

Enhancing Pre-service Teachers' Scientific Inquiry Questioning through Generative AI-Supported Scaffolding

Pawinee Rattanakorn¹, Jadsada Ratniyom¹ & Pattamaporn Kaewkhongkha²

¹Department of Science Education, Faculty of Education, Suan Sunandha Rajabhat University, Thailand

²Science and Technology, Demonstration School, Suan Sunandha Rajabhat University, Thailand

Correspondence: Pawinee Rattanakorn, Department of Science Education, Faculty of Education, Suan Sunandha Rajabhat University, Thailand. E-mail: pawinee.ra@ssru.ac.th

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Abstract

This study examined pre-service science teachers' scientific inquiry questioning ability and the types of inquiry questions generated before and after participating in learning activities using an AI-supported scaffolding strategy. A one-group pretest-posttest design was employed. The research instruments consisted of (1) learning activities using an AI-supported scaffolding strategy, (2) a situational assessment of scientific inquiry questioning ability, and (3) criteria for evaluating scientific inquiry questions. The findings revealed that students' scientific inquiry questioning ability improved from a moderate level before the intervention to a high level after the intervention, with the difference being statistically significant at the .05 level. In addition, the predominant type of students' questions shifted from reasoning questions before the intervention to predictive or forecasting questions after the intervention. Students also reported that AI-generated feedback, together with instructor guidance, helped them identify weaknesses and refine their scientific inquiry questions. These findings suggest that AI-supported scaffolding can serve as a practical approach for supporting pre-service science teachers and science educators in designing learning activities that promote scientific inquiry in 21st-century classrooms.

Keywords: AI-enhanced learning, inquiry-based learning, instructional scaffolding, questioning abilities

1. Introduction

1.1 Introduce the Problem

Science education in the 21st century emphasizes learning environments that enable students to construct knowledge and develop new ideas through cognitive and social interactions. In this context, teachers are expected to act as facilitators by designing learning experiences that accommodate students' interests, abilities, and learning needs (Rattanaanya, Dechpanprasong, & Chaiyaphan, 2023). Questioning is one of the most important instructional strategies for stimulating students' thinking and supporting knowledge construction. Ainscow (2000) reported that constructive questioning increases students' participation during classroom learning, while continuous questioning encourages learners to remain actively engaged throughout the lesson. Therefore, questioning and responding are fundamental components of effective teaching and learning and play an important role in supporting both active learning and 21st-century learning.

Questioning is particularly important at the beginning of a lesson because it stimulates curiosity and motivates students to engage in learning. Well-designed questions can encourage learners to explore new ideas and sustain their interest throughout the learning process (Hankuttum, Selosreechai, & Kenaphoom, 2023). In science education, questioning also supports classroom discussion and argumentation, helps teachers assess students' understanding, and guides scientific inquiry. Effective questions are generally open-ended, allowing learners to connect prior knowledge with new ideas and consider multiple possible explanations rather than simply identifying a single correct answer. Consequently, the types of questions teachers ask can substantially influence students' participation, critical thinking, and higher-order knowledge construction (Chin, 2007; Jituafoa, 2018; Morris & Chi, 2020).

The importance of questioning has been demonstrated across different educational levels. Hanwong and Jittakoat (2019) reported that lower secondary science teachers frequently used open-ended questions to encourage student participation, stimulate interest, and promote analytical thinking. Likewise, Akilli and Kingir (2021)

found that higher-order open-ended questions encouraged elementary students to participate in classroom discussions and express their own perspectives. To encourage students to engage in scientific inquiry, teachers need to be able to formulate questions that promote investigation rather than simple recall. However, previous studies have shown that teachers often ask a large number of questions during instruction, which may reduce opportunities for meaningful learning and student participation (Forster, Penny, & Shalofsky, 2019, citing Wood, 1998; Almeida, 2012). In particular, factual and closed-ended questions that require only one correct answer provide limited opportunities for students to explore ideas, develop explanations, or engage in scientific inquiry. Similarly, Christidou et al. (2025) found that in-service teachers teaching early childhood science relied more on factual and closed-ended questions than on open-ended questions, limiting students' opportunities to develop analytical thinking and construct their own explanations. Germann, Haskins, and Auls (1996) likewise reported that most questions in science classrooms originated from teachers or structured worksheets, leaving students with little opportunity to design investigations or generate their own inquiry questions.

These findings highlight the need to strengthen scientific inquiry questioning ability among pre-service science teachers. As future science teachers, they need to be able to formulate effective inquiry questions that encourage students to investigate scientific phenomena, construct evidence-based explanations, and participate actively in inquiry-based learning.

