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Integration of phenomenon-based and play-based learning in primary science

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ABSTRACT

Primary school students in Thailand continue to struggle with science process skills and creative thinking, a challenge underscored by Thailand's lowest Programme for International Student Assessment (PISA) science scores in 20 years. Traditional instruction emphasizing content memorization while neglecting real-world application has been identified as a major contributing factor. Addressing this issue is critical, as both competencies are foundational for 21st-century learning. This study examined the effects of an integrated phenomenon-based learning and play-based learning (PhBL-PBL) innovation on Grade 2 students' science process skills and creative thinking skills. A one-group posttest-only design was adopted with 41 students in an authentic Thai primary classroom. Data were collected using validated instruments and analyzed through descriptive statistics and one-sample t-tests against predefined performance criteria. Results showed that 92.68% of students achieved creative thinking skills at a good level or above, and 85.37% reached the same threshold for science process skills, with mean scores for both domains significantly exceeding the criterion level ($p<.05$). These findings suggest that integrating phenomenon-based and play-based approaches effectively develops both competencies simultaneously, providing empirical evidence for a developmentally appropriate model of elementary science instruction with potential applicability beyond the Thai educational context.

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1. INTRODUCTION

In the 21st century, science is not merely a body of knowledge but an essential tool for living. Developing citizens with scientific literacy and creative thinking skills has become a primary goal of education worldwide [1]. However, Thailand's science education faces a critical crisis, as evidenced by the Programme for International Student Assessment (PISA) 2022 results, where Thai students' science scores dropped to 409 points, representing the lowest level in 20 years [2]. This decline is particularly alarming given that scientific literacy underpins informed decision-making in an increasingly complex world, making it a concern not only for Thailand but for any nation striving to cultivate 21st-century competencies.

This national decline aligns with empirical evidence from classroom-based assessments indicating a pervasive lack of fundamental science process skills [3]. These gaps are further documented across various educational levels, where deficiencies in both basic and integrated skills remain a significant barrier to student progress [4]. Furthermore, the failure to master essential competencies such as experimentation and data communication during the early stages of education poses a long-term threat to scientific literacy [5].

Crucially, this crisis is compounded by a significant deficiency in creative problem-solving abilities [6], [7]. Without the integration of creative thinking, students are unable to apply scientific knowledge to the complex, unfamiliar situations demanded by modern global standards.

The root causes of these challenges are multifaceted. In many primary classrooms, science instruction still focuses on memorization rather than inquiry and exploration, limiting students' ability to develop science process skills and creative thinking needed for real-world problem solving [8]. In addition, instruction often lacks the systematic promotion of scientific creativity [9], and frequently fails to connect scientific concepts to real-life contexts [10]. This challenge underscores the necessity for transformative educational paradigms that move beyond traditional boundaries to foster deep, multifaceted learning [11].

Beyond these national trends, localized evidence from the research context confirmed similar challenges. Interviews with Grade 1 science teachers from the preceding academic year indicated that students at the participating school demonstrated only fair levels of science process skills and creative thinking skills, based on classroom observations and routine learning assessments conducted by the teachers. While limitations were observed across multiple skill domains, predicting skills and originality were identified as the most problematic areas requiring urgent improvement. These convergent findings at both national and school levels establish a clear need for an evidence-based pedagogical intervention targeting science process skills and creative thinking simultaneously.

To address these problems, the concept of phenomenon-based learning (PhBL) was adopted as the primary driver. Originally established in Finland's curriculum reform [12], [13], PhBL shifts the learning focus from fragmented subjects to holistic, real-world phenomena [14]. Its theoretical foundations are rooted in phenomenological philosophy, which conceptualizes learning as an experiential dialogue between learners and their real-world environment [15]. It emphasizes connecting various dimensions of knowledge so that learners can perceive the "big picture" [16]. As a contemporary pedagogical approach, PhBL has received increasing international research attention and has been implemented across diverse K-12 educational contexts [17]. While the framework initially proposed by Silander [14] remains a foundational pillar, recent empirical studies have further demonstrated measurable improvements in science learning outcomes and student performance following PhBL implementation [18]. Complementary research has also emphasized the role of PhBL in supporting interdisciplinary learning and the development of scientific and creative thinking competencies within contemporary science education [19]. These developments are consistent with growing interest in interdisciplinary teaching in secondary education aimed at preparing students for real-world complexity [20]. This aligns with the concept of Lonka [21], which states that this learning model focuses on problem-solving processes integrated with real situations. Practically, the teacher's role is transformed from a knowledge transmitter to a facilitator, creating a meaningful learning space connected to students' real lives [22], [23].

