. Therefore, students must be technologically savvy to successfully participate in this learning approach. In addition, students must be able to interact and communicate effectively in groups to solve problems in the learning process. Some students who were not actively participating in group activities may hinder the successful achievement of the learning outcomes in this pedagogical approach. In my opinion, the difficulties and limitations outlined by the researchers are very beneficial and should be taken into account before designing a problem-based learning approach to increase the chances of meaningful learning in a classroom.

Unlike the studies cited in [24] and [23], the approach described in [27] implements PBL in seven steps, following Delisle's (1997) model. The researcher outlined the following steps: setting the climate, establishing a connection with the problem, setting the structure, visiting the problem, revisiting the problem, performing, and finally evaluating the performance. According to the researcher, the respondents share the information they collected about the problems they encountered during the revisiting phase. The other steps were not thoroughly explained by the researcher.

On the other hand, [18] included six consecutive stages of PBL implementation in their research. The first stage involves presenting the problem; the second stage involves identifying the problem; the third stage involves conducting scientific inquiry; the fourth stage involves synthesizing the findings, followed by carrying out the experiment, and concluding by presenting the findings. In the first stage, the respondents brainstormed and wrote down ideas regarding the problems posed. In the second stage, the respondents have developed an understanding of the scientific content necessary to solve the problem and formulated it in the form of "need-to-know" questions. In the third stage, respondents gather resources and information based on the questions formulated earlier, followed by summarizing their approach to solving the problem and presenting it in class. The respondents conduct experiments in the fifth stage and report their findings in the last stage. The research paper clearly describes the stages, providing readers with a good understanding of how PBL was used as an intervention in the study. The researcher has outlined three characteristics of well-posed problems that are essential for the success of the PBL intervention. According to [18], the problem must be based on real-life experiences and ill-structured to encourage students to communicate with each other during the problem-solving process. The problem should be thought-provoking to stimulate students' interest in learning and should incorporate their prior knowledge, enabling them to connect it to the intended learning outcome.

Unlike the other research papers mentioned earlier, the study by [21] outlines four stages for administering PBL: brainstorming ideas, organizing learning outcomes, working processes, including outside the classroom, and finally, reporting and presenting the findings. In the first stage, respondents generate ideas based on the given problems in groups, followed by formulating "need-to-know" questions in the second stage, similar to the study by [18]. The following stages involve respondents finding the information needed, designing their hypotheses, carrying out their investigations, and presenting their findings. To ensure the success of this research, all respondents received a briefing regarding the process, and the teachers were provided with teaching manuals to guide the PBL intervention in the laboratory. The researcher mentioned that the teacher facilitated the respondents throughout the learning process. This paper has provided valuable insights into the successful integration of PBL in laboratory instruction.

There are certain similarities among the seven papers reviewed in terms of how PBL is implemented as an intervention to improve the problem-solving skills of participants in chemistry education. Most papers have reported that the first step involves identifying the problem or generating ideas, which indicates that respondents must comprehend the problem posed in the lesson well. This is followed by respondents identifying the construct, or the scientific concept, involved in the lesson. There were some differences in how the researcher supervised the learning process. Some papers reported that the learning process of the respondents was closely observed by the teachers, and one paper included journal writing by respondents on how they directed their own learning process. The papers that explain the PBL framework, its steps, and stages also list several parameters, including the quality of problems posed, the role of the teacher, and the qualities of students that contribute to successful PBL interventions. This information is valuable for the success of future research.

5 CONCLUSION AND SUGGESTIONS

In this systematic literature review, sixteen articles have been analyzed and summarized in accordance with the formulated research questions. The review has attempted to uncover the impact of the problem-based learning approach on students' problem-solving skills, especially in the context of chemistry education. The findings of this paper are expected to fill a gap in the literature, particularly in the field of chemistry education.

All the selected articles propose a constructivist approach, known as PBL, as an intervention to address the lack of problem-solving ability among students. PBL has a significant positive impact on students' problem-solving skills, as reported by all the research articles reviewed. PBL is an approach that originated from constructivist theory, which posits that students learn best when they are actively involved in the instructional and learning processes. PBL promotes meaningful learning and enhances students' ability to solve problems. In the PBL approach, real-life or authentic problems are presented, and students are required to solve the problems by connecting them to the scientific theories they have learned. In the research articles reviewed, the PBL approach is not only incorporated in classroom instruction but also in laboratory instruction. The PBL approach is used to assist students in conducting experiments in chemistry. All the research suggests that the PBL approach enhances students' problem-solving abilities. This enables students to construct their own knowledge and improve their problem-solving skills. Some articles also reported that the PBL approach not only enhances problem-solving skills but also other scientific skills such as critical thinking, analytical thinking [4], and generic science skills [25].

In some of the selected research articles, the discussion of chemistry topics or scientific concepts is mentioned vaguely. The specific content of chemistry knowledge used in the PBL approach appeared unclear. Many scientific concepts in chemistry are considered difficult, such as electrochemistry, and there have been relatively few research studies in this field. [28], [30]. Thus, more research needs to be carried out focusing on problem-solving skills, for instance, on a specific topic or content in chemistry, so that difficult concepts with an abstract nature can be delivered in an engaging manner. This will certainly provide guidance for educators, especially in the field of chemistry, including teachers and lecturers, to successfully adapt this pedagogical approach and induce active learning in their lessons.

On the other hand, some studies discuss the disadvantages of PBL. The incorporation of PBL is believed to be time-consuming and to take a longer period of time to complete [31]. This could be attributed to the fact that students are required to gather relevant information about the concept they are learning and to direct their own learning process. In this process, students can be misguided and waste time looking for appropriate learning materials [32]. According to [33], 21st-century students are highly inclined to using technology, especially mobile devices, for learning. The way they learn emphasizes the ability to learn anywhere, not just in the classroom. Thus, the researcher recommends conducting further studies to better understand the use of mobile technologies in integrating PBL into the instructional process. This could provide valuable insights into maximizing the benefits of PBL and minimizing its drawbacks.

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