1.2 Conceptual Framework and Scaffolding Strategy

The scaffolding strategy is an instructional approach that provides learners with appropriate support according to their level of development and learning needs. This concept is grounded in Vygotsky's (1978) theory of the Zone of Proximal Development (ZPD), which distinguishes between what learners can accomplish independently and what they can achieve with appropriate guidance. The distance between these two levels represents the learner's ZPD and varies across individuals. Through support from more knowledgeable others, such as teachers, peers, or mentors, learners are able to gradually develop their cognitive abilities and become more independent in constructing knowledge (Panhwar et al., 2025). Previous studies have shown that scaffolding is effective in helping teachers design and implement inquiry-based instruction that supports students in achieving their learning goals (Simons & Klein, 2007; van der Valk & de Jong, 2009).

1.3 AI-Supported Scaffolding in Educational Contexts

Artificial intelligence (AI) has increasingly been adopted as a scaffolding tool to provide adaptive guidance, personalized feedback, and instructional support. AI-supported scaffolding enables learners to receive timely assistance during complex tasks while gradually reducing support as their understanding develops (Azevedo et al., 2022; Akram et al., 2025). Ng, Tan, and Leung (2024) reported that generative AI supports students' understanding of scientific concepts by providing explanations, examples, and interactive guidance. Similarly, Ratniyom et al. (2025) found that Microsoft Copilot enhanced students' scientific explanations by helping them connect scientific concepts with real-world phenomena. Lee & Zhai (2024) also showed that intelligent tutoring systems improve student engagement by providing timely and individualized feedback. However, previous studies have focused primarily on conceptual learning and problem solving, whereas the use of AI-supported scaffolding to foster higher-order scientific practices, particularly scientific inquiry questioning, has received limited attention.

1.4 Scientific Inquiry Questioning: Existing Interventions and Research Gap

The ability to formulate investigable questions is a fundamental practice in scientific inquiry. Previous studies have explored a range of instructional approaches, including teacher questioning, prompt-based scaffolding, inquiry-based learning, peer discussion, and structured question-generation activities, to strengthen students' questioning ability. Herranen and Aksela (2019) reported that student-question-based inquiry increases engagement in scientific inquiry but requires sustained teacher guidance to help students formulate and refine investigable questions. Likewise, Chin (2007) showed that teacher questioning scaffolds students' thinking, whereas Pedrosa-de-Jesus et al. (2016) found that structured opportunities for question generation improve the quality of students' questions.

Although these approaches are effective, they rely heavily on teacher facilitation and individualized feedback, making them difficult to sustain in large classrooms. Recent studies have suggested that AI-supported scaffolding can provide adaptive guidance and timely feedback during learning. For example, Lee and Zhai (2024) found that ChatGPT supported pre-service teachers' science learning by providing explanations and instructional guidance, while Cheung et al. (2025) highlighted the growing role of generative AI in delivering personalized learning support in science education. However, little research has examined how AI-supported scaffolding can assist students in constructing, evaluating, and refining scientific inquiry questions.

To address this gap, the present study develops and evaluates an AI-supported scaffolding strategy that positions AI as a questioning facilitator rather than an answer provider. By integrating AI-generated feedback with instructor guidance, the proposed approach is intended to support pre-service science teachers in developing and refining scientific inquiry questions. In addition, this study provides empirical evidence that AI-supported scaffolding can enhance scientific inquiry questioning ability and encourage the development of more advanced inquiry questions, particularly predictive questions. The findings offer practical guidance for integrating AI-supported scaffolding into science teacher education and inquiry-based science instruction.

2. Research Objectives

This study aimed to compare pre-service science teachers' scientific inquiry questioning ability before and after participating in learning activities supported by an AI-integrated scaffolding strategy. It also examined the types of scientific inquiry questions generated before and after the intervention.

3. Method

3.1 Participants

The participants were 19 third-year pre-service science teachers majoring in General Science in the Faculty of Education at a university in Bangkok, Thailand, who were enrolled in the second semester of the 2025 academic year. The sample consisted of 4 male and 15 female students selected through purposive sampling. All participants voluntarily agreed to participate in the study and met the predetermined selection criteria.

3.2 Research Design

This study employed a one-group pretest-posttest design in which all participants received the intervention as part of their regular course. Therefore, no control group was included.