For primary school students, learning through complex phenomena at early stages may be developmentally demanding and potentially cause stress or anxiety. Therefore, integrating play-based learning (PBL) can help learners overcome these limitations, as play aligns with children's natural modes of learning. Humans have evolved to learn through play behaviors [24]. Play helps reduce stress and promote intrinsic motivation [25], while providing opportunities for children to use imagination and experiment within a safe learning environment [26], [27]. Furthermore, integrating play into instructional activities supports holistic development across intellectual, social, emotional, and creative domains [28], which form essential foundations for complex problem-solving and 21st-century skills in science learning [27]. In early childhood settings, science process skills are effectively developed through child-centered approaches including play, exploration and guided discovery [29].

This study provides the first empirical evidence of an integrated PhBL-PBL approach in primary science, demonstrating how both methods can be combined to simultaneously enhance science process skills and creative thinking in Grade 2 students. While PhBL and PBL have been widely examined as separate approaches, their integrated implementation in authentic primary classrooms remains empirically uncharted, particularly in relation to their combined potential to support both science process skills and creative thinking. Although the integration of phenomenon-based and play-based approaches has been recognized in educational systems such as Finland [30], empirical evidence regarding its effectiveness on specific cognitive outcomes at the primary level remains limited. Without understanding how these two approaches can be effectively integrated, teachers may continue to use them separately, missing opportunities to support both science process skills and creativity in young learners. This gap is particularly significant at the primary level, where developmentally appropriate approaches are essential. Therefore, this study addresses the following research question: what are the effects of an integrated PhBL-PBL learning management innovation on Grade 2 students' science process skills and creative thinking? Following a 4-phase research and development (R&D) structure, the innovation itself was developed and validated in a preceding phase, the results of which have been published elsewhere [31].

This article therefore focuses exclusively on the implementation outcomes, specifically the effects of the integrated innovation on Grade 2 students' creative thinking and science process skills. The pedagogical framework was tested with 41 students to provide empirical evidence for a pedagogical solution that balances scientific rigor with developmental appropriateness. This study provides evidence to support the redesign of primary science curricula toward more inquiry-based and play-integrated approaches that align with 21st-century learning goals. Theoretically, this study contributes by demonstrating the synergy between PhBL and PBL as complementary mechanisms. Practically, it provides a developmentally appropriate instructional model for primary science. The findings of this study are expected to contribute practical, evidence-based guidelines for educators and curriculum designers seeking to integrate phenomenon-based and play-based approaches in primary science education, with implications extending to comparable educational contexts beyond Thailand.

2. METHOD

2.1. Research design

This research is a R&D study aimed at investigating the effects of using a learning management innovation based on PhBL combined with PBL to promote creative thinking skills and science process skills among primary school students. In the innovation implementation phase, the researchers employed a one-group posttest-only design. The complete research process consists of four phases: i) studying the conditions and needs for learning management using PhBL combined with PBL for primary school students; ii) developing a learning management innovation based on PhBL combined with PBL to promote creative thinking skills and science process skills of primary school students; iii) studying the effects of using the learning management innovation; and iv) evaluating the results of using the learning management innovation. This article presents results specifically from phase 3, focusing on the effects of the learning management innovation on creative thinking skills and science process skills to confirm its effectiveness when applied in real classroom contexts. A one-group posttest-only design was employed for ethical reasons, as administering repeated performance-based assessments covering eight science process skills and four creative thinking components to Grade 2 students would impose excessive burden. This design was considered sufficient given that the success criteria were set above the minimum standards prescribed by the 2025 Basic Education Core Curriculum [32], and student progress was additionally monitored across all seven lesson plans.

2.2. Sample group

The sample group consisted of 41 Grade 2 students from one classroom. Cluster random sampling was employed, in which one classroom was randomly selected from a total of eight Grade 2 classrooms in the school. This classroom was used as the representative sample for the study.

2.3. Research instruments

2.3.1. Creative thinking skills assessment

The creative thinking skills assessment covers four components: fluency, flexibility, originality, and elaboration (4 items). This is a performance-based and subjective assessment using a 4-level scoring criterion (very good=3 points, good=2 points, fair=1 point, needs improvement=0 point). Items 1-3 measure fluency and flexibility; item 4 measures originality and elaboration. Index of item-objective congruence (IOC) was found to be 1.00 for all items. Difficulty index (p) ranged from 0.35-0.68, discrimination index (r) ranged from 0.35-0.70, and reliability (α) was 0.81.

2.3.2. Science process skills assessment

The science process skills assessment covers eight skills: observing, classifying, measuring, using numbers, using space/time relationships, predicting, organizing data and communicating, and inferring. This is a performance-based and subjective assessment using the same 4-level scoring criterion. Individual performance testing was used, with IOC ranging from 0.80-1.00. Difficulty index (p) ranged from 0.35-0.80, discrimination index (r) ranged from 0.25-0.80, and reliability (α) was 0.80.

2.3.3. Learning management innovation

The learning management innovation based on PhBL combined with PBL to promote creative thinking and science process skills among primary students comprises seven components: principles, objectives, six steps of learning, role of the teachers, role of the learners, learning materials and resources, and assessment and evaluation. The learning activity steps consist of six steps: i) connecting with phenomenon; ii) reacting through play; iii) experiencing and exploring knowledge through play; iv) articulating and sharing ideas; v) transforming knowledge into application; and vi) evaluating and reflecting.

The quality was evaluated by five experts, comprising three specialists in educational innovation and two in science teaching, with a mean score of 4.54 (very good level). The structure of the innovation is illustrated in Figure 1, as developed in previous study [31].

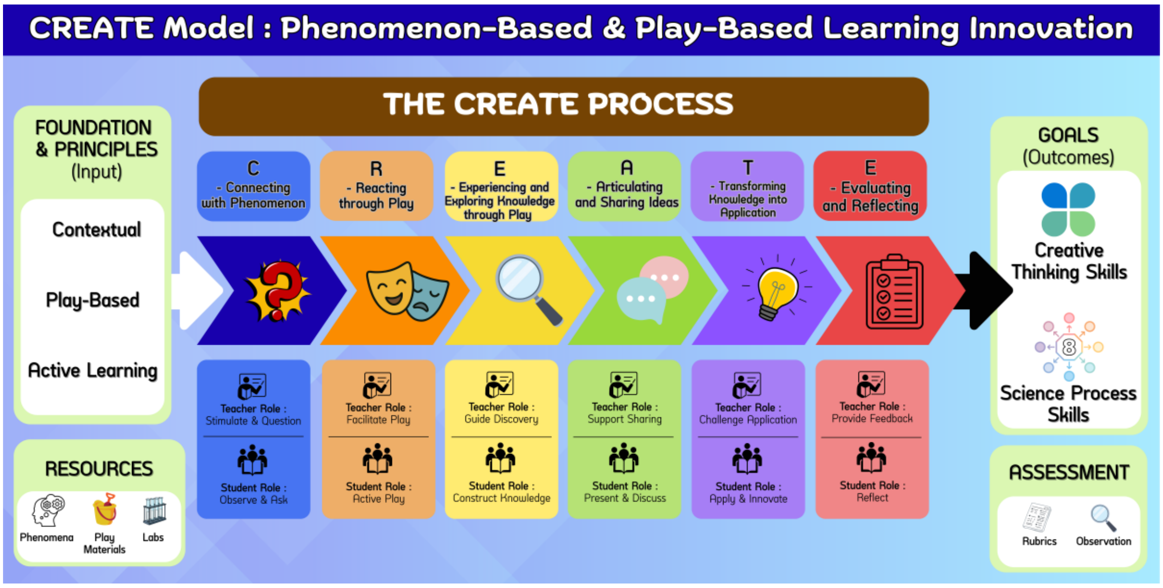

Figure 1. The developed learning management innovation [31]

2.4. Data collection

The learning management innovation was implemented for 10 weeks in a Grade 2 science class, focusing on the unit light and materials, with the researcher collecting data personally. A post-test was administered after the implementation of the innovation. The post-test was used to assess students' creative thinking skills and science process skills.

2.5. Data analysis

Descriptive statistics (mean, standard deviation, and percentage) were used along with t-test compared to predetermined criteria. The researcher set criteria higher than general minimum standards, requiring students to achieve quality level 2 (good) or above to pass the research evaluation criteria. A quantitative target was set that at least 75% of total students must meet this criterion for the innovation to be considered effective. The target mean score criterion was set at 2.00 (out of full score 3.00), equivalent to good quality level. This 2.00 mean criterion serves as the standard for testing because the researcher aimed to verify that students achieved skills above minimum standards and at the quality level expected by the institution, consistent with the learning achievement evaluation guidelines in the Basic Education Core Curriculum Manual for Primary Education (Grades 1-3), Buddhist era 2568, by the Office of the Basic Education Commission [32].

3. RESULTS AND DISCUSSION

3.1. Results

This section presents the results of using the learning management innovation based on PhBL combined with PBL to promote creative thinking skills and science process skills among primary school students. The innovation was developed by the researcher. The results are presented in the following sections.

3.1.1. Results of creative thinking skills assessment

The researcher presents the data analysis results in two parts: i) quality levels and percentage meeting the criteria, and ii) mean score comparison with the criteria. For part 1, the results of creative thinking skills assessment are classified by quality levels. The analysis of students' creative thinking skill levels and the comparison with the number meeting the criteria (75% of the total students) are presented in Table 1.

From Table 1, we found that overall, most students (20 students, 48.78%) achieved level 2 (good) creative thinking skills, followed by level 3 (very good) with 18 students (43.90%), and level 1 (fair) with 3 students (7.32%). Looking at each sub-skill, fluency had the highest performance with 31 students (75.61%) at level 3 (very good). For originality, elaboration, and flexibility, most students scored at level 2 (good) with 58.54%, 56.10%, and 53.66% respectively. Assessment results show that creative thinking skills (good level and above) exceeded the 75% criterion with 38 students (92.68%) passing. All sub-skills met the criteria, led by fluency at 100.00%, followed by flexibility at 92.68%, while originality and elaboration both achieved 90.24%.

For part 2, the comparison of mean creative thinking skill scores with the quality criterion is presented. A one-sample t-test was used to compare the post-learning mean scores with the good criterion (2.00). The results are presented in Table 2. The table shows the overall creative thinking skills mean score was 2.38 (S.D.=0.36) which was significantly higher than the 2.00 criterion (t=6.846, p=0.000). All four sub-skills also exceeded the criteria significantly (p<0.05), ranked highest to lowest: fluency (2.76), flexibility (2.32), elaboration (2.24), originality (2.22).

Table 1. Creative thinking levels and evaluation results against criteria (N=41)

Sub-skill (creative thinking)	Level 0 (needs improvement) n (%)	Level 1 (fair) n (%)	Level 2 (good) n (%)	Level 3 (very good) n (%)	Number meeting criteria (level 2+3) Percentage of students passing the criteria	Evaluation result (criteria 75%)
1. Originality	0	4 (9.76)	24 (58.54)	13 (31.71)	37 (90.24)	Passed
2. Fluency	0	0 (0)	10 (24.39)	31 (75.61)	41 (100.00)	Passed
3. Flexibility	0	3 (7.32)	22 (53.66)	16 (39.02)	38 (92.68)	Passed
4. Elaboration	0	4 (9.76)	23 (56.10)	14 (34.15)	37 (90.24)	Passed
Total	0	3 (7.32)	20 (48.78)	18 (43.90)	38 (92.68)	Passed

Table 2. Post-learning creative thinking scores compared with the criterion (2.00)

Sub-skill (creative thinking)	n	($\bar{X}$)	S.D.	Test value	t	p-value (sig.)
1. Originality	41	2.22	0.61	2.00	2.293*	0.027
2. Fluency	41	2.76	0.43	2.00	11.136*	0.000
3. Flexibility	41	2.32	0.61	2.00	3.329*	0.002
4. Elaboration	41	2.24	0.62	2.00	2.504*	0.016
Total	41	2.38	0.36	2.00	6.846*	0.000

*Statistically significant at the .05 level (p<0.05)

3.1.2. Science process skills assessment results

The researcher presents the data analysis in two parts: i) quality levels and percentage meeting the criteria, and ii) mean score comparison with the criteria. For part 1, the quality levels of science process skills are analyzed. The analysis of all eight science process skills is presented in Table 3.

From Table 3, most students (25 students, 60.98%) achieved level 3 (very good) overall science process skills, followed by level 2 (good) with 11 students (26.83%), level 1 (fair) with 4 students (9.76%), and level 0 (needs improvement) with 1 student (2.44%). Looking at individual skills, all skills had a majority at level 3 (very good). The highest was using space/time relationships (87.80%), then organizing data and communicating (80.49%), inferring (75.61%), classifying (65.85%), predicting (60.98%), measuring (57.93%), observing (54.15%), and using numbers (43.90%).

Overall, 85.37% of students (35 out of 41) achieved the good level or above in science process skills, exceeding the 75% criterion. Every single skill passed the evaluation criteria. From highest pass rates: inferring led at 97.56%, then organizing data and communicating and predicting both at 95.12%, observing and using space/time relationships at 92.68%, measuring at 90.24%, using numbers at 85.37%, and classifying at 75.61%.

For part 2, the comparison of mean science process skill scores with the quality criterion is presented. The post-learning mean scores were compared with the good quality criterion (2.00) using a one-sample t-test. The results of this comparison are shown in Table 4. The table shows the overall science process skills mean score was 2.52 (S.D.=0.27)-significantly higher than the 2.00 criterion (t=12.364, p=.000). Every skill beat the criterion at p<.05. Highest to lowest means: using space/time relationships (2.80), organizing data and communicating (2.76), inferring (2.73), predicting (2.56), measuring (2.48), observing (2.47), classifying (2.41), using numbers (2.29).

Table 3. Science process skill levels and evaluation results against criteria (N=41)

Sub-skills (science process skills)	Level 0 (needs improvement) n (%)	Level 1 (fair) n (%)	Level 2 (good) n (%)	Level 3 (very good) n (%)	Number meeting criteria (level 2+3) Percentage of students passing the criteria	Evaluation result (criteria 75%)
1. Observing	0	3 (7.32)	16 (38.54)	22 (54.15)	38 (92.68)	Passed
2. Classifying	0	10 (24.39)	4 (9.76)	27 (65.85)	31(75.61)	Passed
3. Measuring	0	4 (10.37)	13 (31.71)	24 (57.93)	37 (90.24)	Passed
4. Using numbers	1 (2.44)	5 (12.20)	17 (41.46)	18 (43.90)	35 (85.37)	Passed
5. Using space/time relationships	0	3 (7.32)	2 (4.88)	36 (87.80)	38 (92.68)	Passed
6. Organizing data and communicating	0	2 (4.88)	6 (14.63)	33 (80.49)	39 (95.12)	Passed
7. Inferring	0	1 (2.44)	9 (21.95)	31 (75.61)	40 (97.56)	Passed
8. Predicting	0	2 (4.88)	14 (34.15)	25 (60.98)	39 (95.12)	Passed
Total	1 (2.44)	4 (9.76)	11 (26.83)	25 (60.98)	35 (85.37)	Passed

Table 4. Post-learning science process skill scores compared with the criterion (2.00)

Sub-skills (science process skills)	n	($\bar{X}$)	S.D.	Test value	t	p-value (sig.)
1. Observing	41	2.47	0.29	2.00	10.394*	0.00
2. Classifying	41	2.41	0.87	2.00	3.068*	0.04
3. Measuring	41	2.48	0.41	2.00	7.497*	0.00
4. Using numbers	41	2.29	0.78	2.00	2.395*	0.02
5. Using space/time relationships	41	2.80	0.56	2.00	9.242*	0.00
6. Organizing data and communicating	41	2.76	0.54	2.00	9.005*	0.00
7. Inferring	41	2.73	0.50	2.00	9.348*	0.00
8. Predicting	41	2.56	0.59	2.00	6.05*	0.00
Total	41	2.52	0.27	2.00	12.364*	0.00

*Statistically significant at the 0.05 level ($p<0.05$)

3.1.3. Development trends of creative thinking and science process skills during learning management

The researcher tracked and assessed student development during the seven learning management plans. These assessments were used to examine changes in mean scores for both skill areas. Figure 2 shows that both creative thinking skills and science process skills consistently improved across all seven learning management plans. Although science process skills exhibited a slight decline in plan 3 (2.29), this was likely attributable to students adapting to increased content complexity or more challenging activities, and the scores subsequently showed a clear recovery. By the final plan, the mean scores reached their highest levels: 2.56 for science process skills and 2.36 for creative thinking skills.

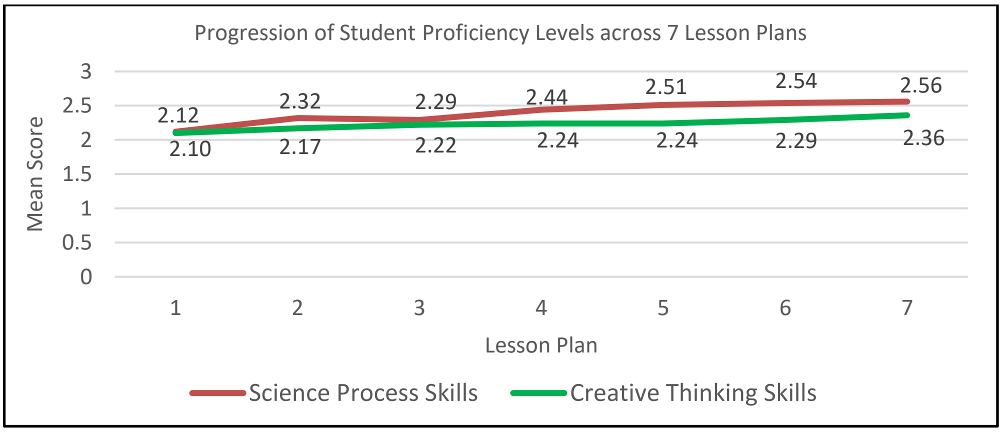

Figure 2. Development trends of mean scores for creative thinking skills and science process skills classified by learning management plans 1-7 (N=41)

3.2. Discussion

The results from using the learning management innovation based on PhBL combined with PBL to promote creative thinking skills and science process skills among primary school students are presented in this section. The innovation was developed by the researcher. The researcher discusses the findings in two main issues.

3.2.1. Creative thinking skills

The findings indicated that 92.68% of students achieved creative thinking skills at good level or above, exceeding the target criterion of 75%, with a mean score ($\overline{X}$=2.38) significantly higher than the good quality criterion (2.00) at the 0.05 level. The consistently increasing trend across all seven learning management plans (from 2.10 to 2.36) suggests that creative thinking development was progressive and cumulative rather than incidental. This indicates that the integrated PhBL-PBL innovation produced a sustained developmental effect across all four sub-components: fluency, flexibility, originality, and elaboration.

The first mechanism concerns phenomenological anchoring as a driver of divergent thinking. By grounding each lesson in authentic, relatable situations such as PM 2.5 air pollution, students were repeatedly prompted to observe, question, and generate responses to problems that held genuine personal relevance. Facing open-ended, real-world problems naturally pushed students beyond single-answer thinking toward exploring multiple perspectives, directly enhancing fluency and flexibility. This type of phenomenological framing positions learners as active sense-makers rather than passive recipients of information, consistent with PhBL principles emphasizing problem-solving grounded in real situations [21], [33], and further supported by Saberi and Nouri [19], who demonstrated that PhBL science instruction engages learners in generating multiple hypotheses and creative explanations, reflecting the divergent nature of phenomenon-based inquiry.

The second mechanism involves play-based psychological safety as a condition for originality and risk-taking. Originality and flexibility are particularly sensitive to evaluative pressure, as students who feel pressure to perform correctly tend to default to conventional responses. The play-based structure of the innovation addressed this by creating a low-stakes environment in which experimentation was not only permitted but expected, reducing performance anxiety and enabling students to propose unconventional solutions with greater confidence. This aligns with Ekeh [34], who demonstrated that play-based pedagogy cultivates creative and divergent thinking by freeing learners from evaluative constraints and enabling them to explore novel solutions, and is further supported by Alotaibi [35], whose meta-analysis reported moderate-to-large effects of game-based learning on both cognitive development and motivation outcomes. The empirical studies of Garaigordobil *et al.* [36], who demonstrated significant gains in verbal and graphic creativity through cooperative-creative play programs, and Fasha and Ruqoyyah [37], who found that game-assisted instruction enhanced scientific creative thinking in primary school students, further corroborate these findings.

Taken together, these two mechanisms functioned synergistically rather than independently. PhBL provided the purpose and intellectual challenge, while PBL provided the affective conditions necessary for students to engage with that challenge creatively. Critically, neither mechanism alone would have been sufficient, as phenomena without psychological safety may have produced anxiety rather than curiosity, while play without authentic cognitive challenge may have produced engagement without intellectual depth. The progressive improvement observed across all seven learning plans suggests that repeated exposure to this combined structure allowed students to internalize creative habits of mind over time, rather than demonstrating isolated bursts of creative performance. This finding is consistent with Khaemmanee [38], who emphasized that systematic innovation development and pilot testing are essential to achieving meaningful and reliable learning outcomes in authentic classroom contexts.

3.2.2. Science process skills

The findings indicated that 85.37% of students achieved science process skills at good level or above, exceeding the target criterion of 75%, with a mean score ($\overline{X}$=2.52) significantly higher than the good quality criterion (2.00) at the .05 level. The consistently increasing trend in average scores across all seven learning management plans (from 2.12 to 2.56) suggests that science process skill development was progressive and sustained throughout the implementation period. Although a slight slowdown was observed in plan 3, likely reflecting students' adaptation to increased content complexity, scores recovered and surged markedly in subsequent plans, indicating that initial difficulty did not impede overall developmental trajectory.

These outcomes may be interpreted through three key mechanisms embedded in the innovation's design. The first is the use of authentic real-world situations as the foundation for learning. Phenomena such as the Wild Boar cave rescue case and PM 2.5 air pollution were selected to engage students in observing complex details, inferring from cause analysis, and predicting possible solutions within meaningful contexts. This approach is consistent with Silander [14], who stated that learning through authentic contexts stimulates self-exploration and explanation, and is empirically supported by Akkas and Cevat [39], whose experimental study demonstrated that PhBL produced significant gains in students' metacognitive awareness, enabling them to monitor and regulate their own reasoning as they engaged with real-world scientific questions.

The second mechanism is the integration of play as a vehicle for authentic skill practice. Activities were designed so that measuring and using numbers occurred through hands-on equipment use, classifying through material differentiation, space/time relationships through layout planning, and predicting through anticipating play outcomes. This design draws on Piaget [40] explanation that symbolic play enables children to assimilate reality into their cognitive structures through diverse actions and exploration, supported by empirical evidence that primary-age learners demonstrate concrete operational abilities such as classification, conservation, and reversibility most effectively through direct, hands-on experience [41]. It is further grounded in Dewey [42] learning by doing concept, which emphasized direct experience and reflection as foundations for meaningful learning, as supported by evidence that structured experiential activities foster deeper engagement and skill development in authentic contexts [43]. Together, these perspectives affirm that play serves as a natural and effective vehicle for children's learning and skill development [24]. The collaborative dimension of these play activities further reflects Vygotsky's social interaction theory [44], [45], supported by empirical evidence demonstrating that cooperative learning positively develops science process skills in elementary science students [46]. With broader meta-analytic evidence further confirming that cooperative learning in science education produces consistently large effects on student outcomes across diverse contexts [47]. This theoretical foundation is reinforced by recent empirical studies, including Peppler *et al*. [48] who found that play-based exploration with hands-on circuitry materials significantly helps young children explore and develop understanding of scientific concepts, and Kewalramani *et al*. [49] who demonstrated that science, technology, engineering and mathematics (STEM)-based play integration fosters scientific inquiry and design thinking.

The third mechanism is the structured progression across learning plans, which was designed to scaffold skill development incrementally. Students were given opportunities to consolidate foundational skills in earlier plans before engaging with more complex applications in later ones, consistent with scaffolding principles grounded in Vygotsky's zone of proximal development [44]. This is supported by Sasse *et al*. [50] who demonstrated that responsive teacher scaffolding adapted to students' needs during primary school science inquiry significantly supports procedural knowledge development, affirming the critical role of guided support in advancing learning within students' developmental range.

The absence of a control group or pre-test data was a deliberate methodological decision grounded in ethical considerations appropriate to primary school contexts. This design limitation is acknowledged; however, the consistency of progressive improvement across all seven learning plans, combined with continuous formative observation and expert-validated instruments, provides sufficient evidence to support the conclusion that observed outcomes reflect the effect of the pedagogical intervention. Nonetheless, the findings are bounded by the study's single-school context and relatively small sample of 41 students, which limits generalizability. Replication across diverse school settings and larger samples would strengthen the external validity of these conclusions. The reliability of the findings is further affirmed through systematic instrument development and expert validation procedures conducted during the R&D process.

These findings carry broader ramifications for primary science education. At the classroom level, they demonstrate that developmentally appropriate integration of phenomenon-based and play-based approaches is not only feasible but empirically effective in real teaching conditions, not merely in controlled or laboratory settings. At the policy level, the results suggest that curriculum frameworks prioritizing rote content delivery may be systematically undermining the development of foundational science competencies. The integrated PhBL-PBL model offers a concrete, evidence-based alternative that curriculum designers and policymakers in Thailand and comparable educational contexts can adopt or adapt. More broadly, these findings contribute to a growing international consensus that early science education must move beyond content transmission toward inquiry-based, contextually meaningful pedagogies if 21st-century competencies are to be genuinely cultivated. Teachers are encouraged to draw on current, contextually relevant phenomena as learning anchors, and to adopt a facilitative role that prioritizes psychological safety and student agency. Future research employing quasi-experimental or experimental designs with control groups would further strengthen causal claims. Longitudinal investigations examining the durability of acquired skills, as well as studies exploring how this model transfers across different subjects and grade levels, would also contribute meaningfully to the evidence base for integrated pedagogical approaches in primary science education.

4. CONCLUSION

This study is important because it shows how integrating PhBL-PBL can effectively develop both science process skills and creative thinking in young learners, providing a practical and evidence-based approach for improving primary science education. The findings provide empirical evidence that students achieved significantly higher scores than the established criteria across all assessed dimensions, with a consistent upward trend throughout the implementation, confirming the effectiveness of the integrated learning innovation. This study provides the first empirical demonstration of an integrated PhBL-PBL approach at the primary school level, showing how both methods can be combined within a single pedagogical framework to enhance science process skills and creative thinking simultaneously. This addresses a significant gap in existing research, where these approaches have typically been examined in isolation. Theoretically, this study demonstrates the synergy between PhBL and PBL, showing how the integration of real-world phenomena and play can support both cognitive and creative development in primary science education. Practically, this study provides a developmentally appropriate instructional model for primary science. These findings support the redesign of primary science curricula toward more inquiry-based and play-integrated approaches aligned with 21st-century learning goals. For practical implementation, teachers can design lessons around real-world issues (environmental problems) and embed structured play activities that allow students to explore, experiment, and reflect on their findings. Future research should extend this model across different subjects and grade levels, as well as employ longitudinal and quasi-experimental designs to examine the durability and generalizability of the observed learning outcomes.

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C : **C**onceptualization
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Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

Informed consent was obtained from all parents of participating students.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the Human Research Ethics Committee, Chiang Mai University (Research Code: CMUREC 67/369).

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [PT], upon reasonable request.

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