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The development of problem-solving of grade 11 students using problem-based learning integrated with questioning strategies

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ABSTRACT

This study examined the effects of problem-based learning (PBL) integrated with questioning strategies on the problem-solving of 19 grade 11 students in the Thai educational context. Participants were selected using a purposive sampling method. The study was developed in an action research. It involved three learning cycles, each encompassing the stages of planning, action, observation, and reflection. The instruments used in the study included a learning management plan designed with PBL and questioning strategies, a problem-solving thinking test, interviews, and observation forms.The data were analyzed using percentage, mean score, and standard deviation. The results indicated that the instructional method had positive effects on the participants' knowledge, thinking skills, and attitudes toward science learning. The findings suggest that integrating PBL with questioning strategies can effectively enhance student engagement and cognitive abilities in science education.

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1. INTRODUCTION

Thinking skills are a crucial part of science education as the nature of the subject is related to investigating facts about phenomena (Santos, 2017; Sun et al., 2022). Students equipped with effective thinking skills can critically analyze information, formulate hypotheses, and draw evidence-based conclusions, enhancing their understanding and engagement with scientific concepts (García-Carmona, 2023). Moreover, good thinking skills are essential for problem-solving, an important process in the science classroom. Problem-solving requires students to identify issues, develop strategies, and implement solutions, fostering their analytical and creative capabilities (Wismath & Orr, 2015). Therefore, problem-solving thinking should be equipped to students to reach educational outcomes, enabling them to tackle complex scientific challenges and apply their knowledge in practical, real-world situations.

To develop problem-solving thinking, several components need to be considered (Dostál, 2015). First, students must be encouraged to engage in critical thinking and reflective practices to understand problems deeply. Furthermore, fostering creativity allows them to generate innovative solutions. Collaborative learning environments enable students to share diverse perspectives and approaches (Wismath & Orr, 2015). Providing real-world problem scenarios helps students apply their knowledge practically. Finally, continuous feedback and assessment guide students in refining their problem-solving techniques. These components collectively create a comprehensive framework for nurturing effective problem-solving thinking in students.

However, in the Thai educational context, the learning environment might not support these components. Specifically, the context has been criticized for being technologically unready, passive, and unpersuasive (Yuenyong & Narjaikaew, 2009; Faikhamta et al., 2018). Most Thai science classrooms, especially in local public schools, operate by having teachers explain what is in the textbook while students listen passively. Experiments are rarely practiced due to a lack of equipment, making science learning unappealing. These circumstances contribute to problems in science education in Thailand, as evidenced by both national and global test results (National Institute of Educational Testing Service, 2022; OECD, 2022). This situation reflects broader issues, as the country remains a technology importer, impacting its overall technological and educational outcomes.

Therefore, an instructional method that aligns with the nature of science education and addresses contextual challenges should be introduced. Problem-Based Learning (PBL) was incorporated into the current study as a teaching approach that allows learners to understand scientific concepts while solving problems (Akcay, 2009; Barrett, 2017; Barrows, 1986; Savery, 2019). According to Savery (2019), PBL is a learner-centered curriculum that grants students the autonomy to tackle real-world problems. Unlike traditional curriculum design, PBL features distinct characteristics: students direct their own learning, the ill-structured nature of authentic cases fosters open inquiry, and cases cover a wide range of problems and subjects. Collaboration with peers is encouraged, and reflection is crucial for consolidating learning. Teachers act as facilitators, supporting students' individual learning and peer collaboration rather than solely disseminating knowledge.

Moreover, the process of questioning is crucial in solving problems. Effective questioning enables students to gather the necessary information for both problem-solving and learning scientific concepts (Herranen & Aksela, 2019). By asking insightful and targeted questions, students can uncover key details that aid in understanding and resolving complex issues (Newton et al., 2018). For example, in a classroom scenario involving a crime case, asking the right questions can help students identify the perpetrator while simultaneously learning about blood types, forensic analysis, and the scientific method. This dual benefit not only makes the learning process more engaging but also deepens their comprehension of scientific principles. Therefore, integrating questioning strategies into the curriculum could significantly enhance the effectiveness of problem-based learning, fostering a more interactive and in-depth educational experience.

