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Exploring the association between deep learning approach, problem-solving skills, digital literacy, and student learning outcomes: a data-driven nonparametric study in science education

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Abstract

Background: The demands of 21st-century education require students to possess higher-order thinking skills, particularly problem-solving abilities, along with adequate digital literacy and optimal academic achievement. However, these competencies are often underdeveloped due to the continued use of surface-level instructional approaches that limit meaningful learning engagement.

Aims: This study aims to examine the association between the deep learning approach, problem-solving skills, digital literacy, and student learning outcomes, as well as to provide empirical evidence of the interrelationships among these variables in the context of science education.

Method: A quantitative correlational design was employed involving 121 tenth-grade students selected through proportionate random sampling from a population of 199 students. Data were collected using validated questionnaires measuring the deep learning approach, problem-solving skills, digital literacy, and learning outcomes. Prior to analysis, validity and reliability tests were conducted. Due to the non-normal distribution of one variable, Spearman's Rho correlation analysis was applied.

Results: The findings revealed significant positive correlations between the deep learning approach and problem-solving skills, as well as digital literacy, both indicating moderate relationships. A weaker but statistically significant correlation was found between the deep learning approach and learning outcomes. Additionally, problem-solving skills and digital literacy demonstrated the strongest relationship among the variables.

Conclusion: These findings suggest that the deep learning approach is closely associated with the development of higher-order thinking and digital competencies, although its direct relationship with learning outcomes is limited. Therefore, integrating deep learning strategies with problem-solving and digital literacy activities is essential to enhance students' readiness for 21st-century learning.

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INTRODUCTION

The development of 21st-century education has positioned problem-solving skills, digital literacy, and learning outcomes as key indicators of successful learning. Problem-solving skills represent higher-order cognitive abilities that involve understanding, analyzing, and systematically resolving complex problems (Ceballos et al., 2026; Kania & Kusumah, 2025; Wu & Molnár, 2022). In modern learning contexts, these skills are essential as students are required to respond to dynamic and multifaceted challenges (Rahimi & Oh, 2024). Moreover, problem-solving is not limited to academic performance but also reflects students' readiness to face real-life situations. Therefore, the

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development of these skills should be prioritized in the educational process. At the same time, digital literacy has emerged as a fundamental competency in contemporary education. Digital literacy encompasses the ability to use technology, access information, and evaluate and apply it critically (Falloon, 2020; Nguyen & Habók, 2024; Oh et al., 2021). These competencies enable students to learn independently and adaptively within technology-rich environments. The integration of problem-solving skills and digital literacy creates a synergistic effect that enhances learning effectiveness. Consequently, both competencies serve as a critical foundation for improving students' learning outcomes.

Digital literacy has been widely recognized as a significant factor in supporting students' academic achievement. Students with strong digital literacy skills tend to manage their learning processes more independently and effectively (Anthonysamy et al., 2020; Blau et al., 2020; Scheel et al., 2022). This ability allows them to access a wide range of relevant learning resources and utilize them efficiently. In addition, digital literacy contributes to increased student engagement in the learning process (Kristanto et al., 2024; Triana & Suryadi, 2025; Yaseen et al., 2025). Such engagement includes active participation, motivation, and deeper comprehension of learning materials. In technology-based learning environments, digital literacy also plays a vital role in fostering critical thinking skills (Alakrash & Razak, 2021; Usfandi Haryaka, 2025; Yuniarti et al., 2024). Students are not merely passive recipients of information but are able to evaluate and process information analytically. This process leads to improved understanding and stronger problem-solving abilities. As a result, digital literacy becomes a key determinant of learning success. Therefore, strengthening digital literacy should be integrated into instructional practices.

However, previous studies indicate that students' problem-solving skills and digital literacy remain underdeveloped. This condition is often caused by the continued use of conventional teaching approaches that emphasize memorization and one-way information delivery. Such approaches tend to limit students' active involvement in the learning process. As a result, students have fewer opportunities to develop higher-order thinking skills. To address this issue, more innovative and student-centered learning approaches are required. One promising approach is the deep learning approach, which emphasizes conceptual understanding and meaningful learning experiences (Sarker, 2021; Taye, 2023). This approach encourages students to actively engage in learning and connect knowledge with real-life contexts. Furthermore, deep learning integrates instructional strategies such as problem-based learning and collaborative learning. Through these strategies, students are not only able to understand content but also apply it in various situations. Therefore, the deep learning approach is considered a potential solution for enhancing problem-solving skills and digital literacy. Ultimately, the implementation of this approach is expected to improve students' overall learning outcomes.

