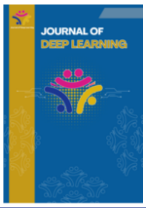

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A STEAM-Integrated Deep Learning Model with Design Thinking to Improve Elementary Students' Critical Thinking Skills

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Abstract

This study aims to analyze the effect of implementing deep learning integrated with STEAM-based pedagogical practices and Design Thinking on improving elementary school students' critical thinking skills. The study employed a quantitative approach using a quasi-experimental method with a nonequivalent control group design. The research sample consisted of 63 fifth-grade students from SD Negeri Rahayu, divided into an experimental group and a control group. The research instrument was an essay-based test that had been validated and tested for reliability to measure students' critical thinking skills. Data analysis included tests of normality, homogeneity, an independent samples t-test, and N-gain analysis. The results revealed a significant difference between the experimental and control groups, with a significance value of 0.000 ($p < 0.05$). The average post-test score of the experimental group was higher than that of the control group, indicating a more optimal improvement. The N-gain analysis showed that the experimental group fell into the moderate category, while the control group was categorized as low. These findings indicate that deep learning integrated with STEAM and Design Thinking is more effective in enhancing students' critical thinking skills. From a pedagogical perspective, the stages of Design Thinking empathize, define, ideate, prototype, and test encourage active student engagement in analysis, evaluation, and reflection processes. The integration of STEAM also provides a holistic, contextual, and multidisciplinary learning experience. Therefore, this approach has the potential to serve as an innovative alternative for 21st-century learning in developing higher-order thinking skills among elementary school students.

Keywords: deep learning, STEAM approach, design thinking model, higher order thinking skills, 21st-century learning.

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1. Introduction

In the 21st century, educational transformation is inseparable from the rapid advancement of digital technologies, globalization, and increasingly complex social dynamics. These developments require education systems to move beyond knowledge transmission toward the systematic development of essential competencies relevant to contemporary challenges. In this regard, 21st-century skills namely creativity, critical thinking and problem-solving, communication, and collaboration have become fundamental for learners (Emilidha et al., 2024). These competencies are crucial in preparing students to navigate a disruptive era in which many conventional occupations are being replaced by automation and artificial intelligence (Widarta et al., 2024). Consequently, modern education must intentionally integrate these skills to enable learners to adapt to change and leverage emerging opportunities (Nurjanah & Purwantoyo, 2023).

Among these competencies, critical thinking is particularly central. It represents a higher-order cognitive ability that enables individuals to analyze information rigorously, evaluate arguments, and make reasoned decisions based on credible evidence. In educational settings, critical thinking supports students in identifying problems, interpreting information, drawing inferences, and evaluating alternative solutions (Lailiyah & Widiyono, 2023). Moreover, it serves as a safeguard against the proliferation of misinformation in the digital age, equipping students with the capacity to critically assess the validity of information (Imaduddin et al., 2026). At the elementary level, fostering critical thinking is especially important, as it forms the foundation for future academic development and informed decision-making (Ariadila et al., 2023).

Despite its importance, evidence suggests that Indonesian students' critical thinking skills remain underdeveloped. Data from the Programme for International Student Assessment (PISA) 2018 indicate that Indonesia ranked 62nd out of 70 participating countries, with average scores in reading (371), mathematics (379), and science (389), all below the OECD average (OECD, 2018). These results highlight students' limited capacity for analysis, evaluation, and problem-solving, underscoring the urgent need for instructional innovation to enhance higher-order thinking skills.

Conceptually, critical thinking is closely linked to logical reasoning. Facione (1990) identifies reasoning as an integral component of critical thinking, particularly in evaluation and conclusion-making. Similarly, Halpern (2014) characterizes critical thinking as a deliberate and goal-directed cognitive process. Other scholars emphasize that it encompasses analysis, evaluation, interpretation, and evidence-based judgment (Facione, 2011). Thus, logical reasoning constitutes the core of critical thinking, involving the ability to construct coherent arguments, draw valid inferences, and identify weaknesses in reasoning.

Effective development of critical thinking requires instructional approaches that promote deep cognitive engagement. One such approach is deep learning, which emphasizes not only the acquisition of knowledge but also its meaningful understanding, application, and reflection in authentic contexts. However, preliminary observations in a fifth-grade classroom at SD Negeri Rahayu (November 2024) revealed that students' critical thinking skills remain suboptimal. Learning tends to be teacher-centered, with students passively receiving information, relying heavily on memorization, and demonstrating limited ability to construct logical arguments. Additionally, students show low engagement in questioning, difficulty in evaluating information from multiple sources, and limited capacity to approach problems from diverse perspectives.

