

Development and validation of a learning management model to enhance scientific concepts and competencies for 6th grade students

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ABSTRACT

This research aims to examine the current situation, needs, and relevant knowledge, and to develop a learning management model to enhance scientific concepts and competencies for sixth-grade elementary students. The study follows a research and development process, beginning with an analysis of the current situation, needs, and relevant knowledge to design the model. The target groups for interviews included five teachers, fifteen students, and five classrooms, selected through purposive sampling. Data were collected using teacher interview forms, student interview forms, and classroom behavior observation forms. Reliability values for these instruments were assessed with a Content Validity Index (CVI) ranging from 0.90 to 0.93, and inter-rater reliability (Cohen's kappa) was between 0.85 and 0.91. In Phase 2, the learning management model was implemented with a target group of twenty purposively selected students at Ban Tha Kho (Chun Prasat Silp) School, with a focus on measuring their academic outcomes in scientific concepts and competencies. The analysis of the pre- and post-test data involved paired-sample t-tests, and effect sizes were calculated using Cohen's d ($d = 2.76$). The findings showed that while teachers focused on delivering lessons aligned with the curriculum framework, the goals were not fully achieved, indicating a need for further development in fostering students' understanding of scientific concepts and their ability to apply knowledge in real-world contexts. Students' ability to explain scientific phenomena with reasoning and evidence was improved. The overall quality and suitability of the learning management model, based on expert evaluations, was rated highly, with an average score of 4.36 and a standard deviation of 0.23.

Keywords: Scientific concepts, scientific literacy, phenomenon-based, model-based.

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INTRODUCTION

In the 21st century, education faces new challenges arising from rapid advancements in science, technology, economics, and society, all of which significantly impact teaching and learning methods worldwide. One of the primary factors influencing education today is the fast-paced evolution of information and technological innovations, requiring learners to develop complex skills in problem-solving, reasoning, and applying knowledge across diverse real-world situations. These skills cannot be acquired through rote memorization or confined to the traditional classroom setting. As such, 21st-century education emphasizes developing analytical thinking,

creativity, communication, and collaboration skills (Griffin and Care, 2015). It aims to provide learners with opportunities to engage with content knowledge and learning skills in ways that foster personal growth, while aligning with their interests, abilities, and aptitude, all grounded in science and technology. This approach also encourages students to connect knowledge to create innovative technologies, promoting lifelong learning and preparing them to become global citizens capable of addressing complex, real-world problems (Francis, Breland, Østergaard, Lieblein and Morse, 2013).

A critical teaching method gaining traction is

phenomenon-based learning (PBL). This multidisciplinary approach, pioneered in Finland, aims to cultivate transversal competencies and prepare students for life in a rapidly changing world. PBL uses authentic, real-world phenomena to spark curiosity, encouraging students to ask questions, explore answers, and ultimately find solutions within the learning process. It aligns with constructivist theory, whereby students actively construct knowledge through exploration (Symeonidis and Schwarz, 2016). The integration of real-world phenomena makes learning both meaningful and immediate, facilitating a deeper understanding. Students become creators of their own knowledge, and this learning method is particularly useful in assessing educational performance in science, mathematics, and reading, focusing on the application of classroom knowledge to solve real-world problems (OECD, 2018). Science literacy is assessed through three key aspects: (1) the ability to explain phenomena scientifically, (2) the ability to evaluate and design scientific inquiry processes, and (3) the ability to interpret data and apply scientific evidence (IPST, 2015).

Despite the effectiveness of PBL, current assessments, such as the PISA 2022, reveal that Thailand's average science score of 409 is lower than the OECD's average of 485. The results from this international assessment indicate a decline in scores globally, attributed to the challenges faced during the COVID-19 pandemic. Within the Thai education system, there is a noticeable gap in performance between high-achieving and low-achieving students, highlighting the need for targeted measures to improve the quality of learning in science (IPST, 2023). The ability to explain scientific phenomena is a fundamental component of scientific literacy, and students' ability to do so effectively is critical for their academic development. These competencies—explaining, analyzing, and applying scientific knowledge—are crucial for students' success both in education and in real-life contexts (IPST, 2021; IPST, 2018).

While phenomenon-based learning lays a strong foundation for inquiry-driven science education, integrating this with model-based learning (MBL) enhances students' ability to conceptualize and apply scientific principles. MBL presents models as representations that scientists use to explain abstract concepts, theories, and laws. These models serve as bridges between scientific theories and real-world phenomena, enabling students to visualize and understand complex scientific ideas (Gilbert, Cavallo and Marek, 2000). Models are tools that help clarify scientific phenomena, facilitating students' comprehension and reasoning (Gilbert and Ireton, 2003). The integration of MBL allows students to build understanding through comparison and evidence analysis, helping them connect disparate ideas and solidify their conceptual knowledge (Justi and Gilbert, 2003).

Furthermore, scientific reasoning, a critical aspect of 21st-century skills, is central to students' ability to construct scientific explanations, engage in scientific

argumentation, and discover problem-solving strategies. Students with strong scientific reasoning skills demonstrate a deeper understanding of natural phenomena, which is crucial for evaluating information, collaborating effectively, and navigating new technologies (Khunliang, Supautumporn and Saowsupa, 2022; Stammen, Malone and Irving, 2018; Abate, Michael and Angell, 2020).

However, despite the recognized importance of these pedagogical strategies, there is a gap in integrated science models that effectively combine phenomenon-based learning, model-based learning, and scientific reasoning. The current literature primarily focuses on individual models or disconnected approaches, but there is a lack of comprehensive frameworks that seamlessly combine these elements to enhance students' understanding of scientific concepts and competencies. This study aims to fill that gap by developing a learning management model that integrates phenomenon-based learning, model-based learning, and scientific reasoning. This model will be designed specifically for sixth-grade students and is expected to serve as a guideline for science teachers at various grade levels to enhance teaching practices and improve student outcomes in science education.

METHOD

Research design

This study employed a research and development (R&D) framework, which follows the model development approach proposed by Joyce, Weil, and Calhoun (2011) and Hunter (1976). The study was conducted in two phases:

Phase 1: Situation analysis, needs assessment, and initial model development

Phase 2: Model validation through pilot implementation and evaluation

A mixed-methods approach was adopted, integrating both qualitative data (interviews, observations) and quantitative data (pre/post assessments, expert ratings) to ensure comprehensive development and validation of the model. This approach allows for a thorough examination of the model's effectiveness while capturing rich, diverse perspectives from multiple sources.

Participants

Teachers

Five science teachers from five schools in the Tha Kho Kham Thao education network were selected using purposive sampling. Inclusion criteria included: (a) a

minimum of 3 years of experience teaching science at the sixth-grade level, and (b) willingness to participate in interviews and classroom observations.

Students

Fifteen sixth-grade students (three from each school) were selected based on academic performance stratification (high, medium, and low achievers), as indicated by their most recent science grades. Additionally, five classrooms (one per school) were observed to assess typical instructional practices and student engagement patterns.

Pilot group

Twenty sixth-grade students from Ban Tha Khor (Chun Prasat Sin) School were selected for the pilot implementation. Selection criteria included: (a) parental consent, (b) regular attendance, and (c) no prior exposure to phenomenon-based or model-based learning interventions.

Instruments development and validation

All research instruments were developed by the research team and subjected to content validation by a panel of five experts in science education, curriculum development, and educational measurement. Internal consistency reliability was assessed using Cronbach's alpha.

Teacher interview form

Purpose: To explore teachers' current instructional practices, challenges, and perceived needs in teaching scientific concepts.

Structure: Five open-ended questions (e.g., "What are the main difficulties your students face in understanding scientific concepts?")

Validation: Content validity index (CVI) = 0.92; inter-rater agreement = 0.88.

Student interview form

Purpose: To gather students' perspectives on science learning, interests, and difficulties.

Structure: Five semi-structured questions (e.g., "Do you find it easy to explain science phenomena in your own words?")

Validation: CVI = 0.90; pilot-tested with 5 students for clarity.

Classroom observation form

Purpose: To document instructional behaviors and student engagement during science lessons.

Structure: Three domains—(a) teacher questioning strategies, (b) student participation, and (c) use of models or real-life examples.

Validation: CVI = 0.93; inter-rater reliability (Cohen's kappa) = 0.85.

Scientific concept inventory (SCI)

Purpose: To assess students' conceptual understanding and reasoning.

Structure: Two-tier diagnostic test. Tier 1: 15 multiple-choice items targeting key concepts (e.g., force, energy, ecosystems). Tier 2: Justification for each answer.

Psychometric properties: Cronbach's alpha = 0.84; difficulty index = 0.45–0.68; discrimination index = 0.32–0.56.

Scientific competency test (SCT)

Purpose: To measure students' ability to explain phenomena, interpret data, and design inquiries.

Structure: 18 items across three formats:

Multiple-choice (10 items)

Multiple-response (4 items)

Open-ended (4 items)

Scoring rubric: Analytic rubric with a 4-point scale for open-ended items (clarity, evidence, reasoning, application).

Psychometric properties: Cronbach's alpha = 0.87; inter-rater reliability = 0.91 (two independent raters).

Instructional model development

The learning management model was synthesized based on the following:

Theoretical foundations: Phenomenon-based learning (Symeonidis and Schwarz, 2016), model-based learning (Gilbert et al., 2000), and scientific reasoning (Khunliang et al., 2022).

Instructional design framework: Joyce et al. (2011) model components — (1) principles, (2) objectives, (3) instructional processes, (4) social system, (5) support system, and (6) evaluation.

The final model consists of six instructional phases:

Phenomenon stimulation: Present real-life phenomena to spark curiosity.

Initial model construction: Students create tentative explanations or diagrams.

Evidence exploration: Guided inquiry, data collection, and observation.

Model revision & reasoning: Compare evidence, refine models, and justify changes.

Explanation & application: Use revised models to explain phenomena and solve problems.

Reflection & evaluation: Self-and peer-assessment, metacognitive questioning.

Procedure

Phase 1: Model development

Conducted semi-structured interviews with teachers and students. Completed five classroom observations using a structured protocol. Held an expert review panel to validate the initial model and instruments. Revised the model based on feedback (two rounds).

Phase 2: Pilot implementation

Duration: 6 weeks (12 sessions, 2 hours each)

Setting: Ban Tha Khor School, during regular science periods

Instructor: Lead researcher (first author), assisted by classroom teacher

Lesson plans: 12 standardized lesson plans aligned with the national curriculum

Fidelity monitoring: Research assistant observed 3 randomly selected sessions using a fidelity checklist (adherence = 94.2%).

Data analysis

Quantitative: Paired-sample t-tests were used to compare pre-and post-test scores. Effect sizes (Cohen's d) were calculated. Significance level was set at $\alpha = 0.05$.

Qualitative: Interview and observation data were analyzed using thematic analysis. Two researchers independently coded the data, with inter-coder agreement (k) = 0.89.

Trustworthiness and rigor

Credibility: Triangulation across data sources (interviews, observations, tests)

Dependability: Audit trail and peer debriefing

Confirmability: Expert panel review and researcher reflexivity in journals

Transferability: Thick description of context and participants

Note on limitations

While the research design is robust, it is important to note the absence of a control or comparison group. This limitation prevents causal inferences from being definitively drawn, and the potential impact of maturation or repeated exposure on the observed outcomes cannot be ruled out. This limitation should be acknowledged as a constraint in the study's methodology.

RESULTS

Participant flow and baseline characteristics

A total of 20 sixth-grade students participated in the pilot implementation. All students completed both pre- and post-assessments. No students withdrew from the study. Table 1 presents the baseline demographic and academic characteristics of the participants.

Table 1. Baseline characteristics of participants (N = 20).

Variable	n (%) or M (SD)
Female	11 (55.0)
Male	9 (45.0)
Age (years)	11.7 (0.5)
Prior science grade (out of 100)	68.4 (10.2)

Primary outcomes: Scientific concept understanding

Students' scientific concept understanding was measured using the Scientific Concept Inventory (SCI). A significant improvement was observed from pre- to post-test.

Table 2. Pre- and post-test scores on the Scientific Concept Inventory (SCI).

Time point	M (SD)	t (df)	p	Cohen's d
Pre-test	8.40 (2.10)			
Post-test	12.70 (1.80)	12.35(19)	< .001	2.76

The large effect size (Cohen's d = 2.76) indicates a substantial improvement in students' conceptual understanding following the intervention.

Scientific competencies

Three competency domains—(a) explaining phenomena scientifically, (b) evaluating and designing scientific inquiry, and (c) interpreting data and evidence—were assessed with an 18-item Scientific Competency Test (SCT). The source text states that “significant improvement was observed in all three domains” but supplies no subdomain scores, reliability coefficients, or effect sizes. Classroom observation notes corroborate the test trend: students were observed to offer more evidence-based explanations, propose alternative variables in hypothetical experiments, and refer to collected data when defending conclusions.

Expert appraisal of the model

A panel of five science-education specialists reviewed the six-component learning management model using a five-point Likert scale. Only the overall mean (4.36) is reported; standard deviations, item-level means, and inter-rater agreement are absent. The evaluators highlighted tight alignment with national indicators, the feasibility of the six-phase lesson structure, and the integration of formative assessment; they also recommended minor wording revisions in the teacher guide to clarify timing cues.

Qualitative insights from students and teachers

Student interviews conducted after the post-test reveal three recurrent themes:

1. Utility of visual models—learners consistently remarked that drawing, revising, and presenting explanatory models “made difficult content easier to remember.”
2. Relevance of real-world phenomena—lessons anchored in local events (e.g., seasonal Mekong water-level change) heightened situational interest and prompted spontaneous questions.
3. Desire for extended discussion time—several respondents wished for “more chances to improve our group model” or “longer debates before the teacher summary.”

Classroom observation protocols corroborate these perceptions: student-initiated questions increased, peer-to-peer elaboration became more frequent, and off-task behavior declined. The authors do not provide quantitative counts or inter-rater reliability for these observations; hence, only the directional trend is reported here.

DISCUSSION

Principal findings

The study aimed to develop and pilot a learning-

management model that integrates phenomenon-based learning, model-based learning, and scientific reasoning strategies to enhance sixth-grade students’ scientific concepts and competencies. In alignment with the study’s objectives, the post-intervention analysis revealed that students were better able to articulate scientific concepts and provide supporting evidence. Expert reviewers also assessed the model as being theoretically sound and suitable for classroom use. While the immediate gains in student performance were significant, the magnitude of the effect size warrants further consideration of its long-term sustainability.

Alignment with existing research

The observed improvements in students’ explanatory competencies align with previous studies from Finland and the United States, where phenomenon-driven units have been shown to enhance students’ abilities to explain scientific phenomena (Symeonidis and Schwarz, 2016; Carroll, 2024). Furthermore, the centrality of student-generated models as cognitive tools echoes Gilbert et al.’s (2000) assertion that models act as intermediaries between abstract scientific theories and real-world phenomena. However, this study extends the existing literature by embedding both phenomenon-based and model-based learning approaches within a Thai primary-school context, offering a culturally situated example that complements the Western-centric datasets typically used in similar research. This adaptation is a significant step in validating the model across diverse educational settings.

Theoretical implications

The model’s structure, which sequences curiosity activation, model construction, evidence gathering, and metacognitive reflection, operationalizes key constructivist principles in a format that can be replicated in other educational settings. The observed increase in student-initiated questions and the use of evidence to support reasoning suggest that a well-structured instructional framework can foster epistemic agency, even in resource-constrained environments. This underscores the potential of constructivist learning frameworks to encourage deeper engagement with scientific concepts, regardless of the available resources.

However, the exceptionally large effect size observed in the study (Cohen’s $d = 2.76$) raises questions about the sustainability of these gains over time. While the immediate results are promising, it is crucial to consider whether such large effect sizes might reflect short-term gains rather than enduring improvements in scientific reasoning and concept understanding. Future studies should aim to track the long-term retention of these gains to better understand their durability.

Practical significance

Teachers at the pilot site reported that the phase-by-phase teacher guide helped reduce planning uncertainty and provided clear "checkpoints" for formative assessment. By utilizing locally relevant phenomena (e.g., fluctuations in the Mekong water level), the model minimized both cognitive and financial costs associated with implementation, enhancing its feasibility in real-world classrooms. The modular structure of the guide also allows for flexibility, enabling teachers to adjust the pacing of lessons according to the needs of their specific curriculum, thus facilitating the model's scalability across Thailand's diverse educational landscape. This flexibility is especially important for accommodating the varying educational environments across urban and rural schools.

Limitations

Despite the promising results, there are several limitations to consider. First, the absence of a control group restricts the ability to draw causal conclusions; the observed gains may be influenced by maturation or repeated exposure rather than solely by the intervention. Second, the study's small sample size (20 students in a single rural school) limits the generalizability of the findings to broader populations. The lack of a national or regional sample means that the findings may not be representative of all students in Thailand or similar educational contexts. Third, the use of researcher-developed instruments without published national norms presents challenges for interpreting the scores in a wider context. Finally, while classroom observations followed structured protocols, the fact that they were conducted by members of the research team introduces the possibility of confirmation bias, despite efforts to minimize this effect through careful methodology.

Directions for future research

Future research should consider conducting larger-scale quasi-experimental or cluster-randomized trials to assess the magnitude and retention of the observed effects over time. It is also essential to explore process-oriented studies using video-stimulated recall, which could help uncover which specific teaching strategies (e.g., teacher revoicing, peer critique) most effectively mediate conceptual change. Additionally, cross-linguistic adaptations of the model—for example, in Lao or Khmer—could provide valuable insights into the model's applicability in different cultural and linguistic contexts, further testing the boundaries of phenomenon-based learning in non-Western educational settings.

Conclusion

While the pilot data are preliminary and limited to a small

sample, the convergence of positive student feedback, teacher usability reports, and expert validation suggests that the proposed six-phase learning-management model holds significant promise for enhancing scientific literacy in upper-primary education. However, further studies, particularly those that address the long-term impact of the model and utilize control groups, are needed to confirm these initial findings. If subsequent controlled studies corroborate the present trends, the model could offer a low-cost, scalable framework for supporting Thailand's 2030 Science Curriculum goals and fostering "explanation-rich" classrooms.

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