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The Effectiveness of Problem-Based Learning Integrated with Differentiated Instruction (PBL-DI) on Elementary Students' Science Learning Outcomes and Creative Thinking Skills

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Abstract: Science learning in elementary schools plays an essential role in developing students' conceptual understanding, scientific literacy, and higher-order thinking skills. However, classroom instruction in heterogeneous settings often faces challenges in accommodating students' diverse readiness, interests, and learning profiles, which may limit optimal learning outcomes. This study aims to examine the effectiveness of Problem-Based Learning integrated with Differentiated Instruction (PBL-DI) in improving elementary school students' science learning outcomes and creative thinking skills on ecosystem topics. This study employed a quantitative approach using a quasi-experimental design with a non-equivalent control group design. The population of this study consisted of fifth-grade students in an elementary school in Bekasi Regency, Indonesia. The sample involved 42 students selected through a purposive sampling technique, consisting of an experimental group (20 students) that received the PBL-DI model and a control group (22 students) that received the Problem-Based Learning (PBL) model. Data were collected using science learning achievement tests and creative thinking skills tests administered before and after the intervention. Data analysis was conducted using paired-samples t-test, independent-samples t-test, and normalized gain (N-gain) analysis. The results showed that both groups experienced significant improvements in science learning outcomes and creative thinking skills. However, the PBL-DI group demonstrated consistently higher performance compared to the PBL group. The independent-samples t-test results showed significant differences between the experimental and control groups in science learning outcomes ($t(40) = 2.777$, $p = 0.008$) and creative thinking skills ($t(40) = 2.396$, $p = 0.021$). Furthermore, the N-gain analysis indicated that the PBL-DI group achieved moderate improvement in science learning outcomes ($g = 0.61$) and creative thinking skills ($g = 0.66$), which were higher than those of the PBL group. In conclusion, the integration of Problem-Based Learning and Differentiated Instruction (PBL-DI) is an effective and adaptive instructional approach for elementary science education. This model supports student-centered learning by facilitating meaningful problem-solving activities while accommodating students' diverse learning needs, thereby enhancing conceptual understanding and creative thinking skills.

Keyword : Problem-Based Learning; Differentiated Instruction; Science Learning; Creative Thinking; Elementary School

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Introduction

Science instruction at the elementary education level serves a vital function in cultivating learners' competence in scientific understanding, fostering sophisticated intellectual reasoning abilities, and enabling students to interpret natural occurrences through scientific frameworks. Modern approaches to science pedagogy recognize that knowledge acquisition transcends the mere dissemination of established scientific principles; rather, it constitutes a dynamic process wherein learners construct understanding through exploratory activities, systematic observation, hands-on investigation, and critical examination of scientific data (Urdanivia Alarcon et al., 2023). Empirical research demonstrates that when science curricula emphasize investigative methodologies and authentic problem-solving situations rooted in learners' contexts, notable improvements occur in students' capacity for logical scientific reasoning, analytical thinking, and the synthesis of theoretical concepts with practical, everyday applications (Wiyarsi et al., 2021; Chen & Chen, 2025). Consequently, elementary science instruction should be structured as an engaging learning experience that motivates students to independently investigate phenomena, critically examine evidence, and develop solutions to authentic scientific challenges.

The educational demands of the contemporary era necessitate a transformation in science pedagogy toward instructional methods centered on student agency and situated, experiential learning that cultivate analytical reasoning, innovative thinking, interpersonal competence, and cooperative learning abilities (Thornhill-Miller et al., 2023). Within the Indonesian educational framework, this pedagogical transformation manifests through the deployment of the Independent Curriculum model, which prioritizes adaptable, purposeful, and individualized instruction calibrated to students' distinctive developmental profiles (Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi [Kemendikbudristek], 2024). The merger of natural sciences with social sciences into an integrated Natural and Social Sciences (IPAS) subject is intended to furnish learners with comprehensive conceptual understanding by means of situated, real-world educational encounters (Kemdikbud, 2022). Notwithstanding these curricular intentions, practical implementation of science education in elementary contexts encounters persistent obstacles stemming from instructional practices that insufficiently respond to the heterogeneity of student preparedness, motivational interests, and individual learning orientations. Standardized teaching approaches frequently produce inequitable outcomes—disadvantaging struggling learners while simultaneously depriving advanced learners of requisite intellectual stimulation (Tomlinson, 2017; Kahmann et al., 2022).

The heterogeneity inherent in student populations constitutes a significant pedagogical consideration, as elementary learning environments encompass learners possessing variable levels of foundational understanding, intellectual capacity, and developmental readiness. Empirical investigations have demonstrated that instruction calibrated to accommodate individual learner variations enhances student engagement and academic achievement by aligning educational experiences with particular learner requirements (Liou et al., 2023). Research evidence indicates that instruction modified to address learner variance fosters increased student involvement and furnishes more tailored educational pathways within classrooms characterized by cognitive and ability diversity (Digna & Widyasari, 2023). Additionally, differentiated approaches to instruction empower educators to respond flexibly to variations in learners' developmental preparedness, personal motivational inclinations, and distinctive learning characteristics, thereby fostering substantively richer educational experiences (T. G. G. and X. Chen, 2020; Pozas et al., 2021). These research conclusions indicate that effective science instruction demands pedagogical strategies capable of sustaining intellectual rigor whilst simultaneously extending appropriate scaffolding and assistance to learners exhibiting differing learning circumstances. Consequently, differentiated instructional approaches represent a pertinent pedagogical solution, as they facilitate educator responsiveness in modifying instructional substance, instructional procedures, and learning output modalities in correspondence with learners' developmental readiness, academic interests, and individual learning characteristics (Tomlinson, 2017).

Problem-based learning (PBL) is one of the instructional models considered suitable for developing scientific thinking skills because it positions authentic problems as stimuli for investigation, analysis, and solution development. Several studies have demonstrated that PBL can improve higher-order thinking skills, scientific reasoning, and collaborative learning through inquiry-based activities (Darmawati & Mustadi, 2023 ; Jannah et al., 2022 ; Wei et al., 2024). Nevertheless, the effectiveness of PBL implementation in heterogeneous classrooms remains a challenge because students have different levels of cognitive readiness and problem-solving abilities (Sweller et al., 2019). Students with higher readiness may independently explore problems, whereas students with lower readiness often require structured guidance and scaffolding to participate effectively in the problem-solving process (Van Geel et al., 2022). This condition indicates that PBL alone may not be sufficient to accommodate diverse learners without additional instructional support.

The integration of PBL and differentiated instruction (PBL-DI) provides an alternative framework for addressing these challenges by combining inquiry-based problem-solving with adaptive learning support. PBL facilitates students to construct knowledge through authentic investigations, while differentiated instruction ensures that learning experiences are adjusted according to students' readiness, interests, and learning profiles. Previous studies have confirmed that PBL promotes students' engagement, problem-solving abilities, and higher-order thinking skills, while differentiated instruction supports achievement and meaningful learning experiences in diverse classrooms (Mursid et al., 2022 ; Liou et al., 2023 ; Wibowo et al., 2024).

However, studies examining the integration of PBL and differentiated instruction in elementary science learning remain limited, particularly in relation to improving learning outcomes and creative thinking skills. Therefore, this study aims to analyze the effectiveness of Problem-Based Learning integrated with Differentiated Instruction (PBL-DI) in improving students' science learning outcomes and creative thinking skills in elementary schools.

Methodology

Research Model

This investigation adopted a quantitative research methodology employing a quasi-experimental research design. The analytical framework selected was a nonequivalent control group design, which incorporated two pre-existing, intact classroom cohorts—specifically an intervention group and a comparison group. This particular design was chosen due to the practical constraints inherent in the research context, wherein the study was situated within authentic classroom environments where the random assignment of individual learners to different groups would prove logistically unfeasible.

The intervention group received instructional treatment utilizing an integrated approach combining Problem-Based Learning with Differentiated Instruction (PBL-DI), whereas the comparison group engaged in conventional Problem-Based Learning (PBL) instruction. Both classroom cohorts completed an initial assessment instrument prior to receiving their respective instructional interventions and subsequently completed a concluding assessment following the completion of instruction. These evaluation instruments were administered to assess the extent to which students demonstrated mastery of scientific concepts and academic content, as well as to evaluate the development of their inventive and creative intellectual capabilities. In order to furnish an explicit and organized examination of the variations between the intervention and comparison groups across each phase of the research—encompassing the baseline assessment, the instructional intervention period, and the concluding assessment—the methodological framework was organized and illustrated in tabular presentation format, as demonstrated in Table 1.

Table 1. Non-equivalent Control Group Design

Group	Pretest	Treatment	Posttest
Eksperimental	O_1	X_1 (PBL-DI)	O_2
control	O_3	X_2 (PBL)	O_4

Description:
O_1 = pretest score of the experimental group
O_2 = posttest score of the experimental group
O_3 = pretest score of the control group

O_4 = posttest score of the control group
X_1 = PBL integrated with differentiated instruction
X_2 = PBL learning model

Participants

The research participants comprised fifth-grade learners attending elementary schools located within Bekasi Regency, Indonesia. The broader population from which participants were drawn encompassed students enrolled in selected state-funded elementary institutions demonstrating comparable patterns of academic achievement and performance.

Purposive sampling methodology was employed for sample recruitment, with selection criteria based on classroom-level equivalence, baseline academic standing, and input from classroom educators. The overall participant cohort totaled 42 learners, distributed as follows: 20 students comprising the intervention group and 22 students forming the comparison group.

Fifth-grade learners were designated as the target population because this developmental stage corresponds with cognitive capacities enabling engagement in systematic logical reasoning, elementary analytical processes, and the transference of scientific principles to authentic, practical contexts. The pedagogical content utilized throughout the investigation centered on ecosystems, encompassing topics such as living and non-living environmental components, interrelationships between organisms, energy transfer chains, interconnected food systems, equilibrium within ecosystems, and sustainability practices.

Data Collection Tools

Information gathering in this investigation utilized two primary measurement instruments: an academic achievement examination in natural sciences and an analytical assessment of imaginative reasoning capabilities. The science achievement instrument was constructed in accordance with the IPAS Phase C educational standards with emphasis on ecosystem-based content. The examination incorporated multiple-response items structured to evaluate cognitive performance across various intellectual levels including comprehension, utilization, analytical examination, critical appraisal, and inventive synthesis as delineated by the contemporary taxonomy of learning objectives (Anderson & Krathwohl, 2001). The assessment was engineered to evaluate learners' capacity to synthesize scientific principles when addressing practical, real-world challenges.

The inventive thinking assessment incorporated open-ended response formats permitting learners to formulate numerous alternative approaches to scientific inquiries. This instrument was constructed according to four measurable dimensions of inventive thinking: productivity, versatility, novelty, and detailed expansion (M. A. Runco et al., 2014).

Both measurement instruments underwent rigorous evaluation by disciplinary experts to verify construct validity and ensure correspondence with intended learning constructs. The validation procedure encompassed assessment of indicator appropriateness, alignment with instructional aims, semantic precision, and technical instrument construction. Quantitative Content Validity Ratio (CVR) assessment revealed that every instrument item demonstrated a CVR coefficient of 1.00, signifying that all components possessed adequate validity for implementation purposes. Subsequently, instruments underwent pilot testing with a student population distinct from the primary research cohort. Internal consistency verification was performed through Cronbach's Alpha coefficient calculation. The science achievement apparatus demonstrated an internal consistency coefficient of 0.945, whilst the creative reasoning apparatus produced an internal consistency coefficient of 0.921. These quantitative indicators demonstrate that both measurement tools exhibited exceptionally robust reliability qualities and demonstrated appropriateness for information collection purposes.

Data Collection Process

Information collection transpired across three sequential stages: preliminary preparation, active instruction, and culminating assessment. During the preliminary preparation phase, instructional designs, pedagogical resources, and measurement tools were formulated and subjected to expert validation. Throughout the active instruction stage, the intervention group received instruction employing the integrated PBL-DI methodology, whereas the comparison group participated in conventional PBL-based instruction.

The instructional application of PBL-DI synthesized problem-centered learning methodologies with customized instruction precepts by differentiating instructional substance, instructional procedures, and learning output formats. Instruction commenced by introducing ecosystem-related authentic dilemmas utilizing diversified instructional materials encompassing written content, visual representations, multimedia resources, and experiential circumstances. Learners subsequently structured their educational endeavors contingent upon their developmental preparedness, personal curiosities, and idiosyncratic learning orientations.

Throughout the information-gathering phase, learners accumulated evidence, scrutinized findings, and formulated resolutions accompanied by strategic instructional support. In the concluding phase, learners communicated their educational accomplishments employing varied communicative modalities including visual displays, written compositions, pictorial representations, three-dimensional constructs, or oral communications. Information examination employed quantitative descriptive and comparative analytical methodologies. Quantitative description was implemented to report central tendencies, variability estimates, floor values, and ceiling values for both measured constructs.

Comparative examination encompassed paired comparison t-analysis to determine distinctions between baseline and concluding measurements within each participant group. Group-level comparison t-analysis was applied to evaluate distinctions in achievement and creative reasoning between the intervention and comparison cohorts. Furthermore, proportional improvement analysis was implemented to ascertain the magnitude of development in both constructs. Proportional improvement classifications were demarcated as minimal ($g < 0.3$), intermediate ($0.3 \le g < 0.7$), and substantial ($g \ge 0.7$).

All quantitative analytical procedures were executed utilizing IBM SPSS statistical software. Quantitative descriptive analysis, distributional normality verification, equivalence evaluation, paired comparison t-analysis, and group comparison t-analysis were all executed to process the accumulated information.

Result and Discussion

Finding

1. **Comparison of Science Learning Outcomes and Creative Thinking Skills between PBL and PBL-DI Groups**

The descriptive analysis results show differences in science learning outcomes and creative thinking skills between students taught using Problem-Based Learning (PBL) and those taught using Problem-Based Learning integrated with Differentiated Instruction (PBL-DI). The PBL-DI group obtained higher mean scores in both science learning outcomes and creative thinking skills compared to the PBL group.

Table 2. Descriptive Statistics of Science Learning Outcomes and Creative Thinking Skills

Variabel	Group			
	PBL		PBL - DI	
Science Learning Outcomes	N	22	N	20
	Mean	73.41	Mean	80.25
	Median	75	Median	80
	Modus	80	Modus	85
	St. Deviasi	7.62	St. Deviasi	8.35
	Maksimum	85	Maksimum	95
	Minimum	60	Minimum	65
Creative Thinking Skills	N	22	N	20
	Mean	77.84	Mean	82.81
	Median	76.56	Median	84.38

	Modus	75	Modus	84.38
	St. Deviasi	7.77	St. Deviasi	5.32
	Maksimum	90.63	Maksimum	90
	Minimum	65.63	Minimum	75.00

Based on Table 2, the group of students who received PBL-DI learning showed higher science learning outcomes than the PBL group. The average science learning outcome in the PBL-DI group reached 80.25, while the PBL group obtained an average of 73.41. This difference indicates that the integration of differentiated learning in the PBL model contributes to student learning outcomes in science learning. In addition to science learning outcomes, the creative thinking skills of students in the PBL-DI group also showed higher achievements than the PBL group. The average creative thinking ability of the PBL-DI group was 82.81, while the PBL group was 77.84. These results indicate that learning that integrates problem solving and differentiated learning provides greater space for students to develop ideas and alternative solutions.

2. Improvement of Science Learning Outcomes after PBL-DI Implementation

Testing of improvements in science learning outcomes after the implementation of PBL integrated with differentiated learning (PBL-DI) was conducted to determine changes in student learning outcomes before and after participating in the learning process. Analysis was conducted using a paired sample t-test by comparing pretest and posttest scores in the group that received PBL-DI learning.

Table 3. Paired Sample t-test Results of Science Learning Outcomes

	Post Test	Pre Test
Mean	80.25	49.50
Variance	69.67	144.47
Df	19	
P(T≤t) two-tail	0.000	
α	0.05	

According to the findings presented in Table 3, the mean performance of learners in science academic achievement prior to receiving the instructional intervention (baseline measurement) was documented as 49.50, whereas upon conclusion of instruction implementing the integrated PBL-DI approach (concluding measurement), the mean performance ascended to 80.25. This elevation demonstrates an improvement in the mean academic achievement of 30.75 points following the implementation of the PBL-DI instructional model. The results obtained from the dependent samples t-analysis revealed a p-value of 0.000 when evaluated against the predetermined statistical significance threshold of $\alpha = 0.05$. Since this computed p-value is substantially lower than the established significance criterion ($0.000 < 0.05$), the analytical findings substantiate the existence of a statistically meaningful distinction in science learning achievement between the initial measurement period and the concluding measurement period subsequent to the application of the PBL-DI methodology.

3. Improvement of Creative Thinking Skills after PBL-DI Implementation

An assessment of creative thinking ability development was administered to examine transformations in learners' inventive reasoning capabilities preceding and following participation in instruction utilizing the PBL-DI instructional model. The analytical examination was performed employing dependent samples t-analysis by systematically contrasting baseline and concluding assessment scores for creative thinking capacity within the cohort receiving PBL-DI-based instruction.

The quantitative findings documented in Table 4 reveal that the mean creative thinking score for learners during the initial baseline assessment was 49.84, whereas upon completion of PBL-DI instruction (concluding measurement), the mean performance increased to 82.81. This elevation illustrates an average improvement of 32.97 points in creative thinking ability following the deployment of the PBL-DI instructional approach. The dependent samples t-analysis produced a p-value of 0.000 when examined against the predetermined statistical significance criterion of $\alpha = 0.05$. Because this computed p-value falls substantially below the designated significance criterion ($0.000 < 0.05$), the results substantiate the existence of a statistically significant distinction between learners' creative thinking capabilities during the initial measurement phase and the concluding measurement phase subsequent to engagement in PBL-DI instruction.

Table 4. Paired Sample t-test Results of Creative Thinking Skills

	Post-test	Pre-test
Mean	82.81	49.84
Variance	39.06	98.78
Df	19	
P(T≤t) two-tail	0.000	
α	0.05	

In addition to the increase in the average score, the change in variance from 98.78 in the pretest to 39.06 in the posttest indicates that students' creative thinking ability after PBL-DI learning has a more homogeneous distribution. These conditions indicate that PBL-DI learning provides opportunities for students with diverse learning characteristics to develop creative thinking skills through more adaptive learning activities.

4. N-Gain Analysis of Science Learning Outcomes and Creative Thinking Skills

Proportional improvement (N-gain) analysis was performed to ascertain the extent of development in students' science academic achievement and creative thinking capabilities subsequent to engagement with instruction employing both the Problem-Based Learning (PBL) and the integrated Problem-Based Learning with Differentiated Instruction (PBL-DI) pedagogical frameworks. The N-gain analytical methodology was employed to quantify the magnitude of transformation in learner performance by systematically comparing baseline assessment and concluding assessment measurements.

The quantitative findings derived from the proportional improvement analysis presented in Table 5 indicate that both instructional cohorts exhibited measurable advancement following their respective instructional experiences. Notably, the cohort receiving PBL-DI instruction demonstrated substantially greater gains relative to the cohort receiving conventional PBL instruction across both measured constructs—specifically in terms of science academic achievement and the development of creative reasoning capabilities.

Table 5. N-Gain Analysis Results

Group	Science Learning Outcomes	Category	Creative Thinking Skills	Category
PBL+DI	0.61	Moderate	0.66	Moderate
PBL	0.43	Moderate	0.58	Moderate

For science learning outcomes, the PBL-DI group achieved an N-gain of 0.61, while the PBL group achieved an N-gain of 0.43. Meanwhile, for creative thinking skills, the PBL-DI group achieved an N-gain of 0.66, while the PBL group achieved an N-gain of 0.58. Based on the N-gain category, all improvements were in the moderate category.

5. Independent Samples t-Test Analysis

A comparative samples t-analysis was implemented to ascertain whether statistically meaningful disparities existed between the intervention and comparison cohorts subsequent to the completion of the instructional intervention. The analytical findings demonstrated that posttest performance in science academic achievement differed significantly across the two groups ($t(40) = 2.777$, $p = 0.008$). The intervention cohort that received PBL-DI instruction obtained a substantially higher mean performance score ($M = 80.25$) relative to the comparison cohort receiving conventional instruction ($M = 73.41$).

Regarding the measurement of creative reasoning capabilities, the comparative samples t-analysis likewise revealed a statistically meaningful disparity between the two instructional cohorts ($t(40) = 2.396$, $p = 0.021$). These empirical findings substantiate the conclusion that the integrated PBL-DI instructional approach demonstrated superior effectiveness relative to conventional Problem-Based Learning methodology in enhancing both students' science academic achievement and the development of their inventive thinking competencies.

Discussion

The empirical findings generated through this investigation furnish quantitative substantiation that the unified integration of Problem-Based Learning methodologies with Differentiated Instruction principles (PBL-DI) produces superior outcomes in advancing both elementary learners' science academic performance and inventive reasoning competencies in comparison to traditional Problem-Based Learning (PBL) approaches. This conclusion is supported by the analytical outcomes of the comparative samples t-analysis, which documented statistically meaningful divergences between the intervention and comparison groups regarding science academic achievement ($t(40) = 2.777$, $p = 0.008$) and creative reasoning capabilities ($t(40) = 2.396$, $p = 0.021$), resulting in the negation of the null hypothesis proposition (H_0). These quantitative results elucidate that the observed distinctions separating the two instructional cohorts emerge not from random variation, but rather stem directly from the specific pedagogical intervention implemented. Furthermore, the elevated mean performance measurements and proportional improvement indices documented within the intervention cohort serve as supplementary confirmation regarding the instructional efficacy of the PBL-DI model.

The superiority of the PBL-DI model can be explained through its ability to integrate inquiry-based learning with adaptive instructional support. While Problem-Based Learning promotes active engagement and conceptual exploration, its effectiveness may be limited in heterogeneous classrooms where students have varying levels of prior knowledge and cognitive readiness. This study shows that without additional support, PBL alone may not fully optimize student learning outcomes, as reflected in the lower achievement of the control group compared to the experimental group.

From a constructivist perspective, learning is an active process of knowledge construction in which students develop understanding through interaction with problems, experiences, and social contexts. Problem-Based Learning operationalizes this principle by engaging students in authentic and contextual problems that require inquiry, collaboration, reflection, and knowledge application. Meaningful learning occurs when students actively connect new information with existing knowledge structures through problem-solving processes (Hmelo-Silver, 2004 ; Pedaste et al., 2015).

Recent studies confirm that PBL encourages active participation, conceptual understanding, and higher-order thinking skills by positioning students as active learners rather than passive recipients of information. PBL provides opportunities for students to explore scientific concepts through investigation, discussion, and problem-solving activities, thereby strengthening conceptual understanding and scientific reasoning in science learning (Dolmans & Loyens, 2016 ; Irsyad et al., 2024).

Furthermore, systematic reviews indicate that problem-based learning environments consistently promote critical thinking, problem-solving abilities, and higher-order cognitive processes through authentic inquiry and collaborative activities (Darwis et al, 2024). In this study, ecosystem-based learning activities provided contextual experiences that enabled students to connect scientific concepts with real-world environmental phenomena, thereby strengthening conceptual understanding and scientific reasoning.

Although PBL provides opportunities for active knowledge construction, constructivist learning environments do not automatically guarantee optimal learning outcomes, particularly in heterogeneous classrooms. Differences in students' prior knowledge, cognitive readiness, and learning pace may influence their ability to process complex scientific problems. Cognitive Load Theory explains that when intrinsic cognitive demands exceed learners' processing capacity, students may experience difficulties in organizing and integrating new knowledge (Sweller et al., 2019). Therefore, inquiry-based learning requires appropriate instructional support to prevent excessive cognitive demands. This condition may explain why the PBL group in this study showed improvement but achieved lower gains compared to the PBL-DI group. Recent discussions in science education emphasize that higher-order thinking development requires not only complex learning tasks but also instructional support that enables students to process scientific information effectively (Yanti & Thohir, 2024)

Differentiated Instruction plays an important role in addressing learner diversity by providing adaptive learning experiences that align with students' readiness, interests, and learning profiles. Differentiated instruction modifies learning content, processes, and products to ensure that students receive appropriate challenges and support (Tomlinson, 2017). Recent empirical studies indicate that differentiated instruction improves student engagement, participation, and academic achievement by creating personalized learning pathways. Systematic review findings also show that differentiated instruction has positive effects on learning outcomes when teachers adapt instructional strategies according to students' characteristics and learning needs (Kahmann et al., 2022 ; Liou et al., 2023 ; Pozas et al., 2021). In this study, differentiation functioned as instructional scaffolding that enabled students with different levels of readiness to participate meaningfully in scientific inquiry activities.

The integration of PBL and Differentiated Instruction (PBL-DI) creates a synergistic learning environment by balancing cognitive challenge and instructional support. This integration is consistent with Vygotsky's sociocultural theory, particularly the concept of the Zone of Proximal Development (ZPD), which emphasizes that students achieve optimal learning when provided with appropriate scaffolding. In the PBL-DI approach, differentiated instruction supports students by adjusting learning experiences according to their abilities, allowing them to engage in problem-solving activities while gradually developing independence. This finding supports previous research suggesting that adaptive and student-centered learning environments enhance learning effectiveness in diverse classrooms (Liou et al., 2023 ; Wibowo et al., 2024).

The improvement in creative thinking skills further demonstrates the effectiveness of PBL-DI. Problem-Based Learning encourages students to engage in divergent thinking through open-ended problems that require multiple perspectives and alternative solutions. These activities promote important dimensions of creativity, including fluency, flexibility, originality, and elaboration (M. Runco & Jaeger, 2012). Recent studies emphasize that inquiry-based and problem-oriented learning approaches contribute significantly to the development of students' creativity and higher-order thinking skills (OECD, 2023 ; Abdulla Alabbasi et al., 2025). Furthermore, research on creative pedagogy shows that integrating problem-oriented learning activities can strengthen students' ability to analyze problems, evaluate alternatives, and generate innovative solutions in science learning contexts. In addition, differentiated instruction strengthens creative expression by allowing students to demonstrate understanding through various learning products, such as posters, models, concept maps, and presentations. This flexibility provides students with opportunities to communicate scientific ideas in creative and meaningful ways.

The N-gain analysis confirmed that both groups experienced improvement; however, the PBL-DI group consistently achieved higher gains in science learning outcomes and creative thinking skills. The higher N-gain scores indicate that instructional adaptation enhances the effectiveness of inquiry-based learning by reducing cognitive barriers and increasing student engagement. Similar findings have been reported in previous research showing that combining problem-based learning with adaptive instructional strategies produces more meaningful and consistent learning improvements (Almulla, 2023 ; Zhao et al., 2024).

The N-gain analysis further supports these findings, showing that both groups experienced improvement; however, the PBL-DI group consistently achieved higher gains in both science learning outcomes and creative thinking skills. This suggests that instructional adaptation reduces cognitive barriers and enhances learning effectiveness in inquiry-based environments. The moderate level of improvement also indicates that the success of PBL-DI is influenced by implementation factors such as teacher readiness, instructional design quality, classroom management, and time allocation.

Overall, the findings highlight that the effectiveness of PBL-DI lies in the integration of three theoretical foundations: constructivism, Cognitive Load Theory, and Differentiated Instruction Theory. Constructivism emphasizes active knowledge construction, Cognitive Load Theory highlights the importance of managing cognitive demands, and Differentiated Instruction ensures learning accessibility for diverse learners. The convergence of these theories positions PBL-DI as an effective instructional model for improving both cognitive achievement and creative thinking skills in elementary science education.

The novelty of this study lies in demonstrating that the integration of differentiated instruction into Problem-Based Learning significantly enhances both academic achievement and creative thinking skills in elementary science classrooms, an area that has received limited attention in previous research. This finding provides empirical support for the importance of combining instructional adaptability with inquiry-based pedagogy to address learner diversity more effectively.

In practical terms, this study suggests that teachers should not rely solely on inquiry-based approaches but also incorporate differentiated strategies to accommodate students' varying abilities. The implementation of PBL-DI requires careful instructional planning, continuous classroom adjustment, and teacher readiness to design flexible learning pathways.

In conclusion, this study provides strong empirical evidence that PBL-DI is more effective than conventional PBL in improving elementary students' science learning outcomes and creative thinking skills. The integration of inquiry-based learning with differentiated instruction offers a more inclusive, balanced, and effective pedagogical approach for supporting diverse learners in science education.

Conclution

This investigation concludes that the unified integration of Problem-Based Learning pedagogy and Differentiated Instruction principles (PBL-DI) constitutes an efficacious pedagogical strategy for advancing elementary-level learners' science academic achievement and inventive reasoning competencies. The pedagogical efficacy of this instructional model is substantiated by the comparative samples t-analysis findings, which documented meaningful distinctions across the intervention and comparison cohorts, together with elevated proportional improvement indices documented in the PBL-DI cohort relative to the conventional PBL cohort.

The research conclusions demonstrate that the instructional superiority exhibited by PBL-DI emanates from the synthesis of investigative learning methodologies and accommodating teaching strategies. Problem-Based Learning cultivates dynamic understanding development through engagement in authentic problem-solving endeavors, cooperative learning experiences, and metacognitive reflection, whereas Differentiated Instruction furnishes pedagogical modifications that address heterogeneity in learner preparedness, individual instructional requirements, and intellectual capability variations. This pedagogical merger cultivates more substantive, learner-autonomous, and educationally inclusive science instruction within elementary educational contexts.

The distinctive contribution of this research resides in demonstrating empirically that the incorporation of differentiated instructional methods within Problem-Based Learning frameworks produces benefits extending beyond conventional cognitive academic accomplishment, simultaneously generating substantial enhancements in learners' imaginative intellectual capabilities within elementary science educational environments.

The investigation acknowledges multiple methodological constraints. The research implementation encompassed a circumscribed participant cohort encompassing fifth-grade learners from a solitary educational institution, which potentially constrains the applicability of conclusions to broader populations. Furthermore, the instructional implementation occurred during a compressed temporal interval, precluding comprehensive examination of enduring consequences associated with sustained PBL-DI implementation.

Subsequent investigations are advised to recruit substantially larger and more heterogeneous participant samples, prolong the duration of instructional implementation, and examine the pedagogical effectiveness of PBL-DI in cultivating supplementary competency domains including scientific comprehension, logical analytical reasoning, and cooperative interaction competencies. Prospective scholarly inquiries might additionally examine its applicability across disparate developmental educational stages and alternative curricular subject domains.

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