Recent studies in science and mathematics education have extensively examined the development of students' problem-solving skills, digital literacy, and learning outcomes through various instructional approaches such as problem-posing, STEM-based learning, and technology-integrated instruction (Akben, 2020; Huang et al., 2020; Tan et al., 2023). In parallel, digital literacy has been widely reported as a significant predictor of learning outcomes, often mediated by factors such as self-efficacy and learning engagement (Yuan et al., 2025), while deep learning has been conceptualized either as a pedagogical framework emphasizing meaningful learning or as a technological construct related to artificial intelligence applications in education (Perrotta & Selwyn, 2020; Zhang et al., 2025). However, existing studies tend to investigate these variables in a fragmented manner, focusing on partial relationships rather than examining their interconnections simultaneously within a unified framework (Kim et al., 2021). Furthermore, most empirical research relies on parametric statistical techniques such as regression and structural equation modeling, which require strict assumptions of normality and interval data, despite the fact that educational data are often ordinal and non-normally distributed (Forthmann et al., 2020; Kaya & Erdem, 2021). Consequently, the application of nonparametric approaches, particularly Spearman's Rho, remains limited in exploring the relationships among deep learning approaches, problem-solving skills, digital literacy, and learning outcomes. Therefore, a clear research gap exists in the need for a comprehensive, data-driven investigation that simultaneously examines these variables using a nonparametric correlational framework within the context of science education.

Based on the above discussion, this study aims to examine the association between the deep learning approach, problem-solving skills, digital literacy, and students' learning outcomes. This research focuses on understanding the relationships among these variables within the context of 21st-century education. In addition, the study seeks to identify the strength and direction of these relationships. The deep learning approach is positioned as the primary variable that is expected to be associated with other variables. This study employs a quantitative approach with a correlational design to obtain objective empirical data. The relationships among variables are analyzed using a nonparametric method to accommodate the characteristics of the data. The use of this method is expected to provide more flexible and accurate analytical results. Furthermore, this study aims to address the limitations of previous research that has not examined these variables in an integrated manner. This research is also expected to contribute to the development of more effective instructional strategies [need citation]. Ultimately, the findings of this study are expected to serve as a reference for educators in designing learning environments that support 21st-century competencies.

LITERATURE REVIEW

The deep learning approach has gained increasing attention as an effective pedagogical strategy in contemporary education. This approach emphasizes meaningful understanding rather than surface-level memorization. Students engaged in deep learning are encouraged to actively construct knowledge through critical thinking and reflection (AlAli & Wardat, 2024; Weng et al., 2023). In this context, learning is viewed as a process of connecting new information with prior knowledge (Blau et al., 2020; Sedrakyan et al., 2020; Smith et al., 2021; von Rueden et al., 2023). Such integration enables students to develop a more comprehensive understanding of concepts. Deep learning also promotes learner autonomy and active participation in the learning process (Nopas, 2025; Rui et al., 2024; Tusino & Dewi, 2025; Zhou et al., 2024). It allows students to explore ideas, ask questions, and engage in inquiry-based activities. Furthermore, this approach aligns with the demands of 21st-century education, which require students to think critically and solve complex problems. By fostering meaningful engagement, deep learning contributes to the development of higher-order cognitive skills. Therefore, the deep learning approach is considered highly relevant for improving the quality of learning in modern educational environments.

Problem-solving skills are recognized as one of the most important competencies in education. These skills involve the ability to identify problems, analyze situations, and generate effective solutions. In academic contexts, problem-solving is closely related to students' cognitive development and reasoning abilities (Almulla & Al-Rahmi, 2023; Amalina & Vidákovich, 2023; Basid et al., 2024; Wu & Molnár, 2022; Zhao et al., 2021). Students with strong problem-solving skills tend to perform better in tasks that require analytical thinking. These skills also support students in applying theoretical knowledge to real-world situations. In addition, problem-solving abilities are essential for adapting to complex and uncertain environments. Educational practices that emphasize active learning tend to enhance students' problem-solving performance (Dixit et al., 2021; Kanphukiew & Nuangchalerm, 2024; Lugosi & Uribe, 2022). Approaches such as inquiry-based learning and project-based learning provide opportunities for students to engage in problem-solving activities. Through these experiences, students develop both cognitive and metacognitive skills. As a result, problem-solving skills play a crucial role in determining students' academic success.

