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Profile of High School Students' Problem-Solving Skills and the Application of Problem-Based Learning: A Preliminary Study

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ABSTRACT

This study's purpose is to obtain a profile of students' problem-solving skills and describe the achievement of implementing Problem-Based Learning (PBL) in high schools. The profile of problem-solving skills was obtained by giving tests and questionnaires to 53 students, while the achievement of implementing the PBL model was obtained by interviewing six students and one chemistry teacher. The research data obtained is then described. The findings revealed that the students' problem-solving skills remained low, namely in the poor and very poor categories with a percentage of 67.93%. Meanwhile, students' problem-solving skills were in the enough category at 20.75%, in the good category at 11.32%, and in the very good category were not found. This study also demonstrates that the teacher's application of learning with the PBL has yet to lead to students achieving the problem-solving skill indicators that are measured. In addition, students' prior knowledge was found to have contributed to the achievement of these indicators. This study suggests adapting and modifying the PBL model's syntax based on all present constraints to develop a new learning model capable of appropriately training students' problem-solving skills by focusing on the side of students' prior knowledge, formulation hypothesis, and reflection activities in learning.

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INTRODUCTION

There have been substantial changes in every aspect of human life in the 21st century. These changes are being driven by the rapid growth of technology, which is resulting in increasingly complicated challenges to human life in a variety of disciplines, including worldwide ties between humans (Chalkiadaki, 2018; Muyambo-Goto *et al*., 2023; Sima *et al*., 2020). As a result, existing developments can change lives in ways that have never happened before (Erdem *et al*., 2019; Levin & Mamlok, 2021; Molino *et al*., 2020). Based on this, an education system that can provide students with the skills needed for the 21st century is required (Afandi *et al*., 2019; Haviz *et al*., 2020; Kim *et al*., 2019; Lavy, 2020; Varas *et al*., 2023). These skills are 1) collaboration, 2) critical thinking and problem solving, 3) communication, and 4) creative thinking and innovation, which are referred to as 4C skills (Astuti *et al*., 2019; Haryani *et al*., 2021; Supena *et al*., 2021; Tang *et al*., 2020; Thornhill-Miller *et al*., 2023; Ye & Xu, 2023).

According to experts, one of many important skills in the 21st century is problem-solving skills (Erdem *et al*., 2019; Funke *et al*., 2018; Yoon *et al*., 2020). Referring to the explanation of Özreçberoğlu & Çağanağa (2018), it is well established that mastering problem-solving skills can help students become better problem-solvers and decision-makers in difficult situations.

However, recent studies indicate that students' problem-solving skills are seriously lacking. (Franestian *et al*., 2020; Jua *et al*., 2018; Kartini *et al*., 2021; Rahmah & Rohaeti, 2018; Rahmawati *et al*., 2018). Not only that, based on the OECD report (2019), it is well recognized that nationally, students' acquisition of problem-solving skills in Indonesia remains relatively low. This is thought to be due to the mastery of science which is still at the second level of the six existing levels, while to be able to master problem-solving skills must at least be at the mastery of science at the fourth level.

Problem-solving skills are an indicator of intellectual behavior and part of higher-order thinking skills (Akben, 2020; Zajuli *et al*., 2019). Based on Polya's heuristic logic (1973), there are ten indicators of problem-solving skills, namely: identifying the problem, formulating the problem, planning to solve the problem, defining the purpose of the problem-solving plan, exploring possible strategies, formulating a hypothesis, carry out the problem-solving plan or experiment, analysing the data, drawing a conclusion, dan reflecting on problem-solving. According to Sari *et al.* (2021), students can gain mastery of these indicators by following learning processes that direct them to think about and solve problems. The development of these skills has a good impact on students' emotional intelligence (Drigas & Papoutsi, 2018) and student learning motivation (Araiza-Alba *et al*., 2021; Georgiou & Kyza, 2018).