3.3 Instruments and Procedures

Three research instruments were used: (1) learning activities based on an AI-supported scaffolding strategy to enhance students' scientific inquiry questioning ability; (2) a scenario-based assessment requiring students to generate scientific inquiry questions; and (3) a three-level scoring rubric that evaluated the quality of the questions in terms of investigability, clarity of variables and measurement, relevance and significance, level of analysis, and feasibility.

The researcher collected and analyzed students' scientific inquiry questioning ability scores before and after the implementation of learning activities using an AI-supported scaffolding strategy. The intervention was conducted over three weeks, with four hours of instruction per week, for a total of 12 hours. The research procedure consisted of three phases.

Phase 1: Assessment of students' initial scientific inquiry questioning ability. Before the learning activities, students completed a scenario-based assessment (Situation A: Laboratory Contamination Problem) to examine their ability to generate scientific inquiry questions based on their prior knowledge and experience.

Phase 2: Learning activities to promote scientific inquiry questioning using an AI-supported scaffolding strategy. AI was used to provide feedback throughout the learning process. The activities were based on Situation B: Sweetened Condensed Milk Quality Control and consisted of four stages.

Stage 1: Providing initial conceptual understanding. The instructor used a scaffolding strategy to help students develop a clear understanding of the characteristics of effective scientific inquiry questions and the types of questions that lead to scientific investigation. The instructor explained the scientific inquiry process, the characteristics and types of scientific inquiry questions, and the evaluation criteria developed by the researcher. Examples of both effective scientific inquiry questions and questions that did not qualify as scientific inquiry questions were then presented. Students participated in discussions to distinguish different types of questions, analyze them, and evaluate them using the established criteria. Finally, the class reviewed and discussed the evaluation results together.

Stage 2: Practising scientific inquiry question generation. Students practised generating scientific inquiry questions based on a given situation with initial guidance from the instructor. Students with different levels of questioning ability were randomly assigned to groups of 3-4 members. They studied Situation B: Sweetened Condensed Milk Quality Control and worked together to generate scientific inquiry questions. Each student was required to generate two scientific inquiry questions. Throughout the activity, the instructor provided guidance and feedback to both groups and individual students. The feedback focused on helping students revise questions that did not meet the characteristics of scientific inquiry questions so that they could be refined to meet the established criteria.

Stage 3: Providing feedback using artificial intelligence. Students received individual feedback from AI based on the established evaluation criteria. During this stage, students used ChatGPT (GPT-4o version, OpenAI) through its standard web interface under the default settings (temperature approximately 0.7) to evaluate their scientific inquiry questions using the assessment rubric. To ensure that AI functioned as an evaluation scaffold rather than an answer provider, students began each session with the following standardized prompt: *"You are an expert at evaluating scientific inquiry questions. Your job is to provide me ideas for how to make my question better based only on the criteria given. You are not allowed to make up new questions for me. Please look at my question and suggest ways to improve it instead."* ChatGPT then reviewed each question, identified areas for improvement, and provided feedback based on the criteria presented in Table 1.

To ensure that AI was used only to provide evaluative feedback rather than generate questions, three measures were adopted.

- **Instructional guidance:** Before the activity, the instructor explained the academic integrity guidelines and emphasized that AI should be used only as a feedback tool.
- **In-class monitoring:** The activity was conducted during class, allowing the instructor to monitor students' screens and ensure that the prompting protocol was followed.
- **Transcript auditing:** Students submitted their complete ChatGPT conversation histories together with their revised questions. The researchers reviewed these records to confirm that students had not requested AI to generate questions directly and that AI had been used only as an evaluation tool.

Stage 4: Question revision and reflection. Students revised their questions based on AI feedback and reflected on the revision process. Each student revised their scientific inquiry questions using the feedback provided by AI together with the knowledge gained from Stages 1 and 2. Students then worked in groups to discuss and analyze their revised questions and selected the best scientific inquiry question from each group member. They were also asked to explain the reasons for revising their questions. Finally, the instructor concluded the activity by asking reflective questions about students' experiences of using AI to improve their scientific inquiry questions.

The assessment used to evaluate students' scientific inquiry questioning ability was developed using the topic Differences Between Boiling Point and Melting Point, which is included in the Grade 7 science curriculum and is one of the topics that the participants are expected to teach during their teaching practice. Three situational scenarios related to the boiling points and melting points of pure substances and mixtures were developed. For each scenario, students were required to generate two scientific inquiry questions that could lead to an investigation of the problem presented.

Scenario A: Laboratory Contamination Problem

A chemistry laboratory has a sample of Substance A, a pure organic compound with a melting point of 110.0 °C. However, when the sample was tested using a melting point apparatus, it began to melt at 105.0 °C and melted completely at 108.5 °C. During the melting process, the temperature continued to increase.