These challenges indicate the need to shift from conventional instruction toward more innovative and contextual learning approaches. One promising strategy is the integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) with Design Thinking within a deep learning framework. The STEAM approach promotes interdisciplinary and contextual learning, enabling students to understand connections across domains while fostering critical and creative thinking (Angga, 2022; Wardani et al., 2023). It also incorporates the Engineering Design Process (EDP) ask, imagine, plan, create, and improve which systematically develops problem-solving skills.

Complementarily, Design Thinking offers a human-centered, iterative approach to problem-solving that emphasizes empathy, collaboration, and solution exploration (Herianingtyas et al., 2024; Rustam et al., 2024). Its stages empathize, define, ideate, prototype, and test actively engage students in authentic problem-solving processes. The integration of STEAM and Design Thinking is therefore expected to create a learning environment that not only enhances conceptual understanding but also strengthens critical thinking through active and reflective engagement (Ajid et al., 2025).

From a pedagogical perspective, deep learning further reinforces this integration by emphasizing meaningful, reflective, and contextual learning experiences. This perspective is supported by the 3P model (Presage–Process–Product) of Freeth et al (2004), Kolb's experiential learning theory, and the Habits of Mind framework (Costa & Kallick, 2020), all of which highlight the importance of active learner engagement in knowledge construction. Moreover, this approach aligns with Indonesia's educational policy, particularly the Pancasila Student Profile, which prioritizes critical thinking, creativity, collaboration, and independence (Kemendikdasmen, 2025).

Based on these considerations, this study aims to examine the effect of implementing deep learning integrated with STEAM-based pedagogical practices and Design Thinking on improving elementary school students' critical thinking skills. It also seeks to explore how this integrated approach can be effectively implemented in classroom practice. The findings are expected to contribute both theoretically and practically to the development of innovative instructional models that enhance the quality of primary education in Indonesia.

2. Method

This study employed a quantitative approach using a quasi-experimental method. The research design applied was a nonequivalent control group design, involving two groups an experimental group and a control group without full random assignment. This design was selected due to practical constraints in randomizing classes within the school setting, while still allowing for a comparative examination of treatment effects.

The population consisted of all fifth-grade students at SD Negeri Rahayu, totaling 164 students. The sample was selected using purposive sampling, based on the comparability of academic characteristics and classroom conditions. The final sample included two classes: Class VB (32 students) as the experimental group and Class VD (31 students) as the control group. The experimental group received instruction through deep learning integrated with STEAM-based pedagogical practices and Design Thinking, while the control group was taught using conventional lecture-based methods.

The research instrument was a 10-item essay test that had been validated and tested for reliability. The items were designed to assess students' critical thinking skills based on established indicators. Specifically, this study adopted six core aspects of critical thinking: focus, reason, inference, situation, clarity, and overview, as presented in Table 1. Each indicator was measured through items that captured students' abilities to identify problems, provide evidence-based reasoning, draw appropriate conclusions, understand contextual situations, articulate concepts clearly, and evaluate their decisions.

Table 1. Critical Thinking Indicators

Critical Thinking Skills	Indicators
Focus	• Identifying the main problem clearly
	• Directing attention to the core issue under discussion
Reason	• Providing answers supported by logical reasoning based on relevant facts/evidence
	• Evaluating whether the given reasons are logically valid for drawing conclusions
Inference	• Drawing appropriate and accurate conclusions
	• Ensuring that the reasoning sufficiently leads to a valid conclusion
Situation	• Understanding and maintaining contextual awareness to clarify the problem
	• Comparing with real-world situations
Clarity	• Explaining the meaning of terms used clearly
	• Ensuring clarity of terms and explanations to avoid misinterpretation in conclusions
Overview	• Reviewing and thoroughly examining the decisions made
	• Evaluating findings, decisions, and conclusions comprehensively

Data were collected through the administration of a pre-test and a post-test to both the experimental and control groups. The pre-test was used to assess students' baseline abilities, while the post-test measured improvements in critical thinking skills following the intervention.