Woolfolk (2021) categorizes problem-solving into complex cognitive processes. This was explained by Sinaga *et al.* (2023), that problem-solving is a means to find a way out of difficulties that cannot be solved quickly. This indicates that learning aimed at practicing problem-solving skills falls under the purview of complex cognitive learning. According to Willford (2017), this categorization is due to a succession of complex cognitive processes that demand thinking and reasoning in the problem-solving process. Woolfolk (2021) also explains, that problem-solving always involves the activity of formulating new answers by applying rules that are not simple to achieve a goal. This was also expressed by Suseelan *et al.* (2022), who noted that real-world problems are frequently presented in strange circumstances and lack unambiguous solutions. As a result, problem-solving activities typically necessitate changing existing knowledge and activities to synthesize novel strategies. Therefore, in the problem-solving process, clear steps are needed to make it easier for students to find solutions to these problems.

PBL is a learning model that includes stages of systematic learning. There are five stages related to problem-solving skills, namely: connecting students with the problem, organizing students to participate in group work, guiding both group and individual investigations, generating and presenting work outcomes, and analysing and evaluating the process of solving problems (Hidayati & Wagiran, 2020; Sari *et al*., 2021). Therefore, this learning model aims to train students' problem-solving skills (Chamidy *et al*., 2020; Maskur *et al*., 2020; Valdez & Bungihan, 2019), and its application involves high-level thinking processes (Ghani *et al*., 2021; Imamah *et al*., 2020; Ramadhani *et al*., 2019). However, recent studies revealed that students' problem-solving skills remained low in this learning design (Kurniawan & Sofyan, 2020; Pristianti & Prahani, 2022; Qotrunnada & Prahani, 2022; Valdez & Bungihan, 2019). This indicates students' higher-order thinking skills remain low. In addition, it was also found that the PBL model is very dependent on students' prior knowledge (Akhdinirwanto *et al*., 2020; Dolmans, 2019; Hemker *et al*., 2017; Lonergan *et al*., 2022; Mabley *et al*., 2020). This finding was also reinforced by Komarudin *et al.* (2020), that students' prior knowledge has a contribution to improving problem-solving skills. These two aspects need to be considered when implementing the PBL model.

Based on the facts given above, it is required to investigate to establish the level of mastery of students' problem-solving skills and to obtain information about the implementation of the PBL model in high school. The goal of this study is to describe the profile of students' problem-solving skills, as well as the implementation of the PBL model to teach these skills in high school. Furthermore, complex problem-solving test questions related to everyday phenomena are given to students to determine the profile of their problem-solving skills. The colligative properties of solutions are a topic in the chemistry subject which is used to compile these test questions. The

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idea of compiling and using these questions tests has never been done in any research, so it is a novelty in this study. The study's findings will be expected to aid in the development of learning models that can train students' problem-solving skills.

RESEARCH METHOD

This is a preliminary study using mixed methods. This study does not aim to test the hypothesis but uses a descriptive research design. As for participants in this study, there were 53 students aged 16-18 consisting of 23 boys and 30 girls who were randomly selected from the entire population, and 1 chemistry teacher. All participants came from a private high school in Jombang, Indonesia. In this case, all students are asked to answer problem-solving skills test questions and fill out a student response questionnaire. Then from the 53 students, 6 students were randomly selected, consisting of 3 boys and 3 girls, to participate in the interview session. Additionally, interviews were conducted with the chemistry teacher who taught the class. A literature review of prior research on PBL learning and students' problem-solving skills was also conducted in this study.

In this preliminary study, four types of data were collected: the results of written tests, the results of student answer questionnaires, the results of teacher interviews, and the findings of student interviews. The written test is designed to assess the students' capacity for problem-solving. The test instrument used was in the form of 10 problem-solving questions which were compiled based on ten indicators of problem-solving skills of Polya (1973) namely: identifying the problem, formulating the problem, planning to solve the problem, defining the purpose of the problem-solving plan, exploring possible strategies, formulating a hypothesis, carry out the problem-solving plan or experiment, analysing the data, drawing a conclusion, dan reflecting on problem-solving. Judging from the acquisition of the mode grades, of the ten questions used, one item was declared valid and the other nine were declared highly valid by three experts.

In this case, the validity of the test items can be determined based on the mode grades of all grades given by experts or validators (Ayu *et al.*, 2019; Hair *et al.*, 2019). In addition, these questions have also received input and improvements from two practitioners. Table 1 displays the validation findings.