2. LITERATURE REVIEW

2.1 Problem-solving Thinking

Problem-solving skills in science learning involve the ability to identify, analyze, and find solutions to complex scientific issues (Adeoye & Jimoh, 2023; Karan & Brown, 2022). These skills encompass a systematic approach to understanding problems, generating hypotheses, experimenting, and drawing evidence-based conclusions. The principles of problem-solving in science include critical thinking, logical reasoning, creativity, and collaboration (Wismath & Orr, 2015). The benefits of developing problem-solving skills in science learning are manifold: students become more adept at tackling real-world problems, enhance their analytical abilities, and foster a deeper understanding of scientific concepts. These skills prepare students for future scientific endeavors and equip them with the tools necessary for innovation and progress in various scientific fields (Karan & Brown, 2022).

Thinking skills are integral to science learning as they enhance the ability to solve problems effectively (Santos, 2017; Sun et al., 2022). For example, critical thinking allows students to evaluate information and arguments, identifying biases and inconsistencies. Analytical thinking helps in breaking down complex problems into manageable parts and understanding their underlying principles. Creative thinking fosters innovation and the development of novel solutions. Reflective thinking encourages students to consider their thought processes and learning strategies, leading to continuous improvement. These thinking skills are crucial in problem-solving, as they enable students to approach scientific problems methodically, think outside the box, and refine their solutions based on reflective insights (García-Carmona, 2023).

Therefore, problem-solving thinking in science learning involves a structured approach to identifying and resolving scientific issues through critical, analytical, creative, and reflective thinking. By integrating these thinking skills, students can systematically address complex problems, generate innovative solutions, and continually improve their understanding and methodologies. The benefits of problem-solving thinking in science education are significant, as it not only enhances students' ability to tackle real-world scientific challenges but also prepares them for future careers in science and technology, fostering a more innovative and scientifically literate society (Snyder & Snyder, 2008).

2.2 Problem-based learning

At the core of Problem-Based Learning (PBL) is an authentic problem used to catalyze self-directed knowledge construction (Akcay, 2009; Barrett, 2017; Barrows, 1986; Savery, 2019). In PBL, learners engage in inquiry, where they must first understand the case, known as problem representation, and then develop solutions through iterative inquiry. This process involves seeking out information, sharing it with peers, and identifying areas of disagreement, which highlight additional knowledge gaps. As groups work to justify their positions and reconcile differences, they engage in meaning-making and develop a shared mental model (Ertmer & Koehler, 2019).

In contrast with a more lecture-based approach, PBL allows learners to engage in higher-order thinking skills as they synthesize diverse information sources with their peers. Research (Savery, 2019) specifically documents various problem-solving competencies fostered by PBL, such as causal reasoning, question generation, analogical reasoning, and decision-making. Additionally, the authentic nature of the cases used in PBL supports affective outcomes of motivation and self-efficacy (Ertmer & Koehler, 2019).

PBL's emphasis on real-world problems and collaborative inquiry not only improves problem-solving skills but also promotes critical, analytical, and reflective thinking. By engaging in PBL, students develop the ability to approach scientific problems methodically, think creatively, and refine their solutions based on reflective insights. This approach prepares students for future scientific endeavors and equips them with the tools necessary for innovation and progress in various scientific fields.