Digital literacy has emerged as a key competency in the digital age. It encompasses the ability to access, evaluate, and utilize digital information effectively. Students with high digital literacy are better equipped to navigate complex information environments (Buchan et al., 2024). This competency supports independent learning and enhances students' ability to manage their own learning processes. Digital literacy is also closely associated with critical thinking skills (Indah et al., 2022; Tinmaz et al., 2022; Yasa et al., 2024). Students are required to evaluate the credibility and relevance of information obtained from digital sources. In addition, digital literacy enables students to use technological tools for problem-solving and knowledge construction. The integration of digital literacy into education promotes more interactive and engaging learning experiences. It also facilitates collaboration and communication among students. Consequently, digital literacy is considered an essential component of modern education.

Learning outcomes represent the measurable results of the learning process. These outcomes reflect the extent to which students achieve the intended learning objectives. Learning outcomes are influenced by various factors, including instructional strategies, student engagement, and learning environments (Carroll et al., 2021; Cayubit, 2022; Li & Xue, 2023). Cognitive abilities such as problem-solving and critical thinking play a significant role in determining learning outcomes (Almulla, 2023; Sholihah & Lastariwati, 2020; Wu & Molnár, 2022). In addition, digital literacy contributes to students' ability to access and process learning materials effectively. The interaction between cognitive and digital competencies creates a foundation for improved academic performance. However, learning outcomes are complex and cannot be explained by a single variable. Multiple factors interact to influence the effectiveness of the learning process. Therefore, understanding the relationships among these variables is essential for improving educational practices. This complexity highlights the need for comprehensive studies that examine multiple variables simultaneously.

Previous studies have examined the relationships among deep learning, problem-solving skills, digital literacy, and learning outcomes. However, many of these studies focus on partial relationships rather than exploring the variables in an integrated framework. In addition, most research employs parametric statistical methods that require strict assumptions about data distribution. Educational data, however, are often ordinal and may not meet these assumptions. As a result, the use of parametric techniques may limit the validity of the findings. Nonparametric methods provide a more flexible alternative for analyzing such data. Despite this advantage, the application of nonparametric approaches in educational research remains limited. This indicates a methodological gap that needs to be addressed. Furthermore, there is a lack of studies that simultaneously examine the relationships among all four variables. Therefore, a comprehensive analysis using an appropriate methodological approach is necessary.

METHOD

Research Design

This study employed a quantitative approach using a correlational research design to examine the relationships among the deep learning approach, problem-solving skills, digital literacy, and students' learning outcomes. The correlational design was selected because the study aimed to identify the strength and direction of associations among variables without manipulating them. This approach allows the researcher to observe naturally occurring relationships within an authentic educational context. The study focused on determining the degree of association among variables rather than establishing causal relationships. Therefore, the findings are interpreted as associations instead of direct effects. The quantitative approach was considered appropriate because the data were collected in numerical form and analyzed using statistical techniques. This design also provides an objective basis for examining relationships among multiple variables simultaneously. In addition, the use of a correlational design aligns with the purpose of generating empirical evidence in educational research. The research was conducted in a formal school setting to reflect real classroom conditions. Thus, the research design provided a systematic framework for analyzing the relationships among the variables under study.

Participant

The participants in this study were tenth-grade students from SMAN 1 Anjongan. The total population consisted of 199 students enrolled in the tenth grade. From this population, a sample of 121 students was selected using proportionate random sampling. This sampling technique was applied to ensure that each class was represented proportionally based on its size. It also ensured that each member of the population had an equal opportunity to be selected as part of the sample. The sample size was considered adequate to represent the population characteristics. The participants were selected based on their involvement in learning activities that incorporated elements of the deep learning approach. This ensured that respondents had relevant experience related to the variables being studied. The participants came from different classes within the same grade level, allowing for broader representation. This diversity enhanced the reliability of the collected data. Therefore, the selected participants were deemed appropriate for achieving the objectives of the study.

Instrument

The data were collected using structured questionnaires designed to measure four variables: the deep learning approach, problem-solving skills, digital literacy, and students' learning outcomes. The deep learning approach was measured as the independent variable, while the other three variables were treated as dependent variables. Each instrument was developed based on relevant theoretical frameworks and adjusted to the context of the study. The questionnaire for the deep learning approach consisted of multiple items that reflected students' engagement in meaningful and reflective learning. The problem-solving skills instrument measured students' ability to analyze and resolve problems systematically. The digital literacy instrument assessed students' ability to access, evaluate, and use digital information effectively. The learning outcomes instrument captured students' perceived academic achievement. All items were measured using a Likert scale ranging from 1 to 5. The questionnaires were distributed to 121 students through an online platform using Google Forms. Data collection was conducted in January 2026 under controlled conditions to ensure consistency in responses.