Table 1. The validation results of test questions

Question number	Indicators of problem-solving skills measured	Validator's assessment			Mode	Category	Description
		V1	V2	V3			
1	Identifying the problem.	4	4	4	4	Highly valid	The formulation of the questions written is in accordance with the problem indicators and problem-solving skills indicators, and the editorial of the questions written can measure the problem-solving skills indicators.
2	Formulating the problem.	4	3	4	4	Highly valid	
3	Planning to solve the problem.	3	4	4	4	Highly valid	
4	Defining the purpose of the problem-solving plan.	4	4	4	4	Highly valid	
5	Exploring possible strategies	3	3	4	3	Valid	
6	Formulating a hypothesis	4	3	4	4	Highly valid	
7	Carry out the problem-solving plan or experiment	4	3	4	4	Highly valid	
8	Analysing the data	4	4	4	4	Highly valid	
9	Drawing a conclusion	4	4	4	4	Highly valid	
10	Reflecting on problem-solving	3	4	4	4	Highly valid	

The validation indicators used in Table 1 namely: 1) the assessment category is highly valid (score 4), if the question formulation matches the question indicators and problem-solving skill indicators, and the question formulation can measure each problem-solving skill indicator, 2) valid assessment category (score 3) if the question formulation matches the question indicators and indicators of problem-solving skills being measured, 3) less valid assessment category (score 2), if the question formulation matches the question indicators but does not match the problem-solving skill indicators measured, and 4) the assessment category is not valid (score 1) if the question formulation does not match the question indicators and problem-solving skill indicators being measured.

Student answers to each item in this study were assessed based on the problem-solving skills assessment rubric. The data from the test results are then computed using a formula used by Jua *et al.* (2018) which aims to determine student achievement on each indicator of Polya's (1973) problem-solving skills measured (X). The formula is as follows.

$$X = \frac{Total\ student\ score\ per\ indicator}{Maximum\ score\ per\ indicator} \text{ X } 100$$

In addition to calculating the achievement of students' problem-solving skills for each indicator, this study also calculated the acquisition of all student scores to determine the level of mastery of these skills. All data obtained were then analyzed using descriptive analysis. Table 2 displays the average number of student scores grouped according to the criteria used by Jua *et al.* (2018).

Table 2. Categories of students' problem-solving skills

Score interval	Category
$X \leq 50,75$	Very Poor
$50,75 < X \leq 65,25$	Poor
$65,25 < X \leq 79,75$	Enough
$79,75 < X \leq 94,25$	Good
$94,25 < X^*$	Very Good

Questionnaires for response students were employed in this study to explore information relating to students' answers to the learning that had taken place, as well as student's perspectives on the challenges encountered when completing written test questions. The percentage of responses gathered from the questionnaire is then calculated and described. The criteria for interpreting questionnaire responses adopt the parameters used by Zalat *et al.* (2021) and Napitupulu *et al.* (2018), as indicated in Table 3.

Table 3. Criteria for interpreting student response questionnaires

Percentage	Criteria
76% - 100%	Strongly Agree
51% - 75%	Agree
26% - 50%	Disagree
0% - 25%	Strongly Disagree

Interviews with students and chemistry teachers were done in this study. Interviews with students are intended to gather information about the PBL learning in which students participate, as well as student's perspectives on the problem-solving skills tests that have been tested. Meanwhile, the interview with the teacher sets out to obtain information about chemistry learning as well as the teacher's implementation of the PBL practice. The data obtained is then described. The flow of this preliminary study is shown in Figure 1.