2.3 Previous studies

Previous studies (e.g., Fadilla et al., 2021; Kertiyani et al., 2022; Novak & Krajcik, 2019; Shamdas et al., 2023; Solomon, 2020; Theabthueng et al., 2022; Valdez & Bungihan, 2019) have found significant benefits of PBL in science education. In brief, the method benefits students' development of knowledge, thinking skills, and attitudes toward science learning. For instance, Fadilla et al. (2021) and Kertiyani et al. (2022) highlight the positive impact of PBL on critical thinking skills, indicating that students engaged in PBL exhibit enhanced abilities to analyze and evaluate information critically. Shamdas et al. (2023) show that a STEM-based PBL model in biology lessons significantly improves high school students' communication skills. Solomon (2020) compares PBL to lecture-based learning in nursing education and finds that PBL leads to better immediate knowledge retention. Valdez and Bungihan (2019) confirm that the PBL approach enhances high school students' problem-solving skills in chemistry. These studies underscore the versatility of PBL in promoting critical thinking, analytical skills, communication, and problem-solving abilities across diverse educational settings. Therefore, the current study applied the principles of PBL and integrated it with questioning strategies to design a learning management plan to improve the problem-solving thinking of Thai grade 11 students. The sole purpose of the study was to examine the effects of problem-based learning integrated with questioning strategies on Thai grade 11 students' problem-solving thinking.

3. METHOD

3.1 Research design

The research employed an Action Research design (Kemmis et al., 2014a, 2014b), following the PAOR cycle: Planning, Action, Observation, and Reflection, conducted in three cycles. In the Planning phase (P), the researcher identified problems related to students' problem-solving abilities, analyzed relevant curriculum and theories, and developed research tools, including lesson plans and various assessment instruments. These tools were refined based on feedback from thesis advisors and five experts. During the Action phase (A), problem-based learning lesson plans integrated with advanced questioning techniques were implemented with the target students. The Observation phase (O) involved monitoring learning activities and student behaviors, recording outcomes, and evaluating with tests and worksheets. In the Reflection phase (R), the researcher analyzed and evaluated the collected data to enhance learning management, revising lesson plans as needed and summarizing the findings to improve overall educational strategies. The current study repeats 3 PAOR cycle to ensure the effectiveness of the problem-based learning management with questioning strategies.

3.2 Participants

The participants consisted of 19 grade 11 students from a public school in Kalasin Province, during the second semester of the 2023 academic year. The students were selected through purposive sampling. The school is situated in a suburban area in a province ranked low in gross provincial product (Office of the National Economic and Social Development Council, 2023) and below average in national science education test scores (National Institute of Educational Testing Service, 2022). For background information, a multiple-choice test with 20 questions was administered to measure problem-solving ability. It was found that 19 students scored below the 70% threshold. These students were chosen as participants, and their scores were analyzed as the study results, while the entire class received similar instruction.

3.3 Research instruments

3.3.1 PBL with questioning strategy Learning management plan

The learning management plan was designed with a focus on classroom management principles (Evertson & Weinstein, 2006; Oliver & Reschly, 2007), utilizing problem-based learning (PBL) as the core approach, integrated with questioning strategies. This plan was implemented to teach the concepts of the digestive system in a biology course. The content covered various topics: Digestion in Animals without a Digestive Tract, Digestion in Animals with an Incomplete Digestive Tract, Digestion in Animals with a Complete Digestive Tract, Intracellular Digestion, Extracellular Digestion, Feeding in Hydra, Feeding in Planaria, Structure and Function of Organs in Mechanical and Chemical Digestion in Humans, and Structure and Function of Organs in Nutrient Absorption.

During learning activities, students were presented with problems related to these topics. For example, they were placed in scenarios such as explaining how an earthworm eats and digests food to a sibling who found one in the garden. Questioning strategies were emphasized, teaching students to ask the right questions to solve problems effectively. This included strategies like probing questions to explore deeper understanding, clarifying questions to remove ambiguities, and hypothetical questions to encourage creative thinking.

The learning management plan was evaluated for its appropriateness and received a very high rating from five scholars and professional teachers.

3.3.2 The problem-solving thinking test

The problem-solving thinking test consists of 3 sets, each containing 4 subjective questions. These questions are based on 5 everyday life scenarios, with 4 questions per scenario, totaling 20 questions. Scoring is conducted according to rubric assessment criteria. The Index of item objective congruence (IOC) of each item was 1.0 rated by 5 experts.