Problem: The sample of Substance A is suspected to be contaminated with a small amount of Substance B, which may affect subsequent experiments in the research project.

Scenario B: Sweetened Condensed Milk Quality Control

The main components of sweetened condensed milk are water, sugar, and fat. During production, the manufacturing plant must carefully control product quality, particularly the water content, because it directly affects the shelf life and quality of the final product. During quality inspection, the boiling point of the product was expected to range from 105 °C to 108 °C because sugar is the main solute in the solution. However, in some production batches, the boiling point reached 112 °C, which was considerably higher than the standard value. In addition, the temperature continued to increase gradually during boiling instead of remaining constant.

Problem: It is hypothesized that the unusually high boiling point may result from an excessively high sugar concentration or the addition of other additives in incorrect proportions.

Scenario C: Quality Control of a Metal Sample

An electronics manufacturing company received a metal sample that should be a pure substance with a constant melting point of 217 °C. However, when samples supplied by a new manufacturer were tested, the material began to melt at 215 °C and melted completely at 220 °C. During the melting process, the temperature gradually increased over a range of 5 °C.

Problem: The broad melting temperature range suggests that the sample is not a pure substance but contains

impurities or other metals, which may affect the manufacturing process and reduce product quality.

Phase 3: Assessment of students' scientific inquiry questioning ability after the implementation of the learning activities using the AI-supported scaffolding strategy in Scenario C: Quality Control of a Metal Sample.

The assessment criteria for scientific inquiry questioning ability consisted of a three-level rating scale covering five components of scientific inquiry questions: (1) investigability (the extent to which a question can be investigated experimentally), (2) clarity of variables and measurement, (3) relevance and significance, (4) level of analytical thinking, and (5) feasibility and resources, as shown in Table 1.

Table 1. Criteria for assessing scientific inquiry questioning ability

Component		Level		
		3 (Good)	2 (Moderate level)	1 (Needs improvement)
Ability to investigate		The question clearly promotes data collection design or experimental procedures. Variables can be managed or controlled to obtain empirical evidence	The question can lead to an investigation. The method still unclears or requires minor revision	The question is a general knowledge question or required theoretical explanation
Clarity of variables and measurement		The question clearly identifies the variables that would be studied and their scope. The answers could be measured or observed quantitatively or qualitatively	The question includes the main variables but lacks specific details or the measurement method is unclear	The variables are incompletely indicated or unclear making it impossible to determine what should be measured or compared
Relevance / significance		The question is crucial or related to the main concept. It stimulates curiosity or challenge.	The question is related to the main topic but it is very common, not challenging, or not leading to new discoveries	The question is not directly related to the main concept/problem or it is the question that already has an answer.
Level of analytical thinking		Questions encourage deep analytical thinking (e.g. establishing quantitative relationships, predictions, data interpretation, or developing framework)	Questions stimulate comparison or investigation of relationships between factors/variables require analytical thinking	Questions focus on identifying or explaining basic phenomena and do not demonstrate higher-order thinking
Feasibility and resources		Questions are feasible within the available timeframe and resources, are safe and adhere to ethical standards	The question is feasible. However, it may require considerable equipment or resources, or involve minor risks	The question is not practically feasible due to limitations in equipment, time, or it could be that it involves safety or ethical risks.

Score Interpretation

Scores of 12-15 indicate a high level of ability in generating scientific inquiry questions.

Scores of 8-11 indicate a moderate level of ability in generating scientific inquiry questions.

Scores of 0-7 indicate that improvement is required or that the student is unable to generate scientific inquiry questions.

3.4 Instruments Development

The research instruments were reviewed by three experts in lower secondary science education and educational evaluation to examine their content validity. The item-objective congruence (IOC) values ranged from 0.67 to 1.00, exceeding the acceptable criterion of 0.50. The instruments were then pilot-tested with 15 participants who had characteristics similar to those of the study sample. The scoring rubric demonstrated good internal consistency (Cronbach's $\alpha = .747$). Inter-rater reliability between two independent raters was assessed using the intraclass correlation coefficient (ICC), indicating excellent agreement (ICC = .948, 95% CI [.846, .983], F (14,

14) = 18.27, $p < .001$). Both raters independently evaluated all student responses using the same scoring rubric. Before scoring, they participated in a calibration session to ensure a common understanding of the evaluation criteria. Any scoring discrepancies were subsequently discussed until consensus was reached, and the agreed scores were used for data analysis.