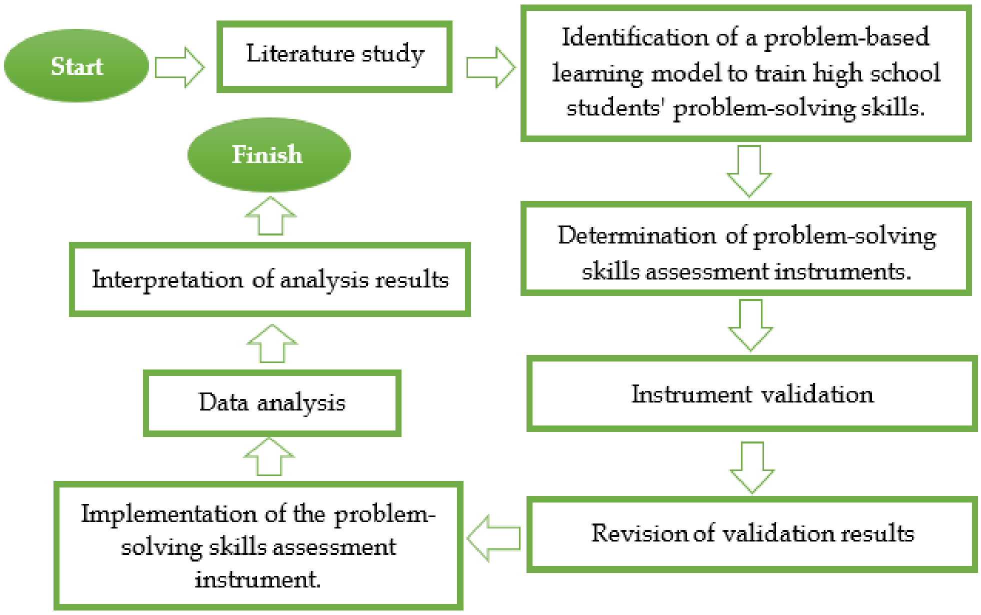

Figure 1. Flowchart of preliminary study

RESULTS AND DISCUSSION

Results

The preliminary study's results included student problem-solving test scores, student response questionnaires, interviews with students, and interviews with chemistry teachers. Table 4 displays the test results for students' problem-solving skills.

Table 4. Test results of students' problem-solving skills in chemistry subjects against each indicator of problem-solving skills

No.	Indicators of Problem-Solving Skills	Score (X)	Category
1.	Identifying the problem	80,66	Good
2.	Formulating the problem	57,08	Poor
3.	Planning to solve the problem	58,49	Poor
4.	Defining the purpose of the problem-solving plan	55,66	Poor
5.	Exploring possible strategies	51,42	Poor
6.	Formulating a hypothesis	34,91	Very Poor
7.	Carry out the problem-solving plan or experiment	35,85	Very Poor
8.	Analysing the data	60,38	Poor
9.	Drawing a conclusion	51,42	Poor
10.	Reflecting on problem-solving	58,02	Poor

The grades in Table 4 are obtained by administering a written test consisting of essay questions. Before students begin answering test questions, the teacher informs them on how to complete it. Once students understand how to answer the questions, they are given 90 minutes to complete the test questions. This study's test results were examined using mastery of the 10 problem-solving skill indicators and problem-solving skill categories. In addition, the percentage for each category is determined one by one. Figure 2 shows the percentage of students who achieved problem-solving skills in the chemistry lessons for each assessment category.

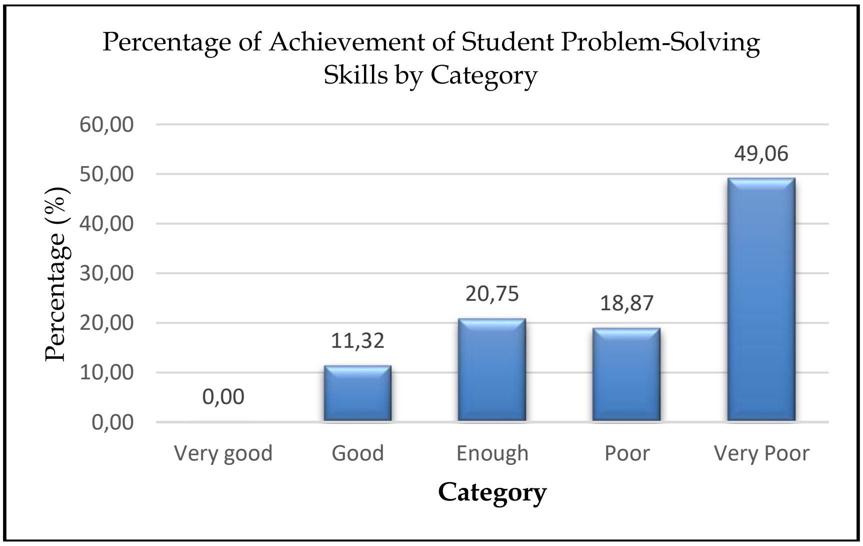

Figure 2. Achievement of problem-solving skills based on each category

To determine responses by students to problems they found after taking the test, student response questionnaires were distributed. Table 5 displays the results of the student responses.

