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Development of Deep Learning-Based Instructional Materials to Improve Cognitive Process Skills in Elementary Science Education

Ully Arta Miladia*, Abdul Fatah, Yuvita Oktarisa
Master's Program in Elementary Education, Universitas Sultan Ageng Tirtayasa, Indonesia.
***Corresponding Author. Email: ullyartamiladia93@gmail.com**

Abstract: This study aims to develop deep learning-based instructional materials on the topic of states of matter and their changes, to determine the feasibility of the developed materials, and to examine their effectiveness in improving students' cognitive process skills. The study employed a modified 4D Research and Development (R&D) model consisting of the define, design, develop, and limited dissemination stages. The participants were 35 fourth-grade students at SDN Serdang 1, Banten Province, Indonesia. The developed products included learning outcomes, learning objective sequences, teaching modules, student worksheets, Canva-based learning media, and assessment instruments. Data were collected through expert validation, student response questionnaires, and pretest–posttest assessments. The data were analyzed using descriptive percentage analysis and normalized gain (N-gain). The results showed that the developed instructional materials were categorized as highly feasible in terms of content, media, and language aspects. Furthermore, the effectiveness test indicated a moderate improvement in students' cognitive process skills after the implementation of the instructional materials. The highest improvement was observed in applying skills (C3), followed by analyzing (C4) and evaluating (C5). These findings indicate that deep learning-based instructional materials can effectively support meaningful science learning and improve elementary school students' cognitive process skills. Therefore, the developed instructional materials may serve as an alternative instructional model aligned with the demands of 21st-century education.

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Introduction

The demands of 21st-century education require students to develop higher-order thinking skills, particularly the ability to apply, analyze, and evaluate knowledge in meaningful contexts. In science education, these cognitive process skills are essential because students are expected not only to understand concepts but also to interpret scientific phenomena logically and apply them in everyday situations (Darling-Hammond et al., 2020; Voogt et al., 2018). However, recent international assessments indicate that Indonesian students still face challenges in higher-order thinking skills, particularly in science learning. The Programme for International Student Assessment (PISA) 2022 reported that Indonesian students' scientific literacy performance remains below the OECD average, especially in analytical and problem-solving competencies (OECD, 2023). Several national studies have also revealed that elementary school students experience difficulties in applying, analyzing, and evaluating scientific concepts due to teacher-centered instruction and limited opportunities for meaningful learning activities (Sari & Sutopo, 2020; Putra & Rahmawati, 2021).

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However, classroom practices in elementary schools remain largely teacher-centered, with instructional activities still dominated by lecture-based methods. This condition limits students' active engagement and reduces opportunities to develop higher-order thinking skills, particularly in the domains of applying (C3), analyzing (C4), and evaluating (C5). Previous studies have shown that passive learning environments hinder the development of these cognitive processes and result in suboptimal learning outcomes (Freeman et al., 2014; Zheng et al., 2020). In addition, the instructional materials commonly used in elementary science learning are generally not designed to support meaningful and active learning. Most learning materials still focus on one-way content delivery and provide limited opportunities for students to actively construct knowledge. Studies have emphasized that instructional materials integrating active learning strategies and digital media can significantly improve student engagement and learning outcomes (Bond et al., 2020; Hillmayr et al., 2020).

The topic of states of matter and their changes is considered challenging for elementary school students because it involves abstract scientific concepts that cannot always be directly observed. Students are required to understand particle changes, temperature effects, and transformation processes that demand not only conceptual understanding but also the ability to relate scientific phenomena to everyday experiences. At the elementary level, students are still transitioning from concrete operational thinking toward more abstract reasoning processes, making it difficult for them to analyze and evaluate scientific phenomena independently (Piaget, 1972; Mayer, 2021). Consequently, students often experience difficulties in understanding science concepts deeply and applying them in different contexts.