Students' scientific inquiry questioning ability was assessed using the evaluation criteria developed by the two researchers, consisting of the principal researcher and an experienced science teacher. Each researcher independently evaluated the same set of student responses. The scores were then compared and discussed until agreement was reached for each component of the evaluation criteria, and the final consensus scores were used in the analysis.

3.5 Data Analysis

The quantitative data were analyzed using the scores obtained from the scientific inquiry questioning ability assessment administered before and after the learning activities. The results of the Shapiro-Wilk test indicated that both the pretest (Shapiro-Wilk = .920, $p = .113$) and posttest scores (Shapiro-Wilk = .956, $p = .488$) were normally distributed. Therefore, a paired-samples t-test was conducted to compare students' scientific inquiry questioning ability before and after the learning activities at the .05 level of significance.

The questions generated by the students before and after the learning activities were then analyzed and classified into two categories: (1) non-scientific inquiry questions and (2) scientific inquiry questions. The latter included five types: (1) comparative questions, (2) reasoning questions, (3) predictive questions, (4) design or invention questions, and (5) exploratory questions. The percentage of each question type was calculated and compared before and after the learning activities.

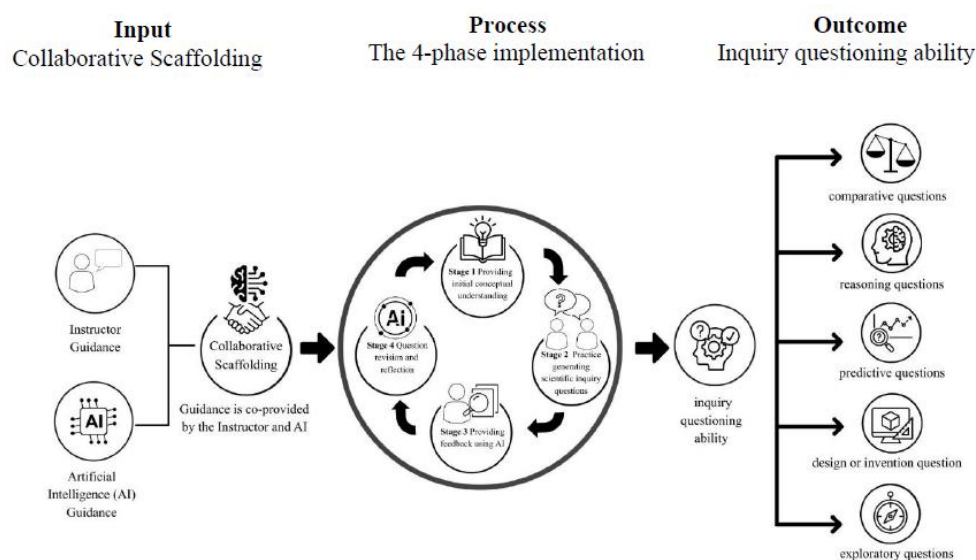


Figure 1. Scaffolding strategy integrated with artificial intelligence (AI)

4. Results

Students' scientific inquiry questioning ability before and after the implementation of the learning activities was compared. Table 2 presents the mean scores and the levels of students' scientific inquiry questioning ability before and after the learning activities.

Table 2. Students' scientific inquiry questioning ability before and after the learning activities

Level of ability	Number of Learners (n = 19)	
	Before learning activities	After learning activities
Good level (12-15 points)	2 (10.52%)	11 (57.89%)
Moderate level (8-11 points)	9 (47.37%)	8 (42.11%)
(Needs improvement) (0-7 points)	8 (42.11%)	-
Total	19 (100%)	19 (100%)
Mean ($\bar{x}$)	8.55	12.00
Standard Deviation (S.D.)	2.09	1.87

Students' scientific inquiry questioning ability before the implementation of the learning activities ($n = 19$) is presented in Table 2. The results showed that 2 students (10.52%) demonstrated a high level of scientific inquiry questioning ability, 9 students (47.37%) achieved a moderate level, and 8 students (42.11%) required improvement or generated questions that were not considered scientific inquiry questions. The mean score was 8.55 (S.D. = 2.09). An analysis of the question types indicated that most were closed-ended questions requiring factual knowledge or information from the given situation (Student 1 = N01). For example:

N06: *"At what temperature does substance A melt?"*

N10: *"Regarding the sample data, at what temperature does melting begin?"*

After the implementation of the learning activities, students' scientific inquiry questioning ability improved. The results showed that 11 students (57.89%) demonstrated a high level of scientific inquiry questioning ability, while the remaining 8 students (42.11%) achieved a moderate level. No students remained in the improvement-needed category or generated non-scientific inquiry questions. The mean score increased to 12.00 (S.D. = 1.87). An analysis of the questions showed that students generated both closed-ended and open-ended questions. The open-ended questions encouraged learners to express their ideas and explore scientific inquiry to obtain answers. For example:

N01: *"Will adding more impurities to the lead make the range of melting temperature become wider than 5°C?"*

N16: *"How does an increase in concentration of the impurity affect the melting rate?"*

A comparison of students' scientific inquiry questioning ability before and after the learning activities was conducted using a paired-samples t -test at the .05 level of significance. The results are presented in Table 3.

Table 3. Comparison of students' scientific inquiry questioning ability before and after the learning activities

Score	df	$\bar{x}$	S.D.	t-test	p-value
before learning activity	18	8.55	2.09	5.03	< .001
after learning activity	18	12.00	1.87		

The mean score after the implementation of the learning activities using the AI-supported scaffolding strategy was significantly higher than that before the implementation. The posttest mean score was 12.00, compared with 8.55 for the pretest. The difference was statistically significant ($t(18) = 5.03$, $p < .001$). The effect size was large (Cohen's $d = 1.15$, 95% CI [0.69, 2.08]), indicating a meaningful improvement in students' scientific inquiry questioning ability. Examples of students' questions generated before and after the learning activities are presented in Table 4.

Table 4. Examples of students' scientific inquiry questions before and after the learning activities

Question	Scientific Inquiry Questions		Level of ability
	Yes	no	
Scenario A: Laboratory Contamination Problem. (pretest)			
How does contamination affect the melting point of substance A?	✓		Moderate level. (The question lacks clarity on how to investigate and encourages finding relationships between variables.)
Does the storage temperature of substance A affect contamination?	✓		Moderate level. (The verification method is unclear and time constraints)
Why do pure substances have a constant melting point?		✓	Needs to be improved. (Ask about definitions/theories)
What is the standard melting point of substance A?		✓	Moderate level. (Ask for raw information from the search)
If you want to prevent contaminants, what should you do?		✓	Moderate level. (Guideline Questions)
Scenario C: Quality control of Metal Sample. (posttest)			
If the mass is the same. Pure metals or alloys are completely melted first.	✓		Good Level. (Questions visualize the experiment clearly)
If you switch from lead to antimony. Can the melting point be lower?	✓		Good Level. (Specific variables can be identified, making data collection accurate)
Does heating faster narrow the melting range of the substance?	✓		Good Level. (Challenge to design an experiment)
If the contaminants increase by 2 times, the melting point will decrease by a few degrees.	✓		Good Level. (Questions focus on analytical thinking. Specify to find the quantity)

The analysis of students' questions before the learning activities showed that they generated both scientific inquiry questions and non-scientific inquiry questions. Most of the questions classified as scientific inquiry questions were rated at a moderate level because they lacked some components required for well-developed inquiry questions. For example:

N01: *"How does contamination affect the melting point of substance A?"* This question could be investigated; however, it lacked clarity regarding the investigation process and the specific variables involved (e.g., the degree of contamination was not specified). In addition, it did not encourage deeper analytical thinking or the generation of new knowledge.

N09: *"Does storage temperature affect the contamination of substance A?"* This question could also lead to an investigation; however, it lacked clarity regarding the research procedure and the specific variables involved (e.g., the temperature range was not specified). In addition, the investigation may have been limited by the time required to conduct the study, as it could take a long period to obtain results.

After analyzing students' questions following the implementation of the learning activities, the results showed that all questions generated by students were scientific inquiry questions, and most contained the essential components of well-developed inquiry questions. For example:

N01: *"If masses are equal, will pure metal or alloy melt first?"*

N19: *"If the amount of contamination is increased twofold, by how many degrees will the melting point decrease?"*

Scientific inquiry questions generated by students that were rated at a high level before and after the learning activities were classified into five categories: comparative questions, reasoning questions, predictive questions, design or invention questions, and exploratory questions. The results showed that before the learning activities, students generated two high-level scientific inquiry questions, both of which were classified as reasoning questions: "Do contaminations cause changes in the melting point of substance A, and how do these changes occur?" and "How does contamination affect the melting point of substance A?"

After the implementation of the learning activities, students generated 11 scientific inquiry questions rated at a high level. Most of these questions were predictive or forecasting questions, such as "If we pull the cooled alloy with the same force applied to pure metal, will the welded joint break first?" and "If more lead contamination is

added, will the melting temperature range become wider than 5 °C?”

Students' questioning processes during the activity were also analyzed by asking them to generate scientific inquiry questions based on Situation B: quality control of sweetened condensed milk, in order to examine the development of their questioning ability. The results showed that during group activities (before implementing the knowledge-scaffolding strategy with AI), students engaged in brainstorming to generate group questions. However, most of the questions were fact-checking questions, questions with predetermined answers, or questions that could only be answered through initial observations. For example:

N03: *“How many main components are contained in sweetened condensed milk products?”*

N14: *“Is the measured boiling point of 112 °C higher than the standard value?”*

After receiving feedback and AI-assisted guidance to support their understanding of how to generate scientific inquiry questions, students were able to produce a greater number of such questions, as illustrated in the following examples:

N03: *“When sweetened condensed milk products are examined, how many types of substances can be identified in the product, and how do their properties differ?”*

N14: *“What factors affect the deviation of the measured boiling point of a substance, and how can these factors be investigated?”*

Students' reflections on the use of artificial intelligence technology to improve the quality of their questions highlighted the benefits of AI in providing suggestions for question improvement, as shown in the following examples:

N07: *“AI helps determine whether my question qualifies as a scientific inquiry question and what needs to be done to generate a good scientific inquiry question.”*

N10: *“AI evaluated my question using the evaluation criteria and gave it a very low score. It then suggested how it should be revised, which helped me generate questions more quickly.”*

N13: *“The teacher's instruction helped me understand the types of scientific inquiry questions, and when AI was integrated, my questions received higher evaluation scores according to the criteria.”*

5. Discussion

This study examined the development of scientific inquiry questioning ability among third-year general science students through learning activities using an AI-supported scaffolding strategy. The findings revealed that students' questioning ability significantly improved after the intervention. This improvement can be explained by Vygotsky's concept of the Zone of Proximal Development, which suggests that learners can develop higher cognitive abilities through appropriate support from more knowledgeable others (Xi & Lantolf, 2020). In this study, the instructor and AI functioned as scaffolding agents by providing guidance, feedback, and suggestions that supported students in developing more advanced scientific inquiry questions.

Before the intervention, most students generated questions that focused on reasoning or retrieving information from the given situations rather than questions that could lead to scientific investigation. This finding suggests that students initially had difficulties identifying relevant variables and transforming observations into investigable questions. The result is consistent with Chin (2007), who reported that many questions used in science classrooms emphasize factual knowledge and predetermined answers rather than promoting higher-order thinking. Similarly, Khumraksa and Vichaidit (2024) found that teachers frequently used closed-ended questions, which limited students' opportunities to develop scientific inquiry thinking.

After implementing the AI-supported scaffolding strategy, students demonstrated improved scientific inquiry questioning ability. This improvement may have resulted from the integration of instructor guidance and AI feedback throughout the learning process. At the beginning of the intervention, the instructor supported students by explaining the characteristics of scientific inquiry questions and providing feedback on their initial questions. Subsequently, AI was introduced as an additional scaffold to help students review, evaluate, and refine their questions.

The development of students' questioning ability through AI-supported scaffolding may be explained by three main processes. First, AI provided immediate feedback that helped students identify limitations in their questions, such as unclear variables or insufficient investigability. Second, AI supported the refinement process by encouraging students to transform general questions into more specific and testable scientific questions. Third, AI provided adaptive support based on students' individual needs, enabling them to gradually develop

independent questioning abilities. These processes reflect the principle of fading scaffolding, in which support is gradually reduced as learners gain greater competence and independence (Molenaar, 2022; Knoop-van Campen et al., 2024; Lämsä et al., 2025).

The findings are consistent with previous studies on AI-supported learning. Akram et al. (2025) found that AI-assisted scaffolding enhanced students' problem-solving abilities and metacognitive awareness by providing timely feedback and supporting self-regulated learning. Similarly, Ng, Tan, and Leung (2024) reported that generative AI supported science learning through explanations, examples, and interactive guidance. In the present study, students reflected that AI feedback was convenient and helped them identify weaknesses in their questions and make improvements. These findings suggest that AI can function as a complementary learning tool that extends instructional support rather than replacing the role of the teacher.

Changes were also observed in the types of scientific inquiry questions generated by students. Before the intervention, most questions were classified as reasoning questions, whereas predictive or forecasting questions became more prevalent after the intervention. This shift indicates that students developed a greater ability to anticipate relationships among variables and consider possible scientific explanations. Predictive questions encourage learners to activate prior knowledge and construct explanations, thereby supporting deeper learning (Fiorella & Mayer, 2016). This finding is consistent with Brod et al. (2018) and Brod (2021), who reported that prediction-based activities enhance student engagement and conceptual understanding. Similarly, Smith and Holmes (2019) found that prediction activities conducted before learning improved students' engagement and learning outcomes.

Although the findings indicate the potential of AI-supported scaffolding, several limitations should be considered. First, the one-group pretest-posttest design without a control group limits the ability to determine whether the observed improvement was solely attributable to the intervention. Other factors, including testing effects, maturation, or additional learning experiences during the three-week intervention period, may have contributed to the results. Second, the relatively short duration of the intervention limits conclusions regarding the long-term development and sustainability of students' questioning ability. Regarding external validity, the participants were third-year pre-service science teachers from a single institution; therefore, the findings may not be directly generalizable to other populations, such as secondary students or in-service teachers. Future studies involving comparison groups, larger samples, and diverse educational contexts are needed to further examine the effectiveness and applicability of AI-supported scaffolding.

The findings also provide practical implications for science teacher education. AI-supported scaffolding can be integrated into science methods courses to provide pre-service teachers with opportunities to practice developing, evaluating, and refining scientific inquiry questions before implementing inquiry-based learning in real classroom settings. However, teacher educators should continue to play an important role in guiding students to critically evaluate AI-generated feedback and use AI appropriately as a learning support tool.

Future research should further investigate how different forms of AI scaffolding influence the development of scientific inquiry questioning ability. Comparative studies examining AI-only support, teacher scaffolding, and combined AI-teacher scaffolding could provide deeper insights into the effectiveness of each approach. In addition, future studies should examine long-term learning outcomes and analyze learner-AI interactions to identify effective prompting strategies for supporting scientific inquiry practices.

6. Conclusion and Implications

The learning activities developed in this study enhanced students' scientific inquiry questioning ability. The findings indicated that before the implementation of the learning activities, most students demonstrated a moderate level of scientific inquiry questioning ability, while some still required improvement or generated questions that were not considered scientific inquiry questions. Most of the questions generated at this stage were closed-ended questions that focused on assessing prior knowledge or retrieving information from the given situations.

After participating in the learning activities, students were able to revise their questions into higher-level scientific inquiry questions. Furthermore, the types of scientific inquiry questions generated by students changed from mainly reasoning questions before the intervention to predictive or forecasting questions after the intervention, which reflected the development of higher-order thinking. These findings suggest that the learning activities integrating a knowledge-scaffolding strategy with artificial intelligence technology, in which the instructor and AI collaboratively provided feedback, effectively supported the development of students' ability to generate scientific inquiry questions.

Suggestions

This study examined the effects of learning activities using a knowledge-scaffolding strategy combined with artificial intelligence technology on students' scientific inquiry questioning ability. However, the intervention was conducted within a limited period of three weeks (12 hours), and the situations used for generating questions were aligned with the learning indicators for Grade 7 students. Therefore, future implementation should incorporate a wider range of situations that are relevant to students' contexts and appropriate for the educational level being taught in order to further promote students' ability to generate scientific inquiry questions.

Future research should include a delayed posttest to determine whether improvements in students' scientific inquiry questioning ability are maintained over time. Such an approach would provide evidence regarding the sustainability of learning outcomes beyond the immediate post-intervention period. In addition, employing a control or comparison group would strengthen the internal validity of the study and provide stronger evidence for evaluating the effectiveness of AI-supported scaffolding.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors initially drafted the entire content in Thai. The manuscript was edited using ChatGPT and QuillBot in order to improve language correctness and structure. After using this tool/service, the authors thoroughly reviewed and verified the final version of our work. AI tools were used strictly for language editing and did not influence the research data or our conclusions. We, the authors, have meticulously reviewed and verified every aspect of this content, and we take full responsibility for its accuracy and integrity.

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Authors contributions

Asst. Prof. Dr. Pawinee Rattanakorn was responsible for the study design, conducting the research, and performing the literature review. Assoc. Prof. Dr. Jadsada Ratniyom contributed to the development of the research instruments and data analysis, while Dr. Pattamaporn Kaewkhongkha assisted in data analysis and the interpretation of the results. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed consent

Obtained.

Ethics approval

This research received ethical approval from Suan Sunandha Rajabhat University (COE.2-011/2026). Participants were fully informed about the scope of the study and data confidentiality prior to providing written informed consent. To ensure strict anonymity at every stage, this research assigned codes to replace individual identifiers.

Provenance and peer review

Not commissioned; externally double-blind peer reviewed

Data availability statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions

Data sharing statement

No additional data are available

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