3.3.3 Interview form

A semi structure interview form was developed to examine the participants' opinions with the learning management. It was employed in each PAOR cycle. The question IOC was 1.0 rated by 5 experts.

3.3.4 Observation form

The student behavior observation form is used to observe the behaviors of individual target students regarding their problem-solving thinking during learning activities. Observations are conducted while the learning activities are taking place.

3.4 Data collection and data analysis

As the study was conducted using an action research design, three cycles of PAOR (Plan, Act, Observe, and Reflect) were established. The first cycle covered the topics of Digestion in Animals without a Digestive Tract, Digestion in Animals with an Incomplete Digestive Tract, and Digestion in Animals with a Complete Digestive Tract. The second cycle focused on Intracellular Digestion, Extracellular Digestion, and Feeding in Hydra. The final cycle addressed Feeding in Planaria, Structure and Function of Organs in Mechanical and Chemical Digestion in Humans, and Structure and Function of Organs in Nutrient Absorption.

Students' problem-solving thinking was evaluated at the end of each cycle. The learning management plan was revised at the end of cycles 1 and 2, based on student observations and reflections from their interviews. Quantitative data were analyzed using percentage, mean score, and standard deviation, with a 70% test score as the threshold. Qualitative data were analyzed using content analysis.

4. RESULT AND DISCUSSION

The results of the study indidcate the continuous improvement of students’ problem-solving thinking throught the learning cycles of PBL learning activities. The detail of each learning cycle is discussed below.

Table 1 The participants’ problem-solving thinking in the 3 PAOR cycles

Learning cycle	Student meeting the criteria		Student not meeting the criteria		Average score
	N	%	N	%	
1	9	42.11	11	57.89	75.13
2	14	73.68	5	26.32	83.22
3	19	100	0	0	79.84

4.1 Learning cycle 1

From the first cycle of the action research, where problem-based learning combined with questioning strategies was implemented for grade 11 students, several findings emerged. Firstly, most students were enthusiastic about the activities, as the teaching approach was student-centered rather than lecture-based. However, students still had doubts and did not fully understand the activities and questions. While students were able to independently search for information, some of the gathered information was inaccurate. Additionally, some students did not actively participate in the activities. Despite these issues, most students demonstrated strong problem-solving abilities, though a few did not exhibit these behaviors.

The problem-solving ability test results revealed that 11 students (57.89%) scored below the 70% threshold. The identified issues included a lack of student participation, reluctance to express opinions or ask questions, confusion due to inaccurate information sources, and unfamiliarity with the activity format.

To address these issues, several solutions were proposed. Teachers reinforced participation with rewards like points and prizes. Individual students were asked to write down problems instead of group writing to ensure everyone's participation. Teachers provided close guidance and recommended reliable information sources. Additionally, teachers familiarized students with the activity format, possibly by introducing group competitions. These measures aimed to enhance student engagement, improve understanding, and foster accurate information gathering.

4.2 Learning cycle 2

From the second cycle of the action research, similar methods were applied, yielding several notable findings. Firstly, student enthusiasm increased due to reinforcement techniques like group and individual points. There was also a reduced number of students with doubts about the activities and questions. Students continued to search for information independently, demonstrating self-reliance in their learning process. However, some students still did not participate actively, leading to point deductions as a penalty. Most students showed strong problem-solving behaviors throughout the cycle.

The problem-solving ability test results were encouraging, with fewer students (N=5) scoring below the 70% threshold. The identified issues included a lack of student participation, some students' misunderstanding of problem scenarios, and confusion between identifying the problem and its causes.

To address these issues, several solutions were proposed. Teachers set penalties or established agreements with students to ensure active participation. Each student was asked to write down key points from the problem scenarios to enhance individual engagement. Additionally, teachers explained the difference between problems and their causes to clear up any confusion. These measures aimed to further improve student understanding and participation in the learning activities.