One approach that has the potential to address these challenges is the deep learning approach. Deep learning emphasizes meaningful understanding, active engagement, reflection, and the ability to connect knowledge with real-life contexts (Hwang & Chien, 2022). Through this approach, students are encouraged not only to memorize information but also to apply, analyze, and evaluate concepts critically. In addition, deep learning promotes student-centered learning experiences that support the development of higher-order cognitive skills and meaningful learning processes.

Several previous studies have discussed the implementation of deep learning approaches and digital learning media in improving student engagement and learning outcomes. However, most studies have focused only on learning strategies or media implementation separately, rather than integrating deep learning principles into a comprehensive set of instructional materials. Therefore, a research gap still exists regarding the development of integrated deep learning-based instructional materials specifically designed to improve cognitive process skills at the elementary school level.

Based on these problems, this study aims to develop deep learning-based instructional materials on the topic of states of matter and their changes, to determine the feasibility of the developed instructional materials, and to examine their effectiveness in improving students' cognitive process skills. The novelty of this study lies in the integration of deep learning principles into a complete set of instructional materials, including learning outcomes, learning objective sequences, teaching modules, student worksheets, Canva-based learning media, and assessment instruments specifically designed to support cognitive process levels C3, C4, and C5 in elementary science learning. This study is expected to contribute theoretically by enriching the literature on deep learning-based instructional material development and practically by providing an alternative instructional model that supports meaningful science learning in elementary schools.

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Research Method

This study employed a modified 4D Research and Development (R&D) model adapted from Thiagarajan, consisting of define, design, develop, and limited dissemination stages (Thiagarajan et al., 1974). The model was modified because the dissemination process was conducted only through limited classroom trials rather than large-scale implementation. This model was selected because it provides a systematic framework for developing instructional materials that are valid, practical, and effective.

In the define stage, a needs analysis was conducted through classroom observations and problem identification related to the low level of students' cognitive process skills, particularly in applying (C3), analyzing (C4), and evaluating (C5) science concepts. This stage also involved curriculum analysis, student characteristics analysis, and material analysis on the topic of states of matter and their changes.

The design stage involved planning and designing the instructional materials, including learning outcomes, learning objective sequences, teaching modules, student worksheets, Canva-based learning media, and assessment instruments. The developed instructional materials were designed based on deep learning principles that emphasize meaningful understanding, active engagement, reflection, and contextual learning experiences.

Furthermore, the develop stage was conducted through expert validation and product revision processes. Validation was carried out by material experts, media experts, and language experts to assess the feasibility of the developed instructional materials in terms of content, design, and language aspects. Suggestions and feedback provided by the validators were used as the basis for revising and improving the instructional materials before implementation. The limited dissemination stage was conducted through classroom trials involving fourth-grade students to evaluate the practicality and effectiveness of the developed instructional materials in improving students' cognitive process skills.

Figure 1. Modified 4D Development Model Used in This Study

The participants in this study consisted of 35 fourth-grade students at SDN Serdang 1, Banten Province, Indonesia. The participants were selected using purposive sampling based on research needs and the relevance of the learning characteristics being studied. SDN

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Serdang 1 was selected because preliminary observations indicated that students experienced difficulties in higher-order cognitive process skills, particularly in applying, analyzing, and evaluating science concepts. In addition, classroom instruction was still dominated by teacher-centered approaches and limited use of interactive instructional materials, making the school relevant to the objectives of this study.

The research instruments were developed systematically to support the achievement of the research objectives, namely to measure the feasibility, practicality, and effectiveness of the developed instructional materials.

The first instrument was the expert validation sheet used to assess the feasibility of the instructional materials. Validation was conducted by material experts, media experts, and language experts. Material validation covered curriculum alignment, conceptual accuracy, content depth, and relevance to deep learning principles. Media validation included visual appearance, readability, design quality, interactivity, and ease of use. Meanwhile, language validation focused on clarity, appropriateness for elementary school students, and accuracy of terminology usage. The validation instrument used a Likert scale ranging from 1 to 5.

The second instrument was the student response questionnaire used to measure the practicality and attractiveness of the developed instructional materials. The questionnaire consisted of several indicators, including ease of use, clarity of material presentation, attractiveness of media design, student engagement, and usefulness in supporting students' understanding. The questionnaire also used a Likert scale ranging from strongly disagree to strongly agree.

The third instrument was a cognitive process skills test in the form of pretest and posttest. The test was designed to measure students' abilities in applying (C3), analyzing (C4), and evaluating (C5) science concepts. The test items consisted of multiple-choice questions developed based on learning outcomes and cognitive process indicators related to the topic of states of matter and their changes.

Data collection techniques in this study included observation, expert validation, student response questionnaires, and learning outcome tests. Observation was conducted during the preliminary stage to identify classroom learning conditions, teaching methods, and challenges encountered in science learning. Expert validation was conducted to evaluate the feasibility of the developed instructional materials before implementation. Student response questionnaires were administered after the implementation process to assess students' responses toward the instructional materials. In addition, pretest and posttest were conducted to determine improvements in students' cognitive process skills before and after the implementation of the developed instructional materials. The obtained data were analyzed using quantitative descriptive analysis supported by qualitative analysis. The expert validation data and student response questionnaire data were analyzed using descriptive percentage analysis. The percentage score was calculated using the following formula:

$$\text{Percentage} = (\text{Obtained Score} / \text{Maximum Score}) \times 100\%$$

The feasibility level was then interpreted according to predetermined criteria ranging from highly feasible to less feasible. Qualitative analysis was used to describe suggestions and feedback provided by the validators. Furthermore, students' cognitive process skill improvement was analyzed using the normalized gain (N-Gain) formula proposed by Hake (1999). The N-Gain analysis was used to determine the effectiveness of the developed instructional materials in improving students' cognitive process skills.

$$N\text{-}Gain = \frac{Posttest - Pretest}{Maximum\ Score - Pretest}$$

Figure 2. The N-Gain Analysis

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The obtained N-Gain values were interpreted based on the following criteria: N-Gain ≥ 0.70 was categorized as high, 0.30 ≤ N-Gain < 0.70 was categorized as moderate, and N-Gain < 0.30 was categorized as low. Through these analyses, this study aimed to provide a comprehensive understanding of the feasibility and effectiveness of deep learning-based instructional materials in improving elementary school students' cognitive process skills

Results and Discussion

Expert Validation Results

The expert validation results indicated that the developed deep learning-based instructional materials were categorized as highly feasible in terms of content, media, and language aspects. The validation process was conducted by material experts, media experts, and language experts to evaluate the quality and appropriateness of the developed instructional materials before implementation.

Table 1. Expert Validation Results

Aspect	Percentage	Category
Material	92%	Highly feasible
Media	90%	Highly feasible
Language	93%	Highly feasible
Average	91.6%	Highly feasible

The results indicate that the developed instructional materials met feasibility standards in terms of content accuracy, media quality, and language appropriateness. These findings suggest that the instructional materials are suitable for implementation in elementary science learning.

Effectiveness Test Results

The effectiveness test was conducted using a one-group pretest–posttest design to determine improvements in students' cognitive process skills after the implementation of the developed instructional materials.

Table 2. Results of Pretest, Posttest, and N-Gain

Description	Average Score
Pretest	60
Posttest	85
N-Gain	0.63
Category	Moderate

The results showed an improvement in students' cognitive process skills after the implementation of the developed instructional materials. The increase in posttest scores indicates that the deep learning-based instructional materials contributed positively to students' understanding of science concepts.

N-Gain Based on Cognitive Process Indicators

Further analysis was conducted based on cognitive process indicators, including applying (C3), analyzing (C4), and evaluating (C5), to identify the extent of improvement at each cognitive level.