Table 5. Student answer questionnaire results

No.	Questions	Percentage of "Yes" Answers	Criteria
1	Do you feel able to identify the problems presented in this problem-solving exercise?	54,72 %	Agree
2	Did your prior knowledge of the problem influence you in answering all the questions?	90,57 %	Strongly Agree
3	When you were asked to write the problem formulation, hypothesis and reflection did you find it difficult?	54,72 %	Agree
4	When you were asked to analyse the data and write conclusions did you find it difficult?	30,19 %	Disagree
5	Do you need lessons that can teach problem-solving skills well?	92,45 %	Strongly Agree

Table 6 displays the results of interviews with students about the PBL learning model they used, as well as student responses to the problem-solving skills test. The interviews were conducted with 6 students from a private high school in Jombang consisting of 3 boys and 3 girls.

Table 6. Results of interviews with students

No.	Questions	Summary of Student Answers
1	Have you ever received chemistry learning by applying the problem-solving learning model (PBL)?	The six students answered that they had attended this lesson in chemistry.
2	After you have followed learning with the PBL model, do you feel capable of solving complex problems related to chemistry in everyday life?	All students answered no because only problems related to chemistry concepts could be solved. According to students, this is because the teacher has never trained how to solve complex problems related to chemistry in everyday life.
3	Do you feel it can identify the problems in the problem-solving skills test questions that have been given to you?	Four students stated that they were able because it was very clear the main problems described in the test questions. Meanwhile, two students stated that they were unable to because it was the first time they had worked on this type of question.

No.	Questions	Summary of Student Answers
4	Which part of the test questions did you find it difficult to answer? Why?	The student answers varied, 2 students answered that they had difficulty in the hypothesis section, 1 student had difficulty in the problem formulation section, 1 student had difficulty in the data analysis section, and 2 students had difficulty in the reflection section. According to them, these difficulties arise because students have never been trained to address complex problems in everyday life through their previous learning.
5	Does your prior knowledge greatly influence your answers to the problem-solving skills test questions? Why?	The six students answered yes. Two students stated that prior knowledge could make it easier for students to complete test questions. One student stated that prior knowledge could lead students to answer test questions easily, and three students stated that prior knowledge greatly influenced students' way of thinking in solving the test questions.

Table 7 displays the results of interviews with teachers regarding the implementation of the PBL model of learning. In this case, interviews were conducted with one chemistry teacher.

Table 7. Results of interviews with chemistry teachers

No.	Questions	Teacher's Answer
1	Have you applied the PBL model to your learning in the past year?	Yes, I have, but on appropriate chemistry topics.
2	For what purpose do you apply the PBL model in learning?	To train students' problem-solving skills on the chemistry topics being taught.
3	What is the level of student mastery of problem-solving skills after studying with the PBL model?	Good enough, but students need to be intensively trained in these skills.
4	Have you ever taught complex problem-solving in everyday life related to chemistry topics?	Never
5	What difficulties do you face when teaching complex problem solving in everyday life related to chemistry topics?	Lack of ideas in developing learning scenarios related to these complex problems.

Discussion

According to the findings of the interviews, teachers have trained students in problem-solving skills in chemistry study by implementing the PBL model. This model is a designed learning model which can help student improve their capacity for problem-solving (Suryani *et al.*, 2020; Valdez & Bungihan, 2019). However, in this preliminary study, it was found that the mastery of these skills was still low, namely the dominant ones were in the poor and very poor categories with a percentage of 67.93%. The rest is in enough category at 20.75%, in the good category at 11.32%, and in the very good category is not found. This is shown in Figure 2. These insufficient skills are caused by students' varying understandings of the topic of colligative properties of solutions as prior knowledge, which has a considerable influence on students' way of thinking when answering test questions. It is supported by the findings of the student questionnaire and the interviews with students. According to the study results of Hemker et al. (2017), that the variety of student's prior knowledge in the application of PBL creates challenges, particularly because of insufficient student prior knowledge in the PBL process.

Students' low problem-solving skills, as shown in Figure 2, are caused by the PBL model's syntax being unable to sufficiently train students' problem-solving skills (Kurniawan & Sofyan, 2020; Pristianti & Prahani, 2022; Valdez & Bungihan, 2019). Arend (2015) describes the PBL model into five syntaxes: 1) pointing students to a problem, 2) organizing students to learn, 3) guiding

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both group and individual investigations, 4) developing and presenting work results, and 5) evaluating and analyzing problem-solving processes. According to these five syntaxes, there was not any learning phase that would train students to formulate hypotheses and reflect. Even though these two factors are essential in the problem-solving process (Filipenko & Naslund, 2016; Kerr, 2016; Woolfolk, 2021). This is reinforced by Dabbagh (2019), who claims that the PBL model's educational approach encourages directed learning by allowing students to construct hypotheses and promote reflection as the major assessment tool in solving each problem. It is confirmed by the results of the student questionnaire and student interviews.

According to the data displayed in Table 4, nine out of ten indicators of problem-solving skills have not been completely mastered by students. This is caused by the lack of prior knowledge of students related to the topic being studied. The results of the questionnaire as well as interviews with students show that there is an important role for students' prior knowledge in the problem-solving process. This is supported by research Lonergan *et al.* (2022) and Mabley *et al.* (2020), that the PBL model is effectively applied when students have good prior knowledge.

In this study, identifying problems is an indicator of problem-solving skills that have been mastered by the majority of students. This is because the presentation of the problem in the test questions has been written properly so that students easily recognize the problem that must be solved. According to Table 4, students' high-level thinking skills remain low due to their low mastering of the nine indicators. It happens because the process of problem-solving necessitates high-level thinking abilities (Akben, 2020; Zajuli *et al*., 2019). This is consistent with the results of a study conducted by Zhao *et al.* (2021), which found that problem-solving skills are key to high-level cognitive skills.

According to Table 5, the majority of the students were able to identify the problem. However, to solve problems almost all students need good initial knowledge. This knowledge greatly influences students in solving problem-solving skills test questions. Most students also stated that in the process of solving problems they still had difficulty formulating problems, formulating hypotheses, and reflecting. However, in terms of data analysis, most students already can analyse the data supplied in the questions. This demonstrates that providing data to students in the form of tables, diagrams, or graphs makes data analysis easier for students. Meanwhile, 92.45% of students claimed that they were required to receive learning that could develop students' problem-solving skills to master problem-solving skills. The student's statement is by the explanation given by Sari *et al.* (2021), that problem-solving skills can be obtained by students through appropriate problem-solving learning steps.

The results of interviews with students, as shown in Table 6, support the findings of low outcomes for students' problem-solving skills based on the tests that were given. In addition, it also strengthens student answers to student response questionnaires. According to Table 6, student learning with the PBL model is still directed toward solving problems related to chemical concepts.This learning has not oriented students to problems in everyday life that are complex. In reality, to face the challenges of 21st century life necessitates mastery of problem-solving skills relevant to complex problems encountered in everyday life. (Gunawan *et al*., 2020; Hobri *et al*., 2020; Kim *et al*., 2019). According to students, this is what causes difficulties in formulating problems, formulating hypotheses, conducting data analysis, and reflecting when answering test questions. Besides that, students also need to strengthen their initial knowledge when carrying out the problem-solving process.

According to the findings of the interviews with the chemistry teacher, as indicated in Table 7, the teacher has implemented problem-solving learning using the model of PBL. However, in this session, students only solve problems based on chemical concepts. The teacher did not discuss difficult challenges that arise in everyday life while carrying out learning. This is allegedly due to the lack of teacher ideas in carrying out the learning. Thus, the information provided by the teacher shows the suitability of student answers at the time of the interview.