Data Analysis

The data analysis began with testing the validity and reliability of the research instruments to ensure the accuracy and consistency of the measurements. Validity testing was conducted to determine whether each item appropriately represented the intended construct. Reliability testing was performed to assess the internal consistency of the instruments. After confirming the quality of the instruments, a normality test was conducted to determine the appropriate statistical method for analysis. The Kolmogorov-Smirnov test was used to examine whether the data followed a normal distribution. The results indicated that at least one variable did not meet the normality assumption. Therefore, a nonparametric statistical method was selected for further analysis. Spearman's Rho correlation was used to examine the relationships among the variables. This method is suitable for analyzing ordinal data and does not require normal distribution assumptions. The analysis focused on identifying the strength and direction of associations among the variables. The results were interpreted based on correlation coefficients and significance values.

Procedure

The research procedure was conducted through several systematic stages. First, the researcher identified the research problem based on existing issues in the educational context. Second, relevant theoretical frameworks were reviewed to support the development of research instruments. Third, the instruments were designed and tested for validity and reliability. Fourth, permission to conduct the research was obtained from the school. Fifth, the sample was selected using proportionate random sampling. Sixth, the questionnaires were distributed to the selected participants through an online platform. Seventh, the researcher ensured that all participants completed the questionnaires independently. Eighth, the collected data were reviewed and organized for analysis. Ninth, statistical analysis was conducted using appropriate methods based on the data characteristics. Finally, the results were interpreted and presented in accordance with the research objectives.

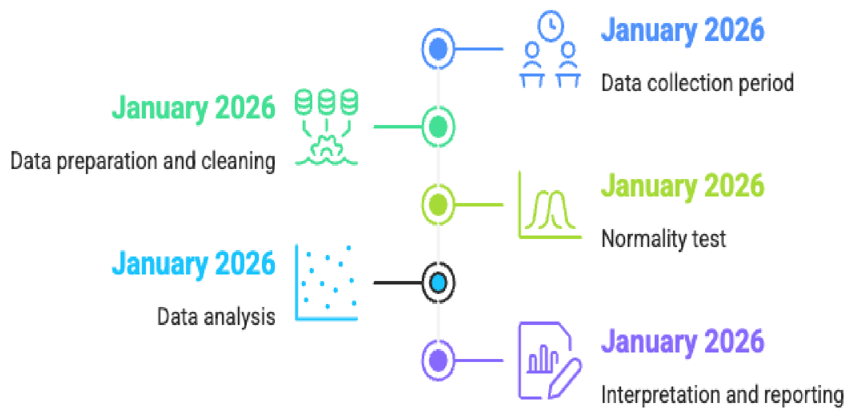

Figure 1. Research framework for improving students' numeracy literacy

RESULTS AND DISCUSSION

Results

This study involved 121 tenth-grade students of SMAN 1 Anjongan who were selected from a total population of 199 students using proportionate random sampling. The data were collected in January 2026 through structured questionnaires distributed via Google Forms. The questionnaires measured four main variables, namely the deep learning approach, problem-solving skills, digital literacy, and students' learning outcomes. The deep learning questionnaire consisted of 20 items, the problem-solving skills questionnaire consisted of 18 items, the digital literacy questionnaire consisted of 18 items, and the learning outcomes questionnaire consisted of 20 items. All items were measured using a five-point Likert scale. Before conducting the main correlation analysis, the data were first examined through validity testing, reliability testing, and normality testing to ensure the quality and suitability of the dataset for statistical analysis.

Instrument validity

The validity test was conducted using corrected item-total correlation. The minimum criterion used to determine item validity was 0.30. Items with a correlation coefficient equal to or higher than 0.30 were categorized as valid, whereas items below this threshold were categorized as invalid. The results show that the majority of items in each instrument met the validity criterion.

Table 1. Summary of instrument validity test

Variable	Number of Items	Valid Items	Invalid Items	Percentage of Valid Items
Deep Learning Approach	20	17	3	85%
Problem-Solving Skills	18	14	4	77%
Digital Literacy	18	15	3	83%
Student Learning Outcomes	20	19	1	95%

As shown in Table 1, the student learning outcomes instrument obtained the highest proportion of valid items, with 19 out of 20 items meeting the validity criterion. The deep learning approach instrument also demonstrated strong item validity, with 17 out of 20 items categorized as valid. Meanwhile, the digital literacy instrument had 15 valid items out of 18, while the problem-solving skills instrument had 14 valid items out of 18. These findings indicate that the instruments generally had acceptable item quality. However, several items did not reach the minimum corrected item-total correlation threshold, indicating that those items may not adequately represent their intended constructs. Therefore, for stronger international publication standards, invalid items should be removed or revised before further analysis.

Instrument Reliability

After the validity test, reliability analysis was conducted using Cronbach's Alpha. This test was used to examine the internal consistency of each instrument. A Cronbach's Alpha value above 0.70 was considered acceptable, indicating that the items within each instrument were sufficiently consistent in measuring the same construct.

Table 2. Reliability test results

Variable	Cronbach's Alpha	Interpretation
Deep Learning Approach	0.824	Very good reliability
Problem-Solving Skills	0.756	High reliability
Digital Literacy	0.783	High reliability
Student Learning Outcomes	0.812	Very good reliability

Table 2 shows that all instruments had Cronbach's Alpha values above 0.70. The deep learning approach instrument obtained a Cronbach's Alpha value of 0.824, indicating very good reliability. The student learning outcomes instrument also showed very good reliability with a value of 0.812. Meanwhile, the problem-solving skills and digital literacy instruments obtained values of 0.756 and 0.783, respectively, indicating high reliability. These results demonstrate that all instruments had acceptable internal consistency and were reliable for measuring the intended variables.

Normality Test

The Kolmogorov-Smirnov test was used to examine the distribution of the data. The normality test was necessary to determine whether parametric or nonparametric statistical analysis should be used. A significance value greater than 0.05 indicates that the data are normally distributed, whereas a significance value below 0.05 indicates that the data do not meet the normality assumption.

Table 3. Normality test results using kolmogorov-smirnov

Variable	N	Mean	Standard Deviation	Sig. Value	Distribution
Deep Learning Approach	121	69.85	7.533	0.200	Normal
Problem-Solving Skills	121	68.98	6.817	0.200	Normal
Digital Literacy	121	67.16	7.620	0.099	Normal
Student Learning Outcomes	121	82.58	13.798	0.000	Not normal

As presented in Table 3, the deep learning approach, problem-solving skills, and digital literacy variables had significance values above 0.05, indicating that these variables were normally distributed. However, student learning outcomes obtained a significance value of 0.000, which is below 0.05. This result indicates that the learning outcomes data were not normally distributed. Because at least one variable violated the normality assumption, the study proceeded with a nonparametric correlation test. Therefore, Spearman's Rho correlation was used to analyze the relationships among variables.

Spearman's Rho Correlation Analysis

Spearman's Rho correlation analysis was conducted to examine the strength and direction of the relationships among the deep learning approach, problem-solving skills, digital literacy, and student learning outcomes. The analysis focused on identifying whether the variables were significantly associated and how strong those associations were.

Table 4. Spearman's rho correlation matrix

Variables	Deep Learning Approach	Problem-Solving Skills	Digital Literacy	Student Learning Outcomes
Deep Learning Approach	1.000	0.517**	0.484**	0.226*
Problem-Solving Skills	0.517**	1.000	0.596**	0.205*
Digital Literacy	0.484**	0.596**	1.000	0.230*
Student Learning Outcomes	0.226*	0.205*	0.230*	1.000

Note: **$p < 0.01$; *$p < 0.05$.

The results in Table 4 indicate that all relationships among the variables were positive and statistically significant. The deep learning approach had a significant positive correlation with problem-solving skills, with a correlation coefficient of $\rho = 0.517$. This result indicates a moderate association, meaning that students who experienced stronger deep learning practices tended to report better problem-solving skills. The deep learning approach was also positively correlated with digital literacy, with a coefficient of $\rho = 0.484$. This finding suggests that deep learning practices were associated with students' ability to access, evaluate, and use digital information effectively. However, the correlation between the deep learning approach and student learning outcomes was relatively weak, although still statistically significant, with a coefficient of $\rho = 0.226$. The strongest correlation was found between problem-solving skills and digital literacy, with a coefficient of $\rho = 0.596$. This result indicates that students with stronger problem-solving skills also tended to have higher levels of digital literacy. Meanwhile, the correlation between problem-solving skills and learning outcomes was positive but weak, with $\rho = 0.205$. Similarly, digital literacy had a weak but significant positive relationship with learning outcomes, with $\rho = 0.230$. These findings suggest that although problem-solving skills and digital literacy are related to learning outcomes, their direct relationships with learning outcomes are not strong. This result indicates that learning outcomes may be influenced by other factors beyond the variables examined in this study.

Table 5. Summary of correlation strength

Relationship Between Variables	Correlation Coefficient	Significance	Strength of Relationship
Deep Learning Approach – Problem-Solving Skills	0.517	$p < 0.01$	Moderate
Deep Learning Approach – Digital Literacy	0.484	$p < 0.01$	Moderate
Deep Learning Approach – Student Learning Outcomes	0.226	$p < 0.05$	Weak
Problem-Solving Skills – Digital Literacy	0.596	$p < 0.01$	Moderate
Problem-Solving Skills – Student Learning Outcomes	0.205	$p < 0.05$	Weak
Digital Literacy – Student Learning Outcomes	0.230	$p < 0.05$	Weak

Table 5 provides a clearer summary of the strength of each correlation. The strongest association was observed between problem-solving skills and digital literacy. Moderate correlations were also found between the deep learning approach and problem-solving skills, as well as between the deep learning approach and digital literacy. In contrast, all relationships involving student learning outcomes were weak, although statistically significant. These results show that the deep learning approach is more strongly associated with students' cognitive and digital competencies than with their learning outcomes. Therefore, learning outcomes appear to be a more complex variable that may require the consideration of additional factors such as motivation, prior knowledge, learning environment, teacher support, and assessment methods.

Relationship	**Visual Strength**
Deep Learning → Problem-Solving Skills	███████████ 0.517
Deep Learning → Digital Literacy	██████████ 0.484
Deep Learning → Learning Outcomes	████ 0.226
Problem-Solving Skills → Digital Literacy	████████████ 0.596
Problem-Solving Skills → Learning Outcomes	████ 0.205
Digital Literacy → Learning Outcomes	████ 0.230

Figure 2. Correlation strength among variables

Figure 2. visually confirms that the highest correlation occurred between problem-solving skills and digital literacy, followed by the relationship between deep learning and problem-solving skills. The correlations involving learning outcomes were visibly weaker than the other relationships. This pattern indicates that the deep learning approach may be more directly related to the development of students' problem-solving skills and digital literacy than to their academic outcomes. The visual representation also strengthens the interpretation that learning outcomes are likely influenced by broader academic and contextual factors.

Overall, the results demonstrate that the instruments used in this study were generally valid and reliable. The normality test indicated that nonparametric analysis was appropriate because one variable did not meet the assumption of normal distribution. Spearman's Rho analysis revealed positive and significant relationships among all variables. The deep learning approach was moderately associated with problem-solving skills and digital literacy, but only weakly associated with student learning outcomes. The strongest relationship was found between problem-solving skills and digital literacy. These findings indicate that deep learning practices are closely related to students' higher-order thinking and digital competencies. However, the relatively weak correlations involving learning outcomes suggest that academic achievement is influenced by multiple factors and cannot be explained solely by the deep learning approach, problem-solving skills, or digital literacy.

Discussion

The overall findings of this study indicate that the deep learning approach is significantly associated with problem-solving skills, digital literacy, and students' learning outcomes. This result suggests that instructional practices emphasizing meaningful understanding, active engagement, and critical reflection contribute to the development of higher-order thinking skills. Deep learning environments encourage students to actively construct knowledge rather than passively receive information (Khodadad, 2023; Weng et al., 2023; Young et al., 2020). This process enables learners to integrate prior knowledge with new concepts in a more meaningful way. Such integration supports deeper cognitive processing and enhances conceptual understanding. Previous studies have consistently reported that deep learning promotes student agency and reflective thinking in learning processes (Hooshyar et al., 2023; Rui et al., 2024; Yang et al., 2024). In addition, research has shown that students engaged in deep learning are more likely to demonstrate improved critical thinking and reasoning abilities. These findings align with theoretical perspectives that emphasize the importance of meaningful learning in knowledge construction. Furthermore, deep learning encourages students to take responsibility for their own learning processes. Therefore, the significant relationships identified in this study reinforce the role of deep learning as a key pedagogical approach in 21st-century education.

The significant relationship between the deep learning approach and problem-solving skills highlights the importance of instructional strategies that promote analytical and reflective thinking. Problem-solving requires students to identify problems, analyze information, and generate appropriