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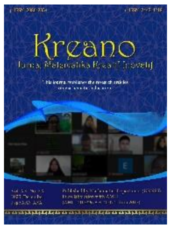

Development of Mathematics Learning Design Using AI-Based Deep Learning Approach to Enhance Students' Digital Literacy

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Abstract

The deep learning approach has become a focus of national education policy to improve education quality in Indonesia and is being implemented in the current curriculum. However, studies developing holistic deep learning instructional designs supported by Artificial Intelligence (AI), particularly to enhance students' digital literacy in mathematics, remain limited. This study aimed to develop a mathematics learning design using an AI-based deep learning approach to improve students' digital literacy, specifically in the topic of elements and nets of cube and cuboid for Grade V. The study employed a Research and Development (R&D) method following the ADDIE development model: Analysis, Design, Development, Implementation, and Evaluation. The research subjects were 20 fifth-grade elementary school students from an elementary school in Surabaya. The research instruments consisted of an AI-based deep learning mathematics teaching module for the elements and nets of cube and cuboid topic in Grade V, a digital literacy questionnaire, and a student response questionnaire. The result of this study is a mathematics learning design using AI-based deep learning approach in the form of teaching module in the topic of elements and nets of cube and cuboid is successfully constructed. The teaching module was proven to be highly valid (validation score is 3.64), highly practical (practicality score is 3.39), and effective to enhance students' digital literacy, with scores increasing from 66.70% to 73.98% (a 7.27% gain). The design aligns with core deep learning principles and supports conceptual understanding, meaningful knowledge construction, and active engagement through AI-based tools. This research contributes to the advancement of mathematics education by offering an implementable and pedagogically grounded mathematics learning design, providing a promising mathematics learning design for integrating AI-based deep learning approaches to enhance students' digital literacy.

Keywords: Mathematics Learning Design; Deep Learning Approach; Artificial Intelligence; Digital Literacy.

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Abstrak

Pendekatan deep learning menjadi fokus kebijakan pendidikan nasional untuk meningkatkan kualitas pendidikan di Indonesia dan mulai diterapkan dalam kurikulum saat ini. Namun, penelitian yang mengembangkan desain pembelajaran deep learning secara holistik dengan dukungan Artificial Intelligence (AI), khususnya untuk meningkatkan literasi digital siswa dalam matematika, masih terbatas. Penelitian ini bertujuan untuk mengembangkan desain pembelajaran matematika dengan pendekatan deep learning berbasis AI sebagai upaya untuk meningkatkan literasi digital siswa, khususnya pada materi unsur-unsur dan jaring-jaring kubus dan balok kelas V. Penelitian ini menggunakan metode penelitian Research and Development (R&D) dengan model pengembangan Analysis, Design, Development, Implementation, dan Evaluation (ADDIE). Subjek penelitian ini yaitu 20 siswa kelas V SD di salah satu SD di Surabaya. Instrumen penelitian yang digunakan yaitu modul ajar matematika dengan pendekatan deep learning berbasis AI pada materi unsur-unsur dan jaring-jaring kubus dan balok untuk kelas V SD, angket literasi digital, dan angket respons siswa. Penelitian ini menghasilkan desain pembelajaran matematika dengan pendekatan deep learning berbasis AI berupa modul ajar materi unsur-unsur dan jaring-jaring kubus dan balok untuk kelas V SD. Modul ajar terbukti sangat valid (skor validasi yaitu 3.64), sangat praktis (skor kepraktisan yaitu 3.39), dan efektif dalam meningkatkan literasi digital siswa, dari skor 66.70% ke 73.98% (peningkatan sebesar 7.27%). Desain pembelajaran ini sejalan dengan prinsip pendekatan deep learning dan mendukung pemahaman konseptual, konstruksi pengetahuan yang bermakna, serta keterlibatan aktif siswa melalui alat berbasis AI. Penelitian ini berkontribusi terhadap perkembangan pendidikan matematika dengan menghadirkan desain pembelajaran matematika yang dapat diimplementasikan dan memiliki landasan pedagogis yang kuat, serta menyediakan desain pembelajaran matematika yang potensial dalam mengintegrasikan pendekatan deep learning berbasis AI untuk meningkatkan literasi digital siswa.

INTRODUCTION

Deep learning instructional approach focuses on fostering deep understanding by gradually developing students' knowledge to form broad and interconnected conceptual structures. In preference to cramming information, it emphasizes creating meaningful relationships among knowledge components, thereby enhancing the effectiveness and quality of learning (Kovač et al., 2025). This instructional approach demonstrates a positive relationship between learning outcomes and global demands, resulting in higher learning outcomes that align with the global demand for transformative and sustainable education (Dalehefte & Canrinus, 2023). The implementation of a deep learning approach in education must be supported by several key supporting components, including a conductive learning ecosystem, broad and meaningful learning partnerships, and the effective integration of digital technology (Suyanto et al., 2025). The key supporting components are essential to realizing the three core principles of deep learning: mindful learning, meaningful learning, and joyful learning. When these principles are applied effectively, the deep learning approach can significantly enhance students' competencies, foster their learning interest and awareness, and encourage active participation in the learning process (Kong & Hao, 2022).

The implementation of the deep learning approach in education represents the government's commitment to accelerate educational transformation, as well as to enhance and expedite the impact of education in preparing a generation to achieve the demographic dividend in 2025 and the Golden Indonesia vision in 2045 (Suyanto et al., 2025). The Head of Primary and Secondary Education Ministry, stated in Tempo (2024) that this approach has been integrated into the learning process through the curriculum currently implemented within the national education system. However, the readiness of teachers to adopt and implement the deep learning approach is still considerably low (Atmojo et al., 2025), posing a challenge to its effective integration into educational practice.

Based on preliminary studies conducted at an elementary school in Surabaya and another in Gresik, the deep learning instructional approach has not yet been fully implemented. Several teachers have begun to be scheduled for training on the implementation of the deep learning approach. Many teachers still have a lack understanding of the deep learning principles, the students' learning experiences should gain through this approach, and the key supporting components required for its implementation. Teachers' understanding of deep learning remains limited to the notion that lessons should be connected to students' daily lives so that they not only understand the concepts but also their applications in real-life contexts. However, the implementation of the deep learning approach will only be successful as outlined by the government for advancing education if teachers understand this approach thoroughly and can design learning appropriately. Therefore, teachers need references of mathematics teaching modules that apply a deep learning approach. Such modules can serve as concrete examples of a holistic, valid, practical, and effective learning design, providing an alternative for teachers to use when designing mathematics learning in their classrooms.

As education shift toward new pedagogies that focus on deep learning, teachers are expected to act as facilitators, helping students make choices, manage their own learning, and take control of their learning process with the support of technology (Abedi, 2024). Therefore, one of the key supporting components of deep learning is the effective utilization of digital technology in learning must be well understood by teachers. One of the technological applications that can be integrated into the learning process is the use of digital learning media and Artificial Intelligence (AI). AI, in particular, can contribute significantly to improving instructional quality, enriching learners' experiences, and deepening students' comprehension of subject content (AlAli & Wardat, 2024; Mustafa et al., 2024). The integration of Artificial Intelligence (AI) in education can play a pivotal role in achieving the Sustainable Development Goals (SDGs) by 2030, as well as the realization of the fourth Asta Cita, which emphasizes the government's commitment to reinforce national development, particularly in the domains of technology and education. The integration of technology in education is connected to students' digital literacy, defined as their ability to effectively engage with digital learning resources (Makhafola et al., 2025). As a global concern, digital literacy must be developed in learning to prepare students for the demands and challenges of the 21st century.

The development of IT- and AI-based mathematics learning has been explored in various studies, such as the study by Nadjla (2024) on AI-based mathematics learning found that the integration of Artificial Intelligence in mathematics instruction was effective in enhancing students' conceptual understanding, mathematical problem-solving skills, educational accessibility, and character development. Furthermore, researches have been conducted on teachers' experiences with AI-based instructional tools (Arvin et al., 2023), as well as exploratory study on teachers' perceptions, challenges, and the pedagogical implications of integrating AI-based ChatGPT into mathematics learning (Egara & Mosimege, 2024). The findings of both studies indicate that AI is still rarely utilized in classroom practice, despite its demonstrated positive impact on teaching effectiveness, student engagement, and conceptual understanding. Realizing the full potential of AI in education requires improved digital literacy and teacher preparedness, supported by comprehensive implementation guidelines (Arvin et al., 2023). Subsequent research on mathematics education utilizing the deep learning approach remains restricted in its integration with IT and AI. For example, the study conducted by Wijaya, et al (2025) applied the deep learning approach at the elementary school level. The main findings indicated that the deep learning approach was successful and had a positive impact on students' critical thinking skills, character development, social abilities, and learning motivation.

A review of existing studies reveals a research gap that has yet to be thoroughly explored. The study by Wijaya, et al (2025), for instance, focuses on the deep learning approach but does not holistically develop an AI-based deep learning instructional design. Meanwhile studies by Egara & Mosimege (2024), Arvin, et al. (2023), and Nadjla (2024) are relevant to the use of AI, yet remain limited in scope and do not comprehensively integrate AI-based deep learning instructional design with students' digital literacy. Moreover, previous research has primarily focused on the use of digital technologies such as applications and interactive learning media (Silwana & Qohar, 2022). There is still a limited number of studies that holistically develop instructional designs based on advanced technologies, such as AI, to support students' digital literacy. Research on deep learning and AI in education has also not explicitly examined their contributions to enhancing students' digital literacy (Nababan et al., 2025). Consequently, the role of AI in creating learning experiences that improve digital literacy is still not widely discussed. Furthermore, mathematics learning, deep learning approaches, and AI-based educational technology are often studied separately (Barokah & Mahmudah, 2025).

Based on relevant previous research described, the development of an integrated mathematics instructional design that combines deep learning approaches and AI-based technologies to enhance students' digital literacy represents a critical and underexplored area of research. States of the art of this research are: a) comprehensive mathematics learning design with an AI-based deep learning approach; b) involving AI (ChatGPT) in mathematics learning linked to students' digital literacy; c) integrating mathematics learning design with a deep learning approach, AI, and 21st century digital literacy needs.

Based on the background problem explained above, it is necessary to conduct research on the development of a mathematics learning design using AI-based deep learning approach as an effort to improve students' digital literacy. The objective of this study is to develop a mathematics learning design that integrates an AI-based deep learning approach to enhance students' digital literacy, with a focus on the topic of elements and nets of cube and cuboid for fifth-grade elementary students. This topic was selected due to its inherent need for interactive visualizations, which can be effectively facilitated through the use of digital technology and AI. Preliminary observations conducted at an elementary school in Surabaya indicate that students encounter difficulties in understanding this topic, and that AI-based technological tools have not yet been utilized to support students' conceptual understanding. The study is expected to provide theoretical contributions in the form of a learning design framework integrating deep learning pedagogy with AI technology to enhance students' digital literacy, as well as AI mechanism capable of facilitating deep learning in mathematics instruction. In addition, it is expected to offer practical contributions in the form of a mathematics learning design that teachers can implement to support mathematics learning with AI-based deep learning approach.

METHOD

This research used the Research and Development (R&D) research method with the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) development model. ADDIE model is a foundational instructional design (Tan et al., 2025). This development model enables learning designers to produce efficient and effective learning practices (Shakeel et al., 2023). Figure 1 presents the research flowchart based on the ADDIE model.

used in the learning process. The AI selected for the learning design is ChatGPT. Consequently, in the development stage, the researchers prepared the learning media using GeoGebra integrated with ChatGPT to support the mathematics learning design based on an AI-based deep learning approach. This integration was chosen because ChatGPT can function as a provider of conceptual explanations, an interactive question-and-answer assistant, critical thinking stimulation through reflective questioning, provision of independent practice exercises, and assistance in operating GeoGebra. Previous studies have also demonstrated that ChatGPT has a positive impact on mathematics learning (Albadarin et al., 2024; Deng et al., 2025; Mai et al., 2024).

Additionally, in the deep learning approach implementation, students are expected to reflect on their own understanding and learning processes. Thus, when designing the mathematics teaching module, the researchers also

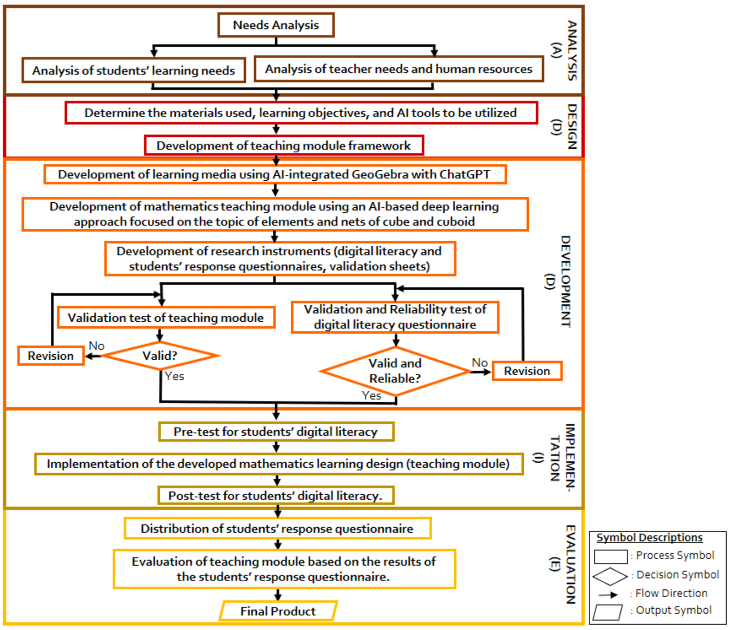

Figure 1. Research Flowchart Based on the ADDIE Model

In the design stage, the activities involved determining the type of AI will be

developed a student reflective journal was designed as a self-reflection worksheet using the Situation (S), Task (T), Action

(A), Result (R), and Reflection (R) or STARR method (Badriah & Permana, 2023). This reflective journal functions as an assessment as learning (assessment aimed at supporting student reflection and learning reflection) (Suyanto et al., 2025) embedded in the mathematics teaching module with AI-based deep learning approach developed.

In the development stage, the validation of teaching module by expert: learning design, material, and learning evaluation experts. For validation and reliability testing of the students' digital literacy pre-test and post-test questionnaires were given by distributing the questionnaires to students who were not research subjects, namely 25 students at an elementary school in Gresik. In addition, in the implementation stage, mathematics learning design implementation was conducted in July 2025 at an elementary school in Surabaya, involving 20 fifth-grade students as research subjects.

The data collection techniques in this study are: a) observation; b) interviews, to analyze the needs of teachers and students, and analyze teacher human resources; and c) questionnaires, student responses questionnaires to practicality test and digital literacy pre-test and post-test questionnaires to effectiveness test.

Data analysis techniques used in this study included validity test analysis, practicality test analysis, and effectiveness test analysis. The validity of the learning design, materials, and learning evaluation was analyzed based on the validity mean score obtained for each indicator (Kartikasari et al., 2023), using the following formula:

$$\overline{x_v} = \frac{Total\ Score}{Number\ of\ Indicators}$$

The validity mean score was grouped into four validity criteria (Damayanti et al., 2025), as shown in Table 1 below.

Table 1. Validity Criteria

Validity Mean Score ($\overline{x_v}$)	Validity Criteria
$3.25 < \overline{x_v} \leq 4.00$	Very Valid
$2.50 < \overline{x_v} \leq 3.25$	Valid
$1.75 < \overline{x_v} \leq 2.50$	Less Valid
$0 \leq \overline{x_v} \leq 1.75$	Not Valid

The learning design, materials, and learning evaluation were feasible for implementation in research if the average score for each criterion was very valid or valid.

Meanwhile, practically analysis was obtained through student response questionnaires. Practicality can be seen from the practicality mean score obtained for each indicator using the following formula (Kartikasari et al., 2023):

$$\overline{x_p} = \frac{Total\ Score}{Number\ of\ Indicators}$$

The practicality mean score was grouped into four practicality criteria (Hasanah et al., 2023), as shown in Table 2.

Table 2. Practically Criteria

Practicality Mean Score ($\overline{x_p}$)	Practicality Criteria
$3.25 < \overline{x_p} \leq 4.00$	Very Practical
$2.50 < \overline{x_p} \leq 3.25$	Practical
$1.75 < \overline{x_p} \leq 2.50$	Less Practical
$0 \leq \overline{x_p} \leq 1.75$	Not Practical

Furthermore, to analyze the effectiveness of enhancing digital literacy, a one-group pre-test post-test comparison experimental design was used. Differences in average pre-test and post-test digital literacy scores were analyzed using Wilcoxon Signed Rank Test since based on the normality test with the Shapiro-Wilk test, it was found that the data was not normally distributed.

RESULT AND DISCUSSION

Results

The stages in the development of a mathematics learning design AI-based deep learning approach are described as follows.

Analysis Stage

At this stage, a need analysis is conducted to identify teachers' challenges in delivering mathematics material, as well as students' difficulties in understanding mathematical concepts. Additionally, an analysis of teacher competencies is carried out, particularly regarding their understanding of mathematics learning through a deep learning approach. Based on interviews with selected students and teachers at an elementary school in Surabaya, the following empirical data were obtained: (a) mathematics learning has not fully implemented the deep learning approach; (b) teachers' knowledge of deep learning is narrow, often perceived merely as an extension of contextual learning; (c) technology-based instructional media are rarely used, as technology is perceived to have minimal impact on students' comprehension; (d) AI has never been utilized in instructional practices; and (e) students perceive mathematics learning environments as monotonous and unengaging.

Design Stage

At design stage, researchers determine the learning material, specifically focusing on the elements and nets of three-dimensional geometric shapes, namely cube and cuboid. Researchers develop the framework for the teaching module, which includes the design of its components as follows: (a) the identification section, comprising student identification, subject matter identification, and graduate profile dimensions; (b) the learning design section, which consists of learning outcomes, interdisciplinary connections, learning topics, learning objectives, pedagogical practices, learning partners, learning environment, and digital integration; (c) the learning experience section, detailing the steps of learning activities; and (d) the assessment section, which encompasses assessments of learning, assessments as learning, and assessments for learning.

At this stage, researchers also select the AI technology to be integrated into learning process, aligning with the principles of the deep learning approach. ChatGPT is chosen with the objective of providing immediate feedback to students, personalizing learning based on individual student needs, and enhancing interactivity by incorporating advanced and cutting-edge technology. It is in line with research by Egara & Mosimege (2024), which indicates that ChatGPT has a positive impact on learning effectiveness, student engagement and comprehension.

Development Stage

At the development stage, researchers prepare ChatGPT-integrated learning media using GeoGebra to be utilized in learning activities. The learning media employed have passed both validity and practicality tests. Furthermore, researchers develop a teaching module using AI-based deep learning approach for teaching elements and nets of cube and cuboid for fifth-grade elementary students, aiming to enhance students' digital literacy. This development process includes the design of the module's cover, layout, and content.

The teaching module consists of

several components: lesson plans, pretest and posttest on material and digital literacy, student worksheets for the topic elements and nets of cube and cuboid, student reflective journals, self-assessment sheets, and peer-assessment sheets. The cover design of the teaching module is illustrated in Figure 2 below.

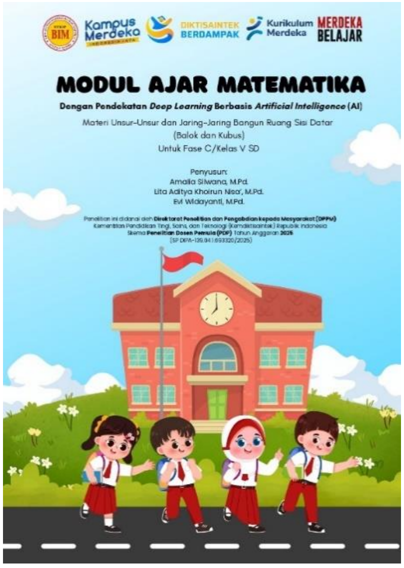

Figure 2. Cover of Mathematics Teaching Module

At this stage, the validity and reliability of the digital literacy pretest and posttest questionnaire were tested by distributing the questionnaire to students who were not research subjects, namely 25 students at an elementary school in Gresik. The validity test of the digital literacy pretest and posttest questionnaire is presented in Table 3 below.

Table 3. Validity Test Result

Statement	Calculated r Value	Table r value	Criteria
P1	0.446	0.3961	Valid
P2	0.427	0.3961	Valid
P3	0.399	0.3961	Valid
P4	0.475	0.3961	Valid
P5	0.741	0.3961	Valid
P6	0.527	0.3961	Valid
P7	0.473	0.3961	Valid
P8	0.464	0.3961	Valid
P9	0.401	0.3961	Valid
P10	0.455	0.3961	Valid
P11	0.473	0.3961	Valid

Based on the validity test result in Table 3, all of the calculated r value for every items is greater than the r table value. Therefore, the 11 items in the digital literacy pre-test and post-test questionnaires are considered valid. Next, a reliability test was conducted. The results of reliability test by SPSS obtained Cronbach's Alpha value 0.661. This value is greater than 0.6, indicating that the questionnaire is reliable. Since the digital literacy pre-test and post-test questionnaire has passed validity and reliability tests, it can be used to measure digital literacy level in research.

Furthermore, the validity test result of teaching module was tested by three experts: learning design expert, material expert, and learning evaluation expert can be seen in Table 4.

According to Table 4, the average score from overall validation results given by the three validators is 3.64, indicating a high level of validity (Damayanti et al., 2025). Therefore, the mathematics learning design with an AI-based deep learning approach that was developed has been proven to be valid and feasible for implementation.

Implementation Stage

In the implementation stage, a trial of the mathematics learning design developed over five meetings was conducted. At the beginning of the lesson, students completed a digital literacy pretest questionnaire and at the end of the lesson, they completed a digital literacy posttest questionnaire. The results of the digital literacy pretest and posttest were used to determine the effectiveness of the learning design in improving students' digital literacy.

Based on SPPS analysis result, the mean digital literacy score of students before being given mathematics learning

Table 4. Validity Result of Teaching Module

Validation Type	Aspect Assessed	Validation Score	Average Score
Learning Design Validation	Compatibility of learning objectives	4.00	3.45
	Compatibility of materials and learning design	3.00	
	Learning steps	3.67	
	Appropriateness of technology integration	3.00	
	Relevance of digital literacy enhancement	3.50	
	Coherence of design component	3.50	
Material Validation	Compatibility of material with learning outcomes	3.80	3.83
	Material accuracy (scientific quality and conceptual precision)	4.00	
	Meaningfulness of material and learning context	3.50	
	Compatibility with deep learning approach	4.00	
	Integration of technology and AI	3.67	
	Language use and presentation	4.00	
Learning Evaluation Validation	Material pre-test and post-test	3.62	3.65
	Student worksheets	3.59	
	Student reflective journals	3.67	
	Student self-assessment	3.67	
	Student peer assessment	3.72	
Average Score from Overall Validation Results			**3.64**

according to the developed learning design was 29.35 and after being given mathematics learning according to the developed learning design was 32.55 or an increase in the mean score of 3.2. In terms of the percentage of the maximum digital literacy score, students' digital literacy score increased from 66.70% to 73.98%. This indicates that the digital literacy score of students improved 7.27% after the implementation of the developed mathematics instructional design. Furthermore, the pretest and posttest scores were compared to determine whether there were significant differences in students' digital literacy before and after the implementation of the developed learning design.

However, before being compared, the data scores were first tested for normality. Based on the SPSS output, the Shapiro-Wilk Significance value for the digital literacy pretest is 0.030. If the significance level used 5%, then Sig. < 0.05. Thus, the digital literacy pretest data is not normally distributed. While the Shapiro-Wilk significance value for the digital literacy posttest is 0.307. Then Sig. > 0.05. Hence the digital literacy posttest data is normally distributed. Therefore, the test for differences between the digital literacy pretest and posttest scores uses a non-parametric test, namely the Wilcoxon Signed Rank Test. Testing the null hypothesis that there is no significant difference in students' digital literacy in mathematics learning with AI-based deep learning approach using SPSS. Based on SPSS output, sixteen students obtained higher posttest scores than their pretest scores. Meanwhile, four students' posttest score decreased.

Null hypothesis testing was continued using the Wilcoxon Signed Rank Test. Based on the test results obtained Z= -3.051 and Asymp. Sig. (2-tailed) = 0.002. By using significance level of 5%, Asymp. Sig. (2-tailed) < 0.05 which means H_0 is rejected so that there is a significant difference between digital literacy before and after mathematics learning with AI-based deep learning approach is carried out. This shows that the developed learning design has proven effective in improving students' digital literacy.

Evaluation Stage

In the evaluation stage, students completed a student response questionnaire to determine their responses to the developed learning design. The results of the student response questionnaire were used to test the practicality of the developed learning design and evaluate the teaching module. The results of the practicality test can be seen in Table 5.

Table 5. Practically Test Result of Teaching Module

Aspect Assessed	Average of Practicality Score
Attractiveness of the learning process	3.33
Meaningfulness of the learning process	3.58
Presentation of learning materials	3.38
Learning materials	3.25
Average Total Score of Practicality Test Result	**3.39**

According to Table 5, the average total score of practicality test result is 3.39, indicating a high level of practical (Hasanah et al., 2023). Therefore, the mathematics learning design with an AI-based deep learning approach that was developed has been proven to be practical.

Discussion

The mathematics learning design for the topic of elements and nets of cube and cuboid was developed using a holistic deep learning approach, in accordance with the deep learning framework proposed by the Ministry of Primary and Secondary Education (Suyanto et al., 2025). The developed learning design is structured to facilitate in-depth exploration of the subject matter through activities grounded in the principles of mindful, meaningful, and joyful learning, aiming to foster experiences of understanding, application, and reflection. This aligns with the core goals of deep learning, which include promoting deep conceptual understanding (Rahayu et al., 2025), encouraging student participation through interactive activities (Mutmainnah et al., 2025), fostering long-term knowledge construction (Bistari et al., 2025), strengthening skills aligned with real-world demands (Akmal et al., 2025), and stimulating students' creative thinking in developing ideas for their projects (Natsir, 2025).

The first step in developing a deep learning-based module is identification, which includes identifying students, identifying materials, and determining the dimensions of the graduate profile (Suyanto et al., 2025). The determination of the graduate profile dimensions is carried out by aligning them with the intended learner outcomes expected upon completion of the learning process. In this instructional design, five dimensions of the graduate profile are selected: (1) critical reasoning, as the learning activities presents students with problems and task that require critical thinking skills (Khusna et al., 2024; Loyens et al., 2023; Sari & Juandi, 2023; Yu & Zin, 2023); (2) creativity, as the lesson involves project-based tasks that demand students' creative thinking (Rehman et al., 2024); (3) collaboration, as group-based activities are incorporated throughout the learning process (Ma, 2025); (4) independence, as despite the collaborative learning, there are tasks that require individual responsibility and self-direction; and (5) communication, as the learning process cultivates communication skills through inter-group discussion, classroom presentations, participation in whole-class discussion, and written self-reflection in reflective journals. The selected graduate profile dimensions are aligned with the learning culture promoted in this design, which emphasizes collaboration, active participation, critical thinking, and student curiosity.

The mathematics learning design with AI-based deep learning approach that has been developed has undergone a validity assessment by experts in learning design, materials, and learning evaluation, yielding a score of 3.64, indicating a very high level of validity. Several improvement notes were provided by the validators including revisions to the layout design of the student worksheet to make them more appealing to fifth-grade elementary students, refinement of the pre-test and post-test content, and the addition of students' self-assessment and students' peer-assessment items related to students' ability to use AI tools. This aligns with previous research, which emphasizes that the use of attractive visual design in presenting learning materials such as the selection of appealing shapes and colours can enhance students' motivation, interest, comprehension, and learning outcomes (Indra et al., 2024). Furthermore, colour selection in design has been shown to influence students' concentration and memory in learning, as well as students' interest in the material (Diachenko et al., 2022).

The developed mathematics learning design has proven to be practical, as indicated by a high practicality score (3.39) based on aspects of learning attractiveness, usefulness, and content quality and its delivery. Mathematics learning using a deep learning approach offers students a unique and meaningful experience. In line with the principle of deep learning, students are guided to be consciously aware of the learning objectives they are expected to achieve by the end of the lesson, students can feel the benefits of learning the material because the content is connected to their daily lives, and are encouraged to think critically about societal conditions and how mathematical concepts can be applied in real-life contexts. This process leads to meaningful learning experience. Learning activities are most effective when they demonstrate relevance beyond the classroom (Hains-wesson & Roux, 2024). In addition, students can also feel more engaged and enjoy working on authentic tasks that deepen their understanding of its real-world applications (Collins, 2022). Through the project of constructing a simple 3D model, students are able to perceive the relevance and real-world application of the mathematical content.

In the project of constructing a simple 3D model, the learning design use integration of interdisciplinary content and the involvement of learning partners. The interdisciplinary aspect in the developed mathematics learning design includes the integration of art and culture subject (in terms of the material application in everyday life) and information and communication technology (ICT) (as students engage in digital-based learning activities using tools such as AI-powered ChatGPT and GeoGebra as a digital learning media). Learning partners represent a key element of deep learning (Suyanto et al., 2025). In this design, art and culture teacher is invited as learning partner to provide students with additional knowledge on constructing cubes and cuboids, and to support them in completing a project by creating simple

3D models. The presence of learning partners in the classroom provides greater opportunities for students to achieve essential 21st-century skills, particularly collaboration, by enabling them to build connection across disciplines (Fitrah et al., 2025) to create authentic learning contexts and support the goals of deep learning (Alwathoni, 2025).

About the practicality of learning design, students are also encouraged to engage in self-reflection regarding the concepts they have understood and those they have not yet mastered, as well as to improve their performance in subsequent lesson as part of learning experience of reflection. In the developed mathematics learning design, for each sub-topic covered students are provided with a reflective journal. This journal is an integral component of mindful learning. It consists of several guided questions that students are required to answer. The questions follow the STARR reflection model, which includes: Situation (S) of the learning context; Task (T), the task students were assigned; Action (A), the actions taken to complete the tasks; Result (R), the outcomes of students' work; and Reflection (R), students' evaluation of learning process. This approach aligns with the STARR reflection model as discussed by Badriah & Permana (2023). This kind of reflection model has proven effective in supporting the self-reflective process. Self-reflection journal plays a crucial role in the learning process. They are believed to help students develop metacognitive awareness of their own thinking processes, while also providing teachers with deeper insights into students' cognitive structures and prior knowledge. Such information can be used to design pedagogical interventions that address students' learning gaps more effectively (Muslim et al., 2025).

The mathematics learning design with AI-based deep learning approach has been proven effective in enhancing students' digital literacy. This learning design incorporates AI tools, specifically ChatGPT, along with the use of GeoGebra as an interactive and engaging digital mathematics learning media. The integration of GeoGebra and ChatGPT was carried out through a structured instructional scenario. In the student worksheet, students were instructed to perform visual exploration activities in GeoGebra and subsequently pose questions to ChatGPT based on their observations. Through this integration, students can visualize mathematical concepts in GeoGebra and then receive explanations and guiding questions from ChatGPT to facilitate reflection and deepen their understanding. The prompts used in ChatGPT were designed to provide concise conceptual explanations, stimulate reflection through open ended and reflective questions for critical thinking, and offer varied problem for practice. Such integration aligns with the principles of the deep learning that emphasize meaningful and joyful learning experiences. AI has been shown to make learning more engaging and creative (Mohamed et al., 2022), which supports the joyful learning principle. Moreover, the use of AI-powered chat bots in education has the potential to advance the role of technology in learning and increase accessibility for all students regardless of their learning pace (Chau et al., 2025). In addition, the integration of digital technologies contributes to improvements in student performance, motivation, and problem-solving abilities (Rodríguez-Jiménez et al., 2023).

The use of GeoGebra as an instructional media includes interactive features that generate three-dimensional simulations of cube and cuboid, thereby facilitating students' understanding of the concepts. The interactive features in the learning media also serve to motivate students to participate more actively in learning process (Sinaga et al., 2022). In addition, the integration of technology in education is essential for improving the learning quality (Maričić et al., 2024), making mathematics more accessible and flexible for diverse types of learners (Gadelha, 2018), and ensuring a more effective and efficient learning process (Ilyas et al., 2023). Teachers are encouraged to embed digital technology in the learning process to promote impactful and motivating learning experiences for students (Abedi, 2024). In the context of Indonesia's *Merdeka Curriculum*, the use of digital technologyis considered a fundamental infrastructure need (Sari et al., 2024) and a critical component in implementing deep learning. The effective application of deep learning approaches depends significantly on teachers' capacity to handle the complexities involved in managing technology simultaneously (Fitrah et al., 2025). Digital technology also facilitates deep learning by fostering critical inquiry, purposeful collaboration, and individualized learning experiences (Asad & Suleman, 2025).

Furthermore, the use of AI in this study was found to have a positive impact on students, as evidenced by the increase in the average post-test scores of students' digital literacy. This finding is consistent with previous research, which has shown that AI offers several advantages, including enhancing conceptual understanding, improving student performance, and making learning more effective (Mohamed et al., 2022). The findings of this study also reveal that the use of AI-powered ChatGPT engaged students' creative thinking skills, particularly in generating prompts. Students were able to formulate prompts based on what they wanted to explore. For several questions listed in student worksheet, students were instructed to gather information from the internet, particularly using ChatGPT. All five student groups submitted different prompts. In this context, it is essential for teachers to guide students in using AI effectively to support learning. AI should not merely be used to solve problems directly; rather, it should be employed to facilitate learning experiences. Therefore, teachers must provide instructional direction on how to make meaningful prompts in order to optimize AI interaction while ensuring alignment with learning objectives (Setälä et al., 2025).

Using technology constructively as a pedagogical tool, rather than merely as a medium for delivering and consuming information, is essential for boosting students' deep learning and empowering them to generate and apply new knowledge in today's world (Abedi, 2024). When technology is integrated meaningfully, it supports learning processes that go beyond memorization and passive engagement. Students are encouraged to explore concepts through interactive tasks, and problem-based digital environments that promote critical thinking and creativity (Meirbekov et al., 2022; Tang et al., 2022). Instead of simply receiving information, learners actively construct understanding by experimenting with digital tools. Moreover, technology enables personalized learning experiences where students can work at their own pace and engage with materials that align with their interests and needs (Fromm et al., 2025). This approach not only increases motivation but also foster digital literacy that are crucial for success in modern, technology-driven societies. By shifting the role of technology from a delivery device to a catalyst for deeper learning, teachers can create richer, more meaningful learning experiences that prepare students to navigate complex real-world challenges and contribute new ideas in an increasingly digital world.

Based on the explanation above, the mathematics learning design using AI-based deep learning approach has been proven to be valid, practical, and effective in enhancing students' digital literacy. Overall, the results of this study emphasize the importance of implementing deep learning approaches and integrating technology into mathematics education in a comprehensive manner. The combination of deep learning with digital technology integration (AI-based ChatGPT and GeoGebra) has led to improved students' digital literacy, increased engagement in learning, and deeper conceptual understanding. The results also highlight several strengths of implementing the developed mathematics learning design using AI-based deep learning approach: it aligns with the principles of mindful, meaningful, and joyful learning; provides an innovative instructional model for teachers to adopt; promotes active, personalized, adaptive, and differentiated learning; enhances flexibility and effectiveness in the learning process; develop 21st-century skills; and leverages a variety of digital learning resources.

Implication of Research

The successful development of mathematics learning design using AI-based deep learning approach has several important implications for mathematics education, particularly for education practitioners, school administrators, policymakers, and educational researchers aiming to enhance students' digital literacy. The effectiveness of the developed mathematics learning design in the form of a teaching module grounded in an AI-based deep learning approach demonstrated its feasibility in increasing student engagement, improving the quality of mathematics learning, and supporting students in developing their digital literacy skills. The learning design encourages students to become critical and creative thinkers, capable of effective collaboration and communication. Therefore, teachers and researchers are encouraged to adopt and further develop holistic mathematics learning designs based on deep learning approaches. They may also be inspired to integrate cutting-edge digital technologies and real-life, project-based learning tasks to foster deep and meaningful learning experiences. For school administrators and policymakers, the success of this learning design emphasizes the importance of providing institutional support and infrastructure necessary for implementing digital innovations in classroom settings.

Future studies may be developed based on the findings of this research, such as developing AI-based deep learning mathematics teaching modules for other mathematical topics or developing AI-based deep learning teaching modules for different subject or educational levels. Future research may also integrate more advanced AI technologies to optimize personalization within deep learning process or employ extended evaluation approaches to examine the long-term impact of AI-based deep learning modules on students' higher-order thinking and problem-solving skills.

Limitation

This research has several limitations. The first limitation lies in the scope of the learning design developed, which was restricted to an AI-based deep learning module for teaching three-dimensional shapes (specifically cube and cuboid) in fifth-grade elementary school. As such, the mathematics content addressed was limited to the topics of element and nets of cube and cuboid for Grade V. Further investigation is needed to determine whether similar instructional modules would be effective in other areas of mathematics, such as number theory, algebra, or statistics. Moreover, the effectiveness of the module in improving students' digital literacy has not been widely tested, as the study involved only 20 students from a single school and was conducted over the course of five meetings. This limited scope restricts the generalizability of the findings; thus, any conclusions should be interpreted with caution. Future research should involve a larger and more diverse sample, as well as an extended duration of implementation to expand upon the current findings.

CONCLUSION

The mathematics learning design using AI-based deep learning approach in the form of a teaching module on the topic of elements and nets of cube and cuboid for fifth-grade elementary students successfully enhanced students' digital literacy and the implemented learning design had a significant positive impact on students' digital literacy. Furthermore, the development process successfully produced a mathematics learning design that is strongly aligned with the core principles of deep learning approach (mindful, meaningful, and joyful learning) through structured learning experiences involving understanding, application, and reflection. The design emphasizes conceptual understanding, meaningful knowledge construction, and active engagement supported by AI-based tools. The resulting product not only satisfied expert criteria for validity and practicality but also demonstrated its capacity to foster personalized, interactive, and cognitively demanding learning experiences that strengthen students' ability to utilize digital resources. This study confirms that the developed learning design is systematically structured, pedagogically grounded, and implementable learning design and contributing a relevant and promising model for the integration of AI-driven deep learning approaches in elementary mathematics education.

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