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Promoting scientific problem-solving skills of Grade 7 students using phenomenon-based learning enhanced by argument-driven inquiry (ADI): a classroom action research model

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ABSTRACT

This classroom action research aimed to (1) improve Grade 7 students' scientific problem-solving skills on the topic of weather change processes, and (2) evaluate learning management approaches using phenomenon-based learning (PhBL) enhanced by argument-driven inquiry (ADI). The participants were 35 Grade 7 students during the 2024 academic year, selected through purposive sampling. The study followed six cycles of action research. Research tools included six PhBL-based lesson plans (18 hours), pre- and post-tests with three open-ended problem scenarios and students' learning journals. Qualitative data from reflective notes and journals were analyzed using content analysis, while quantitative data from tests were examined through mean scores and relative development indices. Findings revealed significant improvement in students' problem-solving skills. The average score increased from 55.62% (good level) before the intervention to 80.67% (excellent level) after the PhBL–ADI activities, with a relative development index of 37.57% (moderate level). The six stages of PhBL instruction – exploring, understanding, investigating, modeling, synthesizing and communicating scientifically – were found to effectively support skill development. Correspondingly, students developed six sub-skills of problem solving: identifying problems, analyzing causes, searching for information, connecting relationships, evaluating solutions and presenting conclusions. This finding indicate that integrating PhBL with ADI can effectively - enhance scientific problem-solving skills in lower-secondary science education.

IMPACT STATEMENT

This study demonstrates the potential of integrating Phenomenon-Based Learning (PhBL) with Argument-Driven Inquiry (ADI) to strengthen scientific problem-solving skills in lower-secondary science education. Through six iterative classroom action research cycles centered on authentic weather and climate phenomena, Grade 7 students progressively developed their abilities to identify and analyze problems, search for relevant information, connect scientific relationships, evaluate possible solutions, and communicate evidence-based conclusions. The study is significant because it provides a practical instructional model that connects real-world phenomena with structured inquiry, scientific argumentation, and collaborative reasoning. Rather than focusing solely on scientific content knowledge, the approach engages students in applying evidence and scientific reasoning to meaningful real-life problems. The findings offer science teachers a classroom-based framework for designing inquiry-rich learning experiences that promote higher-order thinking, scientific literacy, and problem-solving competencies needed for understanding and responding to complex socio-scientific issues, including weather variability and climate change.

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Introduction

The world has now entered the twenty-first century, a period characterized by rapid, complex changes across the economic, technological, social and environmental fields. Among these global issues, climate change has become one of the most urgent challenges facing humanity. Increasing greenhouse gas

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emissions have intensified the greenhouse effect, causing shifts in global temperatures, frequent extreme weather events and widespread ecological disruptions. Addressing these challenges requires a scientifically literate population – individuals capable of interpreting evidence, evaluating competing claims and making informed decisions about complex socio-scientific issues. Science education plays a crucial role in helping learners develop these skills. In line with global movements, Thailand's National Education Plan (2017–2036) emphasizes sustainability, scientific reasoning and lifelong learning as essential skills needed in a volatile, uncertain, complex and ambiguous world. These goals align with international frameworks, such as the OECD Education 2030 vision, which stresses the importance of VASK competencies – values, attitudes, skills, and knowledge – developed through authentic, inquiry-based learning experiences (OECD, 2018; Panich, 2023). Similarly, the PISA 2025 scientific literacy framework highlights students' ability to use scientific evidence to interpret natural phenomena and propose solutions at various societal levels (OECD, 2023).

Understanding weather and climate processes is essential for helping students grasp the causes and effects of climate change. Previous research shows that learning atmospheric science enhances conceptual understanding and encourages environmental responsibility (Driver et al., 1996; Henriques, 2002). Yet, studies consistently reveal that students often find it difficult to analyze information, evaluate evidence and apply scientific models to real-world situations (Lazonder & de Jong, 2012). These difficulties are worsened in digital settings, where students struggle to choose reliable sources, manage various representations and provide clear explanations (Brand-Gruwel et al., 2009; Britt et al., 1994). Problem-solving is widely recognized as a crucial part of scientific literacy and an essential skill for the twenty-first century. Effective problem-solving involves identifying issues, analyzing evidence, creating explanations and evaluating competing claims – skills supported by decades of cognitive and developmental research (Bransford et al., 2000; Case, 1985, 1992). However, in classrooms, students often struggle with open-ended or inquiry-based tasks due to limited opportunities for reasoning, modeling and collaborative knowledge-building (Hmelo-Silver, 2004; Palincsar, 1998). Research also shows that learning improves when students engage in scaffolded inquiry, cognitive apprenticeship and dialogic interactions with peers and teachers (Alexander, 2018; Brown & Campione, 1996; Collins et al., 1989). A strong body of scholarship emphasizes that scientific learning is fundamentally social. Small-group interactions, structured dialogue and peer reasoning help promote conceptual development, especially when students articulate and justify ideas (Alexopoulou & Driver, 1996; Howe et al., 1995, 2005). Dialogic classrooms – marked by shared inquiry, extended discourse and open questioning – foster deeper engagement with scientific evidence and encourage students to consider multiple perspectives (Alexander, 2001; Wilkinson et al., 2017). Therefore, high-quality science instruction should incorporate inquiry, collaboration and discourse to support both conceptual understanding and epistemic growth.

Phenomenon-based learning (PhBL), widely recognized through Finland's curriculum reforms, closely aligns with dialogic, inquiry-driven approaches. PhBL involves students in exploring authentic real-world phenomena, encouraging them to ask questions, develop explanations and connect knowledge across subjects (Symeonidis & Schwarz, 2016). Research indicates that PhBL settings promote reflective inquiry, modeling and conceptual change because students start with observable phenomena and gradually develop complex scientific explanations (Edelson, 2001). International research supports PhBL's effectiveness: Ualikhanova (2024) observed improvements in conceptual understanding in physics classes, while Saberi and Nouri (2025) showed that PhBL enhances three-dimensional learning and students' ability to link scientific ideas with real-world situations. At the same time, research on scientific argumentation emphasizes its importance in science learning. Argumentation helps with conceptual change by involving learners in evaluating evidence, forming explanations and considering different viewpoints (Asterhan & Schwarz, 2007, 2009, 2016; Osborne, 2010). Students understand science better when they take part in collaborative argumentation, express claims, critique each other's reasoning and support ideas with evidence (Baker, 1999; Driver et al., 2000). Structured argumentation settings also develop metacognitive and epistemic skills that are key to scientific problem-solving (Chinn & Buckland, 2012; Lombardi et al., 2013).

Argument-driven inquiry (ADI) offers a research-backed instructional model that combines inquiry and argumentation, guiding students to gather evidence, assess different explanations and develop scientific arguments (Sampson & Gleim, 2019; Walker & Sampson, 2013). ADI builds upon established theories of scaffolding (Quintana et al., 2004; Reiser, 2004), dialogic reasoning and collaborative learning (Andriessen & Baker, 2014). Studies show that ADI enhances students' abilities to analyze data, justify claims and explain scientific concepts (Berland & McNeill, 2010; McNeill & Krajcik, 2007). Combining PhBL with ADI creates a strong teaching approach: PhBL grounds learning in real-world phenomena, while ADI helps structure the reasoning needed to create and assess scientific explanations. Together, these methods promote evidence-based inquiry, dialogic interaction and epistemic growth – essential parts of scientific problem-solving (Manz, 2015; Osborne et al., 2013). Despite substantial international evidence, research in Thailand on how PhBL and ADI together affect students' problem-solving skills remains limited, particularly in lower-secondary science topics, such as weather and climate. This study fills that gap by exploring how PhBL, enhanced by ADI, can improve Grade 7 students' scientific problem-solving skills through ongoing classroom action research (CAR) cycles.

Literature review

Science education and problem-solving in the twenty-first century

Contemporary science education aims to prepare learners to understand and respond to complex socio-scientific challenges through scientific reasoning, inquiry and evidence-based decision-making. Rather than emphasizing factual knowledge alone, current frameworks define scientific literacy as the ability to construct explanations, evaluate evidence and apply scientific knowledge to authentic situations (American Association for the Advancement of Science [AAAS], 1993; National Research Council, 2012). Learning is therefore viewed as an active and socially situated process in which students develop conceptual understanding through inquiry, collaboration and guided participation (Collins et al., 1989; Greeno, 2006; Palincsar, 1998). Within this perspective, scientific problem-solving is considered a core competency. It involves identifying problems, interpreting evidence, constructing explanations and evaluating alternative solutions (Bransford et al., 2000). Research on inquiry- and problem-based learning consistently demonstrates that authentic, ill-structured problems promote reasoning, conceptual understanding and self-directed learning by engaging students in meaningful knowledge construction rather than passive information acquisition (Barrows, 2000; Hmelo-Silver, 2004). Consequently, inquiry-oriented learning environments provide an important theoretical foundation for developing students' scientific problem-solving abilities.

Phenomenon-based learning

PhBL extends constructivist and inquiry-based learning by organizing instruction around authentic real-world phenomena rather than isolated disciplinary content (Symeonidis & Schwarz, 2016). Students investigate observable phenomena, formulate questions, gather evidence, construct explanatory models and integrate knowledge across disciplines. This process encourages deeper conceptual understanding by connecting scientific concepts with meaningful real-life contexts (Edelson, 2001; Krajcik & Blumenfeld, 2006). Previous studies have shown that learning through authentic phenomena promotes conceptual change, reflective inquiry and interdisciplinary thinking (Driver et al., 1996; Linn et al., 2004). Students develop stronger reasoning when they actively generate questions, construct explanations and revise their understanding through collaborative investigation (Davis, 2003; Kuhn et al., 2000; Loh et al., 2001). More recent studies also report that PhBL enhances conceptual understanding and enables students to connect scientific knowledge with everyday experiences (Saberi & Nouri, 2025; Ualikhanova, 2024). These characteristics make PhBL a promising instructional approach for promoting scientific problem-solving.

Argument-driven inquiry

While PhBL provides authentic contexts for learning, students also need structured opportunities to justify explanations using scientific evidence. ADI integrates scientific inquiry with argumentation by engaging learners in constructing claims, evaluating evidence, critiquing alternative explanations and communicating scientific reasoning (Sampson & Gleim, 2019; Walker & Sampson, 2013). ADI is grounded in research demonstrating that scientific argumentation promotes conceptual understanding, critical thinking and metacognitive development (Chinn, 2006). Through structured discourse and evidence-based reasoning, students learn to distinguish between claims and evidence while refining their scientific explanations (Berland & McNeill, 2010; Rapanta et al., 2021). The instructional model also incorporates scaffolding strategies that support learners in progressively developing more sophisticated scientific arguments (Quintana et al., 2004; Reiser, 2004).