4.3 Learning cycle 3

From the third cycle of the action research, the findings were as follows. Most students were enthusiastic due to the non-lecture-based and competitive nature of the activities. Students accurately searched for information independently, demonstrating improved research skills. Additionally, most students exhibited strong problem-solving abilities.

The problem-solving ability test results showed an average score of 79.84%, which was lower than in the second cycle but higher than in the first cycle. In this learning cycle, all the participants passed the threshold of 70%. The main issue identified was students' confusion between identifying problems and finding their causes. This suggests a need for techniques like mind mapping to help students visualize and prioritize problems, thereby enhancing their problem-solving skills.

Overall, the results show that PBL integrated with questioning strategies was effective in the current study. These findings align with previous studies (e.g., Fadilla et al., 2021; Kertiyani et al., 2022; Novak & Krajcik, 2019; Shamdas et al., 2023; Solomon, 2020; Theabthueng et al., 2022; Valdez & Bungihan, 2019), which also highlighted the benefits of PBL in science education. In this study, students developed their knowledge of digestive systems, improved their thinking and problem-solving skills, and were motivated by learning through PBL. The integration of questioning strategies within the PBL framework further enhanced students' engagement and deepened their understanding by prompting them to think critically and explore the subject matter more thoroughly. This approach not only fostered a more active learning environment but also encouraged students to take ownership of their learning process, thereby leading to more meaningful and lasting educational outcomes.

Problem-Based Learning (PBL) is effective because it engages students in active learning, making them the central focus of the educational process. By tackling real-world problems, students apply their knowledge in practical scenarios, which enhances their understanding and retention of scientific concepts (Ertmer & Glazewski, 2019; Savery, 2019). PBL encourages critical thinking, collaboration, and self-directed learning, as students must research, discuss, and propose solutions to complex problems. This method also fosters intrinsic motivation, as students find the problem-solving process engaging and relevant to their lives.

Integrating questioning strategies into PBL enhances its effectiveness by guiding students through the inquiry process. Questioning strategies help students develop higher-order thinking skills by encouraging them to ask probing, clarifying, and reflective questions. This not only deepens their understanding of the subject matter but also helps them identify gaps in their knowledge and think critically about the information they encounter (Newton et al., 2018; Sun et al., 2022). Moreover, effective questioning promotes active participation and dialogue, allowing students to articulate their thoughts, challenge assumptions, and build on each other’s ideas. These interactions are crucial for developing a collaborative learning environment where students can collectively solve problems and construct knowledge.

5. CONCLUSION

The study was conducted to examine the effects of problem-based learning (PBL) integrated with questioning strategies on grade 11 students' problem-solving thinking in the Thai educational context. The study involved three learning cycles, each following the stages of planning, action, observation, and reflection. The results indicate positive effects of the instructional method on the participants' knowledge, thinking skills, and attitudes toward science learning.

The findings of this study have significant implications for educational practice in Thailand and beyond. Integrating PBL with questioning strategies can enhance students' engagement, critical thinking, and problem-solving skills. Educators should consider adopting this approach to create more interactive and student-centered learning environments. Additionally, curriculum developers might incorporate PBL frameworks to promote deeper understanding and application of scientific concepts. The success of this study suggests that similar methods could be beneficial in other subjects and educational settings, potentially leading to overall improvements in educational outcomes.

Despite the positive outcomes, this study has several limitations. The sample size was relatively small, which may limit the generalizability of the findings. Furthermore, the study did not include perspectives from teachers, parents, or administrators, which could provide a more comprehensive understanding of the intervention's impact. Future research should consider larger, more diverse samples and incorporate feedback from various stakeholders to validate and expand upon these findings. Including teacher perspectives would offer insights into the practical challenges and benefits of implementing PBL with questioning strategies, while input from parents and administrators could help identify additional areas of support and improvement for broader adoption.

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