This study's findings indicate the PBL model's limits in training Polya's problem-solving skill indicators. As a result, to overcome all of the constraints of this learning model, the syntax of the PBL model must be developed. This is in alignment with Dolmans' (2019) explanation for adapting and redesigning the PBL model in light of existing constraints. Apart from the ten indicators of Polya's problem-solving skills, variables such as students' prior knowledge mastery, hypothesis formulation, and reflection must be considered while developing the PBL model's syntax. According to Komarudin *et al.* (2020), mastering prior knowledge helps students improve their problem-solving skills. Meanwhile, Kuang *et al.* (2020) discovered that their use of hypothesizing can help students gain knowledge effectively, while Gayathri *et al.* (2021) revealed that reflection activities can assist students in realising mistakes made while learning.

Table 8 displays the findings of the article review about the PBL model, problem-solving skills, higher-order thinking, students' prior knowledge, the importance of the hypothesis and reflection on the problem-solving learning framework.

Table 8. The article review results

Author (year)	Sample (N)	Study Design	Findings/results
Lonergan *et al.* (2022)	N = 257	Quasi-experimental, quantitative, and exploratory.	The PBL model works best only for students a powerful prior knowledge and is less effective for those with poor prior knowledge.
Mabley *et al.* (2020)	N = 14	Qualitative.	During learning with the PBL model, students tend to refer to the prior knowledge they have when solving problems.
Valdez & Bungihan (2019)	N = 86	Descriptive-comparative and pretest-posttest experimental design.	The model of PBL can only increase students' problem-solving skills at low problem-solving levels.
Kurniawan & Sofyan (2020)	N = 40	Quasi-experiment.	Compared to the conventional learning model, the application of the PBL model does not have a higher impact on increasing problem-solving than conventional learning.
Mashluhah *et al.* (2019)	N = 20	Using a one group pretest and posttest design.	The activity of hypothesizing helps students improve their skills in problem-solving.
Komarudin *et al.* (2020)	N = 38	Quantitative experimentation.	Prior knowledge of students is proven to effectively contribute to improving problem-solving.
Muhammed *et al.* (2022)	N = 57	Quantitative experimentation.	Prior knowledge can improve students' understanding and ability to think systemically.
Bubnys (2019)	N = 71	Qualitative.	Reflection activities in learning can give each individual in-depth self-perception, personal strengths, and awareness of the limitations of self-competence.
Hamdan *et al.* (2019)	N = 78	Quantitative with design quasi-experimental	Learning with HOTS has an impact on increasing the achievement of assessments before and after learning. Meanwhile, traditional learning alone cannot have a significant effect on increasing HOTS.
Hadiprayitno *et al.* (2022)	N= 76	Adopt and adapt the one-shot case study research design.	Based on the study's findings, HOTS questions can reveal skills in problem-solving. According to the results of the problem-solving skill analysis, student's problem-solving skills are in the medium range.

Author (year)	Sample (N)	Study Design	Findings/results
Silitonga *et al.* (2020)	N = 46	Experiment using pretest-posttest control group design.	HOTS learning through problem-solving strategies are more effective than practising strategies. Furthermore, it was discovered that strategies for solving problems were effective in enhancing students' physics HOTS.
Pozas *et al.* (2020)	N = 232	Quantitative	Students' prior knowledge has an influence on improving motivation and metacognition.
Satrio Nangku & Rohaeti (2019)	N = 63	Quasi experimental using posttest only control group design	Problem-based learning can improve learning outcomes and can also improve students' conceptual understanding and verbal communication skills.

CONCLUSION

Based on data and discussions, it is possible to conclude that students' problem-solving skills remain low. Furthermore, based on student response questionnaires, student interviews, and teacher interviews, it was shown that the application of the PBL model in chemistry lessons conducted by teachers had not trained complex problem-solving in everyday life. This resulted in students not mastering problem-solving skills based on existing indicators. For this reason, teachers need to orient learning to master these skills so that students can formulate problems, plan problem-solving, define goals, create strategies, formulate hypotheses, carry out experiments, analyse data, draw conclusions, and be able to reflect. This ability is useful for solving complex problems. In addition, mastery of students' prior knowledge also needs to be considered in implementing problem-based learning. This preliminary study has implications for the importance of developing the learning syntax of the PBL model that can train students' problem-solving skills, which are embodied in a learning model.

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