Integrating PhBL and ADI to promote scientific problem-solving

PhBL and ADI are complementary instructional approaches. PhBL provides meaningful real-world contexts that stimulate inquiry and problem identification, whereas ADI structures the reasoning process through evidence evaluation, justification and scientific argumentation. Together, they engage students in investigating authentic phenomena, constructing explanatory models, evaluating competing ideas and communicating evidence-based conclusions. The effectiveness of this integration is supported by three complementary lines of research. First, studies of problem-based learning demonstrate that authentic, ill-structured problems foster flexible reasoning and transferable problem-solving skills (Capon & Kuhn, 2004; Hmelo-Silver, 2004). Second, inquiry research highlights the importance of scaffolding, reflection and model construction in developing scientific understanding (Puntambekar & Kolodner, 2005; Quintana et al., 2004). Third, argumentation research consistently shows that evaluating evidence and justifying claims strengthens conceptual understanding and higher-order reasoning (Chinn, 2006).

Collectively these perspectives suggest that integrating PhBL with ADI creates a coherent instructional framework in which authentic phenomena stimulate inquiry, while structured argumentation supports scientific reasoning and evidence-based problem-solving. When implemented through iterative CAR cycles, this integration provides continuous opportunities for students to refine their explanations, strengthen analytical reasoning and develop scientific problem-solving skills.

Research framework

The research framework shows how PhBL, combined with ADI, functions as the main instructional method to enhance Grade 7 students' problem-solving skills. The PhBL model provides the foundational structure, guiding students through exploration, questioning, investigation, model building, knowledge synthesis and scientific communication. The ADI elements – argumentation, evidence assessment and claim–evidence–reasoning (CER) – are integrated into the final phases of PhBL to strengthen reasoning and scientific justification. In each action research cycle, students work with real-world climate and weather phenomena, enabling them to experience genuine scientific problem-solving. These teaching processes directly impact the development of students' six problem-solving sub-skills, which are the study's dependent variable. The action research cycles allow for ongoing improvement of teaching strategies through classroom observations, learning journals and student performance data. The framework represents an ongoing process where instructional adjustments improve both teaching and learning outcomes, ultimately leading to better scientific problem-solving skills, as shown in Figure 1.

Research design

This study used a CAR approach to improve Grade 7 students' problem-solving skills related to weather and climate change. The research included six continuous action cycles based on the PAOR model by Kemmis and McTaggart (2000), which describes action research as a spiral of self-reflective cycles, as shown in Figure 2.

This study followed the Kemmis and McTaggart action research model, which consists of four iterative stages: planning, acting, observing and reflecting, implemented across six action research cycles (Kemmis et al., 2014). During the planning stage, six PhBL lesson plans and the research instruments were developed. In the acting stage, students completed a pre-test before participating in one PhBL lesson in each cycle. During the observing stage, the researcher and co-observers documented classroom activities using observation forms, reflective journals and field notes while assessing students' scientific problem-solving performance through learning activities. In the reflecting stage, data from each cycle were analyzed to identify strengths and areas for improvement, and the findings were used to refine the subsequent lesson. After completing all six cycles, students completed a post-test using the same assessment to evaluate changes in their scientific problem-solving skills.

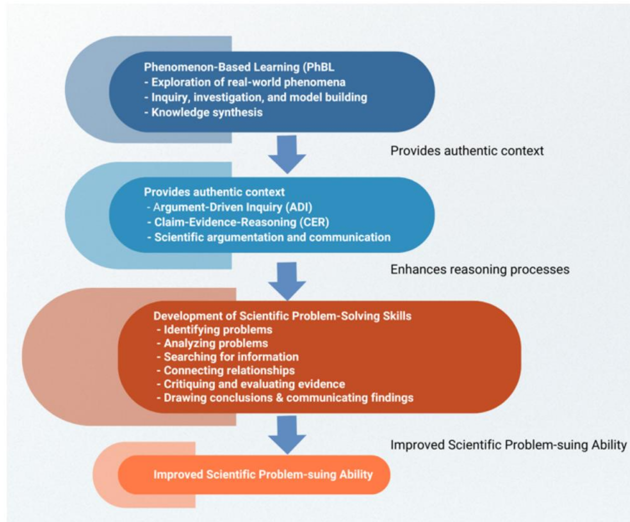

Figure 1. Conceptual research framework.

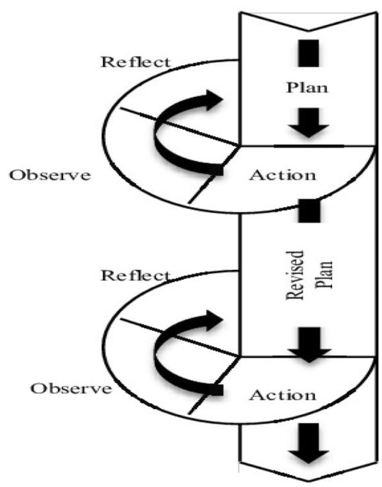

Figure 2. Illustrates the action research cycle by Kemmis & McTaggart (2000). Source: Kemmis and McTaggart model (1988, pp. 1–14, as cited in Burns, 2010).

The study was conducted during the first semester of the 2024 academic year, spanning from January 2024 to January 2025. The instructional intervention focused on the Science learning area under the theme 'Weather and Climate Change Processes'. Six phenomenon-based lesson plans were designed and implemented, with each lesson consisting of three hours of classroom instruction, resulting in a total of 18 instructional hours. In addition, students completed ∼60 hours of self-directed learning activities outside the classroom. The six instructional units addressed the following real-world phenomena: (1) is sunscreen really necessary? (2) heat stroke, (3) royal rainmaking, (4) weather forecasters, (5) lightning and storms and (6) global climate change. These topics were selected to provide authentic contexts that encouraged students to investigate scientific concepts, construct evidence-based explanations and develop scientific problem-solving skills through PhBL.

Research participants

The study involved 35 seventh-grade students enrolled in the 2024 academic year at a school in Phuket Province. The sample was chosen through purposive sampling based on these criteria:

1. Students in Grade 7/1 enrolled in science during the first semester of 2024.

2. Students voluntarily agreed to participate and could provide complete research data throughout the study.
3. Participants had obtained their parents' or guardians' consent.
4. The researcher, who served as the science teacher during the first semester, taught the students.
5. Student identities were protected by assigning code numbers (S1–S35) instead of real names.

Research context

This study was conducted from January 2024 to January 2025 at a municipal school in Phuket City Municipality, Phuket Province. The school enrolled 135 Grade 7 students, divided into three classes: two general program classes and one language and communication program (LIP) class. Participants were purposively selected from the LIP class. Students in this program received enhanced instruction in language and communication skills and regularly used technology to support their learning. All participants voluntarily agreed to participate in the study, provided complete research data throughout the study period and obtained parental consent before participating. Written informed consent was obtained from the parents or legal guardians of all participating students before data collection began. Additionally, verbal assent was obtained from the students themselves. Written parental consent was required for participants who were minors, in accordance with institutional and national ethical guidelines. Verbal assent from students was considered appropriate and sufficient, as the activities involved routine classroom work and posed no physical or psychological risks beyond those of normal educational practices. All participants were clearly informed about the purpose of the study, the voluntary nature of participation, their right to withdraw at any time without penalty, and the measures taken to ensure confidentiality and data protection. These procedures were carried out in accordance with the ethical approval granted by the Human Research Ethics Committee.

PhBL lesson plans

To guide the development of the six PhBL lesson plans used in this study, the instructional design was built around the main stages of the PhBL framework, as shown in Table 1. Each stage plays a specific pedagogical role, helping students move from initial observation to evidence-based scientific reasoning. Table 1 shows an overview of the six stages, their goals and examples of classroom activities used to implement each stage in the context of weather and climate change learning.

Research instrument

To investigate how Grade 7 students develop their problem-solving skills through PhBL, four main research tools were created: the PhBL lesson plans, phenomenon-based activity worksheets, a problem-solving skills test and structured learning journals. Each tool was systematically developed and validated, including expert review and index of item-objective congruence (IOC) analysis, to ensure quality, accuracy and alignment with the study's goals. The first set of tools included six PhBL lesson plans, each designed for a three-hour teaching session, totaling 18 hours. These plans focused on the theme Weather and Climate Change Processes and were titled: Is Sunscreen Really Necessary? Heat Stroke, Royal Rainmaking, Weather Forecasters, Lightning and Storms, and Global Climate Change. The lesson plans followed the main stages of PhBL, such as phenomenon exploration, conceptual understanding, inquiry and investigation, model building, knowledge synthesis and scientific communication.

The lesson-plan development started with defining learning objectives aligned with the Basic Education Core Curriculum B.E. 2551 (Revised 2560). Relevant research and literature in climate science, inquiry learning and phenomenon-based teaching were reviewed to guide the lesson structure. Content was then cross-checked with the Grade 7 Science curriculum to ensure it met all required standards. To establish content validity, all six lesson plans were reviewed by three experts in science education and curriculum design. Each expert assessed how well the learning objectives matched the instructional content using the IOC. IOC scores ranged from 0.67 to 1.00, indicating strong content validity. Items with IOC scores below 0.50 were revised for clarity and correctness before final approval.

Table 1. Stages, purposes and example activities of the PhBL process.

Stage	Purpose	Example activities
1. Phenomenon exploration	To introduce students to real-world phenomena and stimulate curiosity through observation.	• Viewing videos or images of weather events
• Analyzing weather maps/data	–	–
• Discussing unusual climate occurrences	–	–
2. Understanding the phenomenon	To help students generate questions, identify variables and gather evidence to understand the phenomenon.	• Formulating inquiry questions
• Brainstorming causes of heat stroke or skin damage	–	–
• Reading short texts on ozone or climate issues	–	–
3. Inquiry and investigation	To allow students to investigate the phenomenon using scientific process skills and evidence-based approaches.	• Conducting simple experiments (e.g. heat absorption tests)
• Comparing humidity or temperature data	–	–
• Using digital tools or weather apps for data collection	–	–
4. Model construction	To support students in visualizing and representing scientific relationships through model creation.	• Creating diagrams or concept maps of weather systems
• Building simple models (e.g. convection currents)	–	–
• Designing charts showing cause–effect relationships	–	–
5. Knowledge synthesis	To enable students to analyze results, integrate information and develop structured conclusions.	• Group discussions to combine findings
• Completing synthesis worksheets		
• Presenting summarized results		
6. Scientific communication and reasoning	To develop students' ability to communicate, justify explanations and propose solutions using scientific reasoning.	• Presenting evidence-based explanations
• Writing scientific arguments using ADI structure	–	–
• Proposing preventive measures for climate-related issues	–	–

Table summarizing the six stages of phenomenon-based learning, including the instructional purpose of each stage and representative classroom activities used in the weather and climate change unit.

Alongside the lesson plans, the researcher developed six phenomenon-based activity worksheets, each matching a specific PhBL lesson. These worksheets served as formative assessments of students' problem-solving skills, requiring them to observe real-world phenomena, analyze information, identify relationships, critique evidence and develop solutions. Performance was measured with a problem-solving rubric aligned with the six subcomponents defined in the study. Like the lesson plans, the worksheets were reviewed by three experts. They evaluated clarity, relevance and how well each item matched the targeted problem-solving skills. The IOC scores ranged from 0.73 to 1.00, showing high alignment. Any items with IOC scores below the threshold were revised based on expert feedback.

To measure students' growth in problem-solving, a problem-solving skills test was given as a pre- and post-test. Each test included three real-world scenarios related to weather and climate phenomena, with six open-ended questions per scenario, for a total of 18 questions and a 30-point score. Pre-test scenarios covered topics like world ozone day, heat stroke and mosquito populations, while post-test scenarios addressed ozone depletion, monsoon troughs and global warming. These test items were reviewed by experts, with IOC scores ranging from 0.80 to 1.00, indicating excellent content validity. Lower-scoring items were rewritten for better clarity, scientific accuracy and alignment with the scoring rubric. A pilot test was conducted with a similar group of Grade 7 students, and reliability was checked using Cronbach's alpha, which showed acceptable internal consistency.

Finally, the learning journal was a qualitative tool used to capture students' reflections and teacher observations throughout the six cycles of action research. The journal included prompts to document student engagement, challenges faced, emerging problem-solving behaviors and instructional reflections. Experts reviewed the journal's structure for relevance and thoroughness, resulting in IOC scores from 0.67 to 1.00, confirming its suitability for systematic qualitative data collection.

Data analysis

Data obtained from the research instruments were analyzed in three interconnected components to address the research objectives. The first component involved assessing students' problem-solving skills. Pre-test responses were collected and scored to determine students' baseline abilities related to the topic 'Processes of Weather and Atmospheric Changes'. Scores were converted into percentage values and interpreted using evaluation criteria adapted from the Programme for International Student Assessment (Organisation for Economic Co-operation and Development, 2004). These criteria categorized students' performance into four levels – excellent, good, basic and low – based on their mastery of the six sub-skills of problem solving. Behavioral indicators for each level were used to assess the extent to which students could identify problems, gather information, analyze relationships, evaluate solutions and present logical conclusions. The second component examined the development and refinement of PhBL activities and their impact on students' problem-solving skills throughout six action research cycles. Data from the researcher's and co-observers' learning journals were analyzed using content analysis. All entries were read thoroughly, with significant statements extracted, interpreted and synthesized to identify recurring strengths, challenges and areas for improvement in each cycle. To improve the credibility of the qualitative findings, source triangulation was used by comparing journal entries from both the researcher and co-observers to verify consistency in observations and interpretations.

Additional data were derived from students' activity worksheets, which served as formative assessments of problem-solving skills during instruction. These worksheets were scored according to the established rubric, and percentage scores were calculated to determine students' performance levels using the same criteria adapted from PISA (2003). Likewise, the problem-solving skills test, administered before and after the intervention, provided quantitative data on changes in students' abilities. Both instruments – the activity worksheets and the problem-solving test – were used together to strengthen the reliability of findings through method triangulation. The final component focused on evaluating students' overall problem-solving development after participating in the PhBL learning activities. This was accomplished using the relative gain score, calculated from pre- and post-test results. The relative gain score captured the extent of improvement relative to each student's initial performance. Scores were then interpreted using four developmental levels: very high, high, moderate and low. This analysis provided a comprehensive picture of students' progress and the effectiveness of the PhBL process in fostering problem-solving skills related to weather and atmospheric change phenomena.

Research result

This study examined the development of Grade 7 students' scientific problem-solving skills through six cycles of PhBL on the topic *Processes of Weather and Atmospheric Changes*. Six lesson plans (18 instructional hours) were implemented using the six-stage PhBL framework. Students' learning outcomes were evaluated through problem-solving assessments, activity worksheets, classroom observations and learning journals.

Development of scientific problem-solving skills

Table 2 presents students' problem-solving performance across the six learning cycles. Overall, the results indicate a clear upward trend in scientific problem-solving, with mean scores increasing from '7.91' in Scenario 1 to '9.34' in Scenario 6. Although there was a slight decline in Scenario 2 ($M = 7.60$), students' performance improved consistently from Scenario 3 onward, suggesting progressive development in analytical reasoning and scientific problem-solving.

The slight decrease observed in Scenario 2 appears to reflect students' adjustment to inquiry-based learning and increasingly complex investigative tasks. Learning journals revealed that students initially experienced difficulty evaluating multiple sources of information. For example, one student reflected, 'I checked three websites … the meteorology site was more reliable' (S14), indicating the early development of evidence evaluation skills.

Table 2. Descriptive statistics of problem-solving scores ($n = 35$).

Scenario	Mean	SD	Min.	Max.
Scenario 1	7.91	1.20	6	10
Scenario 2	7.60	1.17	6	10
Scenario 3	8.14	1.19	6	10
Scenario 4	8.66	0.97	7	10
Scenario 5	8.63	1.17	6	10
Scenario 6	9.34	0.76	7	10

Table presenting the mean scores, standard deviations, minimum scores and maximum scores of students' scientific problem-solving performance across six learning scenarios.
SD: standard deviation; *N*: number of students. These descriptive statistics illustrate a steady upward *t*.

Table 3. Progression analysis of mean score improvement across learning cycles.

Scenario pair	Mean difference (ΔM)	Interpretation
Scenarios 1 and 2	−0.31	Initial cognitive load caused slight performance dip during early inquiry.
Scenarios 2 and 3	+0.54	Students adjusted to inquiry tasks; improvement began.
Scenarios 3 and 4	+0.52	Strong gains in analysis and model construction skills.
Scenarios 4 and 5	−0.03	Performance stabilized; no meaningful decline.
Scenarios 5 and 6	+0.71	Largest increase: students demonstrated mastery-level skills.
Overall (S1–S6)	+1.43	High overall improvement across full PhBL sequence.

Table showing the changes in mean problem-solving scores between consecutive learning scenarios, demonstrating students' progressive improvement throughout the six instructional cycles.

From Scenario 3 onward, students demonstrated continuous improvement in identifying causal relationships, integrating evidence and constructing scientific explanations. Classroom observations showed greater confidence during collaborative inquiry and increased participation in scientific discussions. By the final learning cycle, students produced more coherent, evidence-based explanations and communicated scientific ideas more effectively. One student reflected, 'Climate change used to feel far away. Now I see it affects our daily lives' (S22), while another commented, 'Making the Canva poster helped me explain climate solutions more clearly' (S6). Overall, the six learning cycles revealed a sustained progression from basic observation to more sophisticated scientific reasoning. Students became increasingly capable of analyzing evidence, constructing explanatory models and communicating scientifically, suggesting that repeated engagement with authentic phenomena effectively strengthened their scientific problem-solving skills.

Progression across learning cycles

By comparing mean scores from Scenario 1 through Scenario 6, Table 3 highlights patterns of growth, periods of stagnation or decline, and points at which instructional adjustments influenced student performance. Furthermore, the progression analysis.

The analysis of students' scores across the six PhBL scenarios reveals a clear pattern of progressive improvement in scientific problem-solving ability. Although students showed a slight dip in performance from Scenario 1 to Scenario 2 – a common occurrence when learners are first adapting to inquiry-based expectations – the decline was minimal and short-lived. Early worksheet samples confirm this adjustment period; for example, in Scenario 2, one student wrote: 'Heat stroke happens because of hot weather… I think the sun is stronger now but I am not sure what causes it', showing uncertainty in distinguishing surface-level observations from underlying causal factors. Beginning in Scenario 3, students demonstrated steady growth as they became more familiar with the learning process, the structure of the tasks and the analytical demands of the activities. This improvement is reflected in learning journal entries, such as: 'I checked two websites and compared the explanations of cloud types. Now I understand why cumulus clouds are important for rainmaking' (Journal, S11), showing clearer information searching and evidence comparison. By Scenario 4, worksheets revealed more precise analytical reasoning. One student explained weather-map interpretation by writing: 'The low-pressure system moves toward the north-east, so the rainfall increases in that region. The monsoon trough connects the two systems, causing heavy storms'. This represents a shift from listing facts to constructing relationships between meteorological factors. Subsequent cycles continued to show consistent gains, reflecting students' increasing confidence and competence in identifying problems, evaluating evidence, constructing

Table 4. Instructional sequence and problem-solving skill development in PhBL.

Components of problem-solving (six sub-skills)	Observed behavior before learning	Observed behavior during activities	Observed behavior after completing activities
1. Observing and identifying problems	Most students identified problems consistent with the situation; *Mean* = *86.66%*.	All students accurately identified problems; *Mean* = *100%*.	All students consistently identified problems; Mean = 100%.
2. Analyzing problems	Most students identified causal factors aligned with the situation; *Mean* = *86.66%*.	Most students accurately identified causal factors; *Mean* = *97.16%*. One student (S1) showed inconsistency in Activity sheet 1.	All students correctly identified causal factors; Mean = 100%.
3. Searching for information to solve problems	Students collected partially correct but incomplete information; scientific concepts only partly identified; *Mean* = *41.66%*.	Students gathered more relevant information but still incomplete; lacked cross-disciplinary knowledge (e.g. geography); *Mean* = *69.16%*.	Students collected more complete and relevant information; scientific concepts appropriately identified; *Mean* = *88.33%*.
4. Analyzing and connecting relationships to solve problems	Students unable to propose feasible solutions; incorrect or missing scientific concepts; *Mean* = *48.33%*.	Students proposed feasible solutions connected to causal factors; scientific concepts partly aligned; *Mean* = *88.33%*.	Students proposed feasible solutions linked to causal factors; coverage still partial; Mean = 71%.
5. Critiquing and evaluating	Students identified some strengths and limitations, partially aligned with proposed solutions; *Mean* = *51.66%*.	Most students identified strengths and limitations aligned with solutions; *Mean* = *96.66%*.	Most students continued evaluating strengths and limitations appropriately; Mean = 72.33%.
6. Drawing conclusions and presenting	Students drew partial conclusions with limited evidence; *Mean* = *41.66%*.	Students drew clear, evidence-based conclusions; preferred digital media presentations; *Mean* = *77.50%*.	Students continued presenting clear, evidence-based conclusions using digital tools; Mean = 75.66%.

Table comparing students' performance on six scientific problem-solving sub-skills before learning, during classroom activities, and after completing the phenomenon-based learning intervention.

explanations and communicating scientific reasoning. A journal entry from Scenario 5 noted: 'In our group we argued about which storm was more dangerous, but we used data from the map to decide. I learned that evidence is more important than guessing'. This illustrates growth in collaborative reasoning and evidence-based decision-making. The most substantial improvement occurred between Scenarios 5 and 6, when students applied accumulated knowledge and skills with greater accuracy and independence. Their final worksheets contained more coherent, model-based explanations, such as: 'El Niño causes the ocean surface to warm. This changes wind direction and reduces rainfall in Thailand. Our community must prepare for drought by saving water and planting heat-resistant crops'. This final phase indicates not only skill acquisition but also the internalization of higher-order reasoning processes fostered by the phenomenon-based approach. Overall, the progression across the six cycles highlights the effectiveness of PhBL in gradually scaffolding complex scientific thinking, enabling students to reach higher levels of performance by the end of the instructional sequence, as shown in Table 4.

Development of problem-solving sub-skills

The results show that students made measurable progress during and after the activities compared to their pre-learning performance. Evidence from learning journals supports this improvement. For instance, early in the sequence, one student wrote: 'I know UV light is harmful, but I'm not sure which part of sunlight causes the problem', illustrating initial uncertainty in Sub-skill 1: observing and identifying problems. After repeated cycles, however, a different student noted: 'I can identify the exact cause now—UV radiation—not just "sunlight"'. These shifts reflect the substantial gains observed in problem identification and causal analysis. The most significant improvement occurred in the sub-skills of identifying, analyzing and critiquing problems, with post-learning scores approaching perfection. Students' worksheets demonstrated clearer causal reasoning and stronger analytical connections, such as: 'Heat stroke is caused by extreme temperature and dehydration. If humidity is high, the body loses heat slower, so the risk increases'. This type of precise relationship-building aligns with the growth documented in Sub-skills 2 and 4. Notably, the sub-skills that rely heavily on prior knowledge and cross-disciplinary understanding – such as searching for information and establishing causal relationships – improved considerably but still revealed gaps. A journal entry from Scenario 4 reported: 'I searched for storm names but didn't know different oceans have different naming systems. I had to check the world map again'. This reflects how incomplete geographical background knowledge initially limited performance but gradually improved with teacher scaffolding. Students demonstrated high engagement and stronger reasoning when communicating solutions through digital media. Their final digital presentations (Canva posters and e-books) contained more coherent explanations, such as: 'El Niño warms the Pacific Ocean surface, causing winds to weaken. This reduces rainfall in Thailand. Communities should store water and monitor drought risks'. Such examples demonstrate advancement in Sub-skill 6: drawing conclusions and presenting solutions scientifically, which aligns with the high post-learning scores in Table 4.

Overall, the six PhBL lesson plans effectively fostered higher-level scientific problem-solving skills. The integration of real-world phenomena, iterative inquiry cycles and technology-enhanced communication enabled students to demonstrate deeper reasoning, stronger use of evidence and more coherent model-based explanations – confirming the value of PhBL in promoting scientific reasoning about weather and atmospheric processes.

Discussion

The findings of this study demonstrate that PhBL, enhanced by ADI, effectively promoted Grade 7 students' scientific problem-solving skills across six iterative action research cycles. Students showed progressive improvement in all six sub-skills of scientific problem solving, including identifying problems, analyzing causal factors, searching for relevant information, connecting scientific relationships, evaluating alternative solutions and communicating evidence-based conclusions. Evidence from learning journals, classroom observations and performance tasks consistently indicated that the structured six-stage PhBL process supported students in moving from intuitive explanations toward more systematic and evidence-based scientific reasoning. These findings support previous research emphasizing that inquiry-based learning is most effective when accompanied by appropriate instructional scaffolding. Hmelo-Silver et al. (2007) argued that inquiry environments become more productive when learners receive conceptual and procedural guidance rather than completely unguided exploration. Similarly, the six instructional stages implemented in this study functioned as recursive scaffolds that gradually shifted responsibility from teacher to students while maintaining opportunities for conceptual support and scientific reasoning (Brown & Campione, 1996; Linn et al., 2004). This gradual release of responsibility appears to explain the continuous improvement observed across the six learning cycles.

The findings also highlight the importance of dialogic interaction and collaborative learning in promoting scientific problem solving. Students progressed from initial reluctance to ask questions and critique ideas to actively participating in group discussions, role-playing activities and scientific presentations. This development is consistent with Alexander's (2001, 2018) concept of dialogic teaching, in which purposeful classroom dialogue supports collective knowledge construction. Likewise, previous studies have shown that collaborative discussion promotes conceptual change when students are encouraged to explain, negotiate and justify their ideas (Alexopoulou & Driver, 1996; Howe et al., 1995). These collaborative opportunities were intentionally embedded throughout each PhBL cycle, allowing students to gradually develop confidence in scientific communication.

Another important finding concerns the role of scientific argumentation. Throughout the intervention, students became increasingly capable of constructing evidence-based explanations, evaluating competing claims and justifying their proposed solutions. This progression supports previous research suggesting that argumentation is fundamental to conceptual change and higher-order reasoning (Asterhan & Schwarz, 2007, 2009, 2016; Osborne, 2010). Repeated engagement in evidence-based discussion enabled students to coordinate claims, evidence and reasoning more effectively, reflecting the learning progression proposed by Berland and McNeill (2010). Rather than simply acquiring scientific knowledge, students gradually developed the epistemic practices characteristic of scientific inquiry. The improvement observed in information searching and knowledge integration further demonstrates the value of combining PhBL with ADI. Students progressively learned to evaluate multiple information sources, integrate knowledge across scientific disciplines and construct more coherent explanations of weather and climate phenomena. These findings are consistent with the knowledge integration framework (Linn et al., 2004) and studies highlighting the importance of scaffolded inquiry for developing transferable scientific reasoning (Lombardi et al., 2013, 2016). Collectively, the results suggest that authentic phenomena, collaborative inquiry and structured scientific argumentation function synergistically to enhance students' scientific problem-solving abilities.

Conclusion

This study demonstrates that integrating PhBL with ADI provides an effective instructional approach for developing Grade 7 students' scientific problem-solving skills. Through six iterative action research cycles, students showed continuous improvement across all six dimensions of scientific problem solving, supported by increasingly sophisticated evidence-based reasoning, collaborative dialogue and scientific communication. The findings extend previous research by demonstrating how authentic real-world phenomena, structured inquiry and scientific argumentation can be systematically integrated within a CAR framework to promote meaningful learning in lower-secondary science education. Rather than improving only conceptual understanding, the instructional model also fostered students' abilities to analyze complex situations, evaluate evidence, justify solutions and communicate scientifically, which are essential competencies for addressing contemporary socio-scientific issues, such as weather variability and climate change.

These findings suggest that PhBL enhanced by ADI offers a practical and theoretically grounded model for science teachers seeking to promote higher-order thinking and scientific literacy. Future research should examine the implementation of this instructional approach across different science topics, educational levels and learning contexts, while employing larger sample sizes and comparative research designs to further establish its effectiveness and generalizability.

Implication

1. PhBL should be designed as an inquiry-driven and dialogic learning environment.
   Effective PhBL requires teachers to guide students through iterative cycles of questioning, investigation, modeling and explanation while intentionally orchestrating collaborative dialogue and argumentation (Alexander, 2018; Hmelo-Silver et al., 2007; Osborne, 2010). Authentic, context-rich phenomena and recurring opportunities to critique and justify ideas help students gradually appropriate scientific language and discourse norms (Anderson et al., 2001; Driver et al., 2000).
2. Structured argumentation and critical questioning are essential for strengthening problem-solving.
   Students showed greater improvement when tasks required evaluating solutions, considering alternatives and providing justification, confirming that argumentation frameworks, such as CER, Toulmin's model and critical questions, should be embedded into routine science instruction (Berland & McNeill, 2010). Prompts that elicit counterarguments and critiques deepen reasoning and conceptual understanding (Nussbaum & Kardash, 2005).
3. Peer collaboration must be intentionally structured to enable equitable participation and deeper reasoning. Shifts from teacher-dominated talk to balanced student participation highlight the need for explicit discussion norms, shared roles and reflective group discourse (Alexopoulou & Driver, 1996; Howe & Zachariou, 2019). Well-structured small-group interaction supports conceptual growth and more sophisticated argumentation (Manz, 2015).
4. Complex scientific phenomena require cross-disciplinary integration. Students' difficulties with geography, storm categorization or socio-cultural concepts illustrate that scientific problem-solving is inherently interdisciplinary. Curriculum design should intentionally connect science with geography, social studies, ethics and local cultural frameworks to help students integrate ideas coherently (Corcoran et al., 2009; Linn et al., 2004). Climate-related and socio-scientific contexts provide opportunities for developing epistemic cognition and plausibility reasoning (Lombardi et al., 2013, 2016; Nussbaum et al., 2011).
5. Teachers need sustained professional learning to enact high-quality PhBL. Implementing dialogic, inquiry-rich PhBL with strong argumentation demands advanced pedagogical content knowledge and beliefs aligned with constructivist, student-centered instruction. Professional development should equip teachers to design phenomena, orchestrate discussions, manage disagreement

productively and assess students' argumentation and problem-solving development (Brown & Campione, 1996; Wilkinson et al., 2017).

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Author 1 conceptualized the study, conducted data collection, performed data analysis and provided critical revisions to earlier versions of the manuscript. Author 2 conducted data collection, prepared the materials and drafted the initial manuscript. Both authors reviewed and approved the final version of the manuscript.

Author contributions

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Ethical approval/considerations

This study followed the principles of the Declaration of Helsinki. Ethical approval was granted by the Human Research Ethics Committee at Phuket Rajabhat University. The study received approval under Certificate of Approval (COA) No.: PKRU 2566/24. All participants were informed about the study's purpose, and their consent was obtained before data collection.

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Data availability statement

The datasets generated and/or analyzed during this study are not publicly available due to participant confidentiality and ethical restrictions. Research instruments used in the study are available in the supplementary files.

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