Table 3. N-Gain Based on Cognitive Process Indicators

Indicator	Cognitive Level	N-Gain	Category
C3	Applying	0.72	High
C4	Analyzing	0.65	Moderate
C5	Evaluating	0.52	Moderate
Average	-	0.63	Moderate

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The results indicate that the highest improvement occurred at the applying level (C3), while analyzing (C4) and evaluating (C5) showed moderate improvement. These findings suggest that the developed instructional materials were more effective in facilitating concept application than higher-order evaluative thinking skills.

Discussion

Feasibility of Instructional Materials

The validation results indicated that the developed deep learning-based instructional materials were categorized as highly feasible in terms of content, media, and language aspects. These findings demonstrate that the instructional materials were systematically designed in accordance with curriculum demands, students' characteristics, and deep learning principles. The high feasibility level also reflects the alignment between learning objectives, instructional activities, assessment components, and the use of digital learning media integrated into the instructional materials.

From the content aspect, the instructional materials were considered relevant to elementary science learning because they facilitated meaningful learning experiences and supported the development of cognitive process skills. The integration of contextual activities and problem-solving tasks encouraged students to actively construct knowledge rather than merely receive information passively. This finding is consistent with previous studies emphasizing that well-designed instructional materials can improve students' engagement and conceptual understanding (Bond et al., 2020; Hillmayr et al., 2020).

In terms of media and language aspects, the use of Canva-based learning media contributed positively to the visual quality and attractiveness of the instructional materials. Visual representations, illustrations, and interactive learning displays can support elementary school students in understanding abstract science concepts more concretely. According to Mayer's Multimedia Learning Theory, the combination of visual and textual information can facilitate students' cognitive processing and improve understanding more effectively than text-only instruction (Mayer, 2021). Therefore, the integration of Canva-based media in this study supported the feasibility and practicality of the developed instructional materials.

Improvement of Cognitive Process Skills

The effectiveness test results demonstrated that the developed instructional materials contributed positively to the improvement of students' cognitive process skills. The improvement in pretest and posttest scores indicates that deep learning-based instructional materials can facilitate more meaningful science learning experiences and encourage students to engage actively in the learning process.

A more detailed analysis based on cognitive process indicators showed that the highest improvement occurred at the applying level (C3), while the analyzing (C4) and evaluating (C5) levels showed moderate improvement. This finding indicates that the developed instructional materials were more effective in helping students apply science concepts in contextual situations than in facilitating higher-order evaluative thinking skills.

The high improvement in applying skills (C3) may be influenced by the use of contextual learning activities and visual learning media integrated into the instructional materials. Through deep learning-based activities, students were encouraged to connect science concepts with real-life situations, enabling them to apply knowledge more meaningfully. In addition, Canva-based visual media helped students understand abstract concepts related to states of matter and their changes through concrete illustrations and interactive displays. This finding is consistent with previous studies indicating that contextual learning and multimedia integration can improve students' conceptual understanding and application skills (Hwang & Chien, 2022; Mayer, 2021).

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Meanwhile, the lower improvement in evaluating skills (C5) compared to applying skills (C3) may be influenced by the cognitive characteristics of elementary school students. According to Piaget's theory of cognitive development, children aged 9–10 years are generally still in the concrete operational stage, where logical thinking abilities are developing but abstract evaluation and critical judgment remain limited (Piaget, 1972). Consequently, students may find it easier to apply concepts in familiar contexts than to evaluate scientific situations critically.

In addition, although the Canva-based learning media successfully supported visual understanding and concept application, the instructional activities may not yet have sufficiently facilitated reflective discussion, argumentation, or critical evaluation tasks. Evaluation skills require deeper reasoning processes, repeated practice, and opportunities to justify opinions through discussion-based learning activities. Therefore, the moderate improvement in C5 indicates that higher-order cognitive skills require longer and more intensive instructional interventions.

These findings are also supported by Cognitive Load Theory, which explains that students have limited cognitive capacity when processing new information (Sweller et al., 2019; Paas & van Merriënboer, 2020). Well-structured instructional materials can reduce unnecessary cognitive load and support students in understanding concepts more effectively. However, higher-order thinking skills such as analysis and evaluation require more complex cognitive processing and gradual scaffolding. Therefore, although students showed improvements in cognitive process skills, the development of evaluative thinking abilities requires sustained and repeated learning experiences.

Furthermore, the findings of this study are in line with previous studies indicating that technology-supported learning environments can improve student engagement, conceptual understanding, and cognitive achievement, although additional scaffolding strategies are still needed to optimize students' critical thinking and evaluative abilities (Erdem, 2024; Hwang & Chien, 2022). Therefore, the implementation of deep learning-based instructional materials should be accompanied by reflective and discussion-oriented learning activities to further strengthen higher-order cognitive skills.

Pedagogical Implications of Deep Learning-Based Instructional Materials

The findings of this study indicate that the integration of deep learning principles, structured instructional materials, and digital learning media can improve the overall quality of elementary science learning. Deep learning-based instructional materials encourage students to become more actively involved in the learning process through meaningful activities, contextual problem-solving, and interactive learning experiences. This approach shifts classroom learning from teacher-centered instruction toward more student-centered learning practices.

In addition, the use of Canva-based learning media contributed to increasing students' learning motivation and engagement. Interactive visual media helped students understand science concepts more concretely and reduced difficulties in learning abstract material. These findings suggest that the integration of technology-based learning media into instructional materials can support more effective and meaningful learning experiences for elementary school students.

This study also highlights the importance of designing instructional materials that are not only focused on content delivery but also consider cognitive development, instructional strategies, and students' learning characteristics. Through the integration of deep learning principles, students are encouraged not only to understand concepts but also to apply, analyze, and evaluate information critically. Therefore, deep learning-based instructional

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materials can serve as an alternative instructional model aligned with the demands of 21st-century education.

Nevertheless, this study has several limitations, particularly regarding the limited sample size and relatively short duration of implementation. The classroom trial was conducted only in one class, which may limit the generalizability of the findings. Therefore, future studies are recommended to involve larger and more diverse samples and implement longer intervention periods to obtain more comprehensive findings regarding the effectiveness of deep learning-based instructional materials in improving students' higher-order cognitive skills.

Conclusion

The findings of this study demonstrate that deep learning-based instructional materials can support meaningful science learning at the elementary school level by encouraging active engagement, conceptual understanding, and higher-order cognitive processes. The integration of structured instructional materials, student-centered learning activities, and Canva-based digital media contributed positively to students' ability to apply, analyze, and evaluate scientific concepts in science learning.

This study also highlights the importance of designing instructional materials that are not only focused on content delivery but also cognitively supportive and contextually meaningful. Through the implementation of deep learning principles, students were encouraged to participate actively in the learning process and construct knowledge through meaningful learning experiences.

Furthermore, the developed instructional materials provide practical contributions for elementary school science learning by offering an alternative instructional model aligned with the demands of 21st-century education. The findings of this study indicate that the integration of deep learning approaches and interactive digital media has strong potential to improve the quality of science learning and support the development of students' cognitive process skills.

Recommendation

Based on the findings of this study, several recommendations can be proposed. First, elementary school teachers are encouraged to utilize deep learning-based instructional materials as an alternative approach in science learning to support students' cognitive process skills and promote more meaningful learning experiences. The integration of contextual learning activities and interactive digital media can help create more student-centered learning environments.

Second, schools are expected to support the implementation of innovative instructional practices by providing adequate technological facilities and professional development opportunities for teachers. Such support is important to enhance teachers' ability to design and implement technology-integrated instructional materials effectively.

Third, future researchers are recommended to further develop deep learning-based instructional materials across different subject areas and educational levels involving larger and more diverse samples. Future studies may also investigate additional variables, such as critical thinking skills, learning motivation, collaborative learning, and long-term learning outcomes, to obtain more comprehensive findings regarding the effectiveness of deep learning-based instructional materials.

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