Data analysis was conducted in several stages. First, normality was assessed using the Kolmogorov–Smirnov test to determine whether the data were normally distributed. Second, homogeneity of variance was examined using Levene's test (based on the mean) to ensure the equivalence of variances between the experimental and control groups (Imaduddin et al., 2026). Hypothesis testing was then performed using an independent samples t-test to identify significant differences between the two groups.

In addition, the effectiveness of learning improvement was evaluated using normalized gain (N-gain) analysis. The N-gain score was calculated to determine the extent of improvement in students' critical thinking skills after the intervention, with interpretation based on low, moderate, and high gain categories. This analysis provides a more comprehensive evaluation of the effectiveness of deep learning integrated with STEAM and Design Thinking compared to conventional instruction.

Through this methodological framework, the study is expected to yield valid and reliable findings in assessing the impact of the instructional intervention on the enhancement of elementary school students' critical thinking skills.

3. Result and Discussion

Based on the results of the data analysis and the interpretation of the research findings, the discussion focuses on several key aspects that reflect the empirical and theoretical contributions of implementing deep learning integrated with STEAM-based pedagogical practices and Design Thinking. The discussion not only highlights the quantitative improvement in students' critical thinking skills but also examines the underlying learning processes and the role of multidisciplinary integration in shaping meaningful learning experiences.

To provide a more comprehensive understanding, the discussion is structured into three interrelated themes: the effectiveness of the instructional approach, the underlying pedagogical mechanisms, and the contribution of the STEAM approach in supporting deep learning.

Table 2. Structure of Results and Discussion

Focus	Description
Overall Focus	Analysis and interpretation of findings reflecting empirical and theoretical contributions of deep learning integrated with STEAM and Design Thinking
Quantitative Findings	Improvement in students' critical thinking skills based on statistical analysis
Learning Process Analysis	Examination of underlying learning processes during the intervention
Multidisciplinary Integration	Role of STEAM integration in creating meaningful learning experiences

a. The Effectiveness of STEAM-Integrated Deep Learning with Design Thinking in Enhancing Critical Thinking Skills

The findings indicate that the implementation of deep learning integrated with STEAM-based pedagogical practices and Design Thinking has a significant impact on improving elementary school students' critical thinking skills. This improvement is not only evident from the comparison of pre-test and post-test scores but is also supported by inferential statistical analysis and effectiveness measurement using the N-gain index.

Descriptively, both the experimental and control groups showed an increase in mean scores. However, the improvement observed in the experimental group was substantially greater than that of the control group. This suggests that the implemented instructional approach makes a meaningful contribution to enhancing students' critical thinking skills, particularly within a contextual and experience-based learning environment.

Table 3. Comparison of Mean Pre-test and Post-test Scores of Critical Thinking Skills

Group	Pre-test	Post-test	Gain
Experimental	48.40	81.50	33.10
Control	44.35	70.58	26.23

As shown in Table 3, the experimental group demonstrated an improvement of 33.10 points, whereas the control group improved by only 26.23 points. The difference of 6.87 points indicates a substantial disparity in learning outcomes between the two groups. The greater improvement observed in the experimental group suggests that deep learning integrated with STEAM and Design Thinking provides a more effective learning experience in fostering students' critical thinking skills (Laksmiwati et al., 2024).

From a pedagogical perspective, this improvement can be explained by the characteristics of deep learning, which emphasize active student engagement in both cognitive and metacognitive processes (Biggs & Tang, 2011). Within this approach, students do not merely receive information but actively construct knowledge through exploration, analysis, and reflection. This is consistent with the concept of deep learning, which prioritizes conceptual understanding and the transfer of knowledge to real-world contexts (Fullan & Langworthy, 2014; Andriyani et al., 2025).

Furthermore, the integration of STEAM contributes significantly to enriching students' learning experiences through a multidisciplinary approach. Students are not only exposed to theoretical concepts but also apply them in authentic contexts involving science, technology, engineering, arts, and mathematics (Yakman, 2008; Herro & Quigley, 2016). This approach enables students to recognize connections across disciplines and develop critical thinking skills more comprehensively.

To further substantiate these findings, the effectiveness of the intervention was examined using the N-gain index, which provides a measure of the extent of students' improvement following the treatment.

Table 4. N-Gain Analysis of Critical Thinking Skills

Group	N-gain	Percentage	Category
Experimental	0.63	63.11%	Moderate
Control	0.46	46.29%	Low

As presented in Table 4, the mean N-gain score of the experimental group (0.63) falls within the moderate category, whereas the control group (0.46) is classified as low. This difference indicates that deep learning integrated with STEAM and Design Thinking is more effective in enhancing students' critical thinking skills compared to conventional instruction.

The N-gain results suggest that the instructional approach applied in the experimental group facilitates more optimal student improvement. This can be attributed to the active engagement of students throughout the learning process, which encourages critical, creative, and reflective thinking. Learning activities involving the exploration of real-world problems and collaborative solution development provide opportunities for students to develop higher-order thinking skills (Trilling & Fadel, 2009).

Furthermore, the hypothesis testing using an independent samples t-test yielded a significance value of 0.000 ($p < 0.05$), indicating a statistically significant difference between the experimental and control groups. This finding reinforces the evidence that deep learning integrated with STEAM and Design Thinking has a significant effect on improving students' critical thinking skills.

From a theoretical perspective, these findings are consistent with previous studies suggesting that problem-based and constructivist learning approaches effectively enhance critical thinking skills (Darling-Hammond et al., 2020; Bellanca, 2010). The integration of Design Thinking further contributes to the development of analytical, evaluative, and reflective abilities through its structured and iterative processes (Facione, 2011).

In conclusion, the effectiveness of deep learning integrated with STEAM and Design Thinking is demonstrated not only through improved academic performance but also through the comprehensive development of students' critical thinking processes. This approach offers an innovative alternative for addressing the demands of 21st-century education, particularly in fostering higher-order thinking skills relevant to future challenges.

b. Pedagogical Mechanisms: The Role of Design Thinking Stages in Developing Critical Thinking Skills

The improvement in students' critical thinking skills in the experimental group can be attributed not only to the implementation of the STEAM approach but also to the structured pedagogical mechanisms embedded in the stages of Design Thinking empathize, define, ideate, prototype, and test (Purnomo et al., 2026). Each stage contributes specifically to the development of different dimensions of critical thinking, making the learning process more systematic, contextual, and reflective.

The empathize stage serves as the foundation of the learning process, in which students engage in observation and interviews to understand problems directly. This stage encourages deeper and more contextual problem identification, aligning with the focus and situation dimensions of critical thinking (Adhantoro et al., 2026). Direct engagement with real-world contexts enhances students' sensitivity to problems and strengthens their initial analytical abilities.

In the define stage, students process the information gathered to formulate problems more systematically. This stage requires analytical and synthetic thinking, closely related to the reason dimension, particularly in constructing logical, evidence-based arguments. It strengthens students' ability to organize information and identify causal relationships in a structured manner (Darling-Hammond et al., 2020).

The ideate stage provides a space for students to generate multiple solution alternatives collaboratively and creatively. At this stage, students not only develop ideas but also evaluate their feasibility based on specific criteria. This reflects critical thinking in the clarity and reason dimensions, as students are required to articulate ideas clearly while considering the relevance and logical coherence of the proposed solutions (Trilling & Fadel, 2009).

Table 5. The Relationship between Design Thinking Stages and Critical Thinking Indicators

Design Thinking Stages	Learning Activities	Critical Thinking Indicators
Empathize	Observation and interviews on real-world problems	Focus, Situation
Define	Problem analysis and formulation	Reason
Ideate	Idea generation and evaluation	Reason, Clarity
Prototype	Development of solution models/products	Inference
Test	Testing and evaluation of solutions	Overview

As shown in Table 5, each stage of Design Thinking is directly aligned with specific critical thinking indicators. This alignment suggests that Design Thinking is not merely a problem-solving approach but also an effective pedagogical framework for fostering higher-order thinking skills. The empathize and define stages support the development of a deep understanding of problems, while the ideate and prototype stages encourage students to generate and refine solutions through logical analysis. The test stage provides a reflective space in which students critically evaluate the outcomes of their thinking (Purnomo et al., 2026).

More broadly, this alignment indicates that the learning process is not linear but iterative and reflective. Students are not limited to generating solutions; rather, they continuously evaluate and refine their ideas. This is consistent with the concept of metacognitive regulation in critical thinking, where individuals actively monitor and evaluate their own cognitive processes (Facione, 2011).

The prototype stage offers an applied learning experience in which students translate abstract ideas into tangible forms. This process involves inferential thinking, as students draw conclusions based on available data and evidence. Through direct implementation, students test the validity of their ideas, thereby strengthening evidence-based reasoning (Adhantoro et al., 2026).

Finally, the test stage represents a crucial evaluative phase in the development of critical thinking. At this stage, students assess the effectiveness of their solutions, receive feedback, and reflect on the outcomes. This process aligns with the overview indicator, which involves the ability to review and critically evaluate decisions in a comprehensive manner.

Table 6. Distribution of Improvements in Critical Thinking Indicators in the Experimental Group

Indicator	Pre-test	Post-test	Gain
Focus	50.20	82.10	31.90
Reason	47.85	80.75	32.90
Inference	46.30	79.60	33.30
Situation	49.10	81.25	32.15
Clarity	48.75	82.40	33.65
Overview	47.40	81.10	33.70

As shown in Table 6, all critical thinking indicators in the experimental group demonstrated relatively consistent improvement. The highest gains were observed in the overview and clarity indicators, indicating substantial development in students' evaluative and explanatory abilities (Imaduddin et al., 2025). This suggests that the test and ideate stages of Design Thinking play a significant role in fostering students' reflective and communicative skills.

The relatively uniform improvement across all indicators further indicates that the approach does not target a single dimension of critical thinking but rather integrates multiple dimensions simultaneously. This finding aligns with the principles of deep learning, which emphasize the interconnection between conceptual understanding, application, and reflection (Biggs & Tang, 2011).

Moreover, these pedagogical mechanisms support the implementation of student-centered learning, where students actively construct knowledge through direct experience. Such processes enhance both cognitive and emotional engagement, resulting in more meaningful and sustainable learning outcomes (Fullan & Langworthy, 2014).

In conclusion, the improvement in students' critical thinking skills observed in this study can be attributed not only to the STEAM approach but also to the structured, iterative, and reflective pedagogical mechanisms inherent in Design Thinking. The integration of these approaches creates a learning environment that effectively supports the development of higher-order thinking skills, making it highly relevant for 21st-century education.

c. STEAM Integration as a Holistic Framework for *Deep Learning*

The findings indicate that the integration of the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach within a deep learning framework, combined with Design Thinking, makes a significant contribution to the holistic development of students' critical thinking skills. This approach extends beyond cognitive development to include affective and psychomotor dimensions, thereby fostering more meaningful, contextualized, and problem-oriented learning experiences (Rakhmadi et al., 2025).

In practice, each STEAM component plays a complementary role in supporting the learning process. Science encourages students to understand phenomena through observation and experimentation; technology facilitates access to information and the documentation of learning processes; engineering engages students in designing and constructing solutions; arts promote creativity and aesthetic expression; and mathematics supports quantitative analysis and data-driven decision-making (Yakman, 2008; Herro & Quigley, 2016). The integration of these components enables students to approach problems from multiple perspectives and to develop more comprehensive solutions.

Table 7. The Role of STEAM Components in Deep Learning

STEAM Components	Implementation in Learning	Contribution to Critical Thinking
Science	Observation and analysis of environmental phenomena	Analysis, interpretation
Technology	Information retrieval and documentation	Information evaluation
Engineering	Design and development of prototypes	Problem-solving, inference
Arts	Creative design and presentation of solutions	Creativity, clarity
Mathematics	Measurement and data analysis	Reasoning, precision

As shown in Table 7, each STEAM component contributes uniquely to the development of critical thinking skills. Science and mathematics primarily support analytical and logical reasoning abilities, while engineering and technology foster evidence-based problem-solving skills. Meanwhile, the arts provide opportunities for students to express ideas creatively and communicate them effectively. This integration creates a balance between analytical and creative capacities, which are essential characteristics of critical thinking (Uslan et al., 2025).

The findings further indicate that STEAM-based learning is not fragmented but integrative and transdisciplinary in nature. Students do not learn concepts in isolation; rather, they develop an understanding of the interconnections among concepts within authentic contexts. This is consistent with constructivist theory, which posits that knowledge is constructed through the interaction between experience and reflection (Pangestu et al., 2026). In addition, this approach supports the development of higher-order thinking skills, including analysis, evaluation, and creation (Imaduddin et al., 2026).

Furthermore, the integration of STEAM within a deep learning framework enhances students' active engagement in the learning process. This is reflected in increased participation in discussions, exploration of ideas, and collaboration in problem-solving activities.

Table 8. Students' Level of Engagement in the Learning Process

Engagement Aspects	Experimental Group (%)	Control Group (%)
Discussion Participation	85.60	62.40
Group Collaboration	88.20	65.10
Idea Exploration	83.75	60.30
Problem Solving	86.90	68.45

As shown in Table 8, the level of student engagement in the experimental group is consistently higher than that of the control group across all aspects. This finding indicates that STEAM-based learning integrated with Design Thinking fosters a more interactive and participatory learning environment. High levels of student engagement are a key indicator of successful deep learning, as active involvement is positively associated with improved understanding and the development of critical thinking skills (Fullan & Langworthy, 2014).

This result further underscores that the STEAM approach positions students as active agents in the learning process. Rather than passively receiving information, students are actively involved in knowledge construction through collaborative and exploratory activities. This aligns with the principles of student-centered learning, which emphasize the central role of learners in the educational process (Pangestu et al., 2026). Moreover, higher engagement reflects stronger intrinsic motivation, a crucial factor in promoting meaningful learning experiences (Fadlullah et al., 2026).

In addition to enhancing engagement, the integration of STEAM also supports students' ability to apply knowledge in real-world contexts.

Table 9. Students' Ability to Apply Knowledge in Real-World Contexts

Application Aspects	Experimental Group	Control Group
Conceptual Understanding	82.40	71.20
Project-Based Application	85.75	69.85
Knowledge Transfer	80.60	67.30
Learning Reflection	83.10	70.25

As shown in Table 9, the experimental group demonstrates higher performance across all aspects of knowledge application compared to the control group. This indicates that STEAM-based learning not only enhances conceptual understanding but also strengthens students' ability to apply knowledge in real-world contexts.

These findings suggest that the integration of STEAM supports the core objectives of deep learning, namely the ability to understand, apply, and reflect on knowledge (Biggs & Tang, 2011). The higher level of knowledge transfer observed in the experimental group indicates that students are able to connect learned concepts with everyday contexts. This aligns with the view that meaningful learning occurs when new knowledge is integrated with prior experience (Adhantoro et al., 2026).

Furthermore, the strong performance in learning reflection demonstrates students' capacity to independently evaluate both their learning processes and outcomes, which is a key component of metacognitive skills. Such reflective practices enable continuous improvement in understanding and learning strategies (Fadlullah et al., 2026).

Overall, the integration of STEAM within a deep learning framework, combined with Design Thinking, has been shown to create holistic, meaningful, and future-oriented learning experiences. This approach not only enhances critical thinking skills but also fosters collaboration, creativity, and the ability to apply knowledge in authentic contexts. Therefore, it holds significant potential as an innovative instructional model for primary education in Indonesia.

4. Conclusion

Based on the findings and discussion, this study concludes that the implementation of deep learning integrated with STEAM-based pedagogical practices and Design Thinking is effective in enhancing elementary school students' critical thinking skills. Empirically, this effectiveness is evidenced by statistically significant differences between the experimental and control groups, as indicated by higher post-test mean scores and the results of the independent samples t-test ($p < 0.05$). Furthermore, the N-gain analysis shows that the experimental group achieved a moderate level of improvement, while the control group remained at a low level, confirming the superior effectiveness of the proposed approach compared to conventional instruction.

From a process-oriented perspective, the observed improvement is closely associated with the structured pedagogical mechanisms embedded in the Design Thinking stages empathize, define, ideate, prototype, and test. These stages systematically promote students' abilities in analysis, evaluation, inference, and reflection through iterative and contextual learning processes. As a result, students not only develop a deeper conceptual understanding but also demonstrate the ability to apply and evaluate knowledge in authentic contexts.

Moreover, the integration of the STEAM approach contributes to the development of holistic and multidisciplinary learning experiences. The synergy among science, technology, engineering, arts, and mathematics enables students to enhance critical thinking comprehensively, while also fostering active engagement, collaboration, creativity, and knowledge transfer. This leads to more meaningful learning, as students are directly involved in solving real-world problems.

In conclusion, deep learning integrated with STEAM and Design Thinking represents an innovative and effective instructional approach for developing higher-order thinking skills, particularly critical thinking, in primary education. This approach is therefore recommended for broader implementation in classroom practice and may serve as a reference for curriculum development and educational policy aimed at promoting 21st-century competencies. Future research is recommended to expand the scope of participants and contexts, as well as to examine the impact of this approach on other competencies such as creativity, collaboration, and digital literacy to strengthen the generalizability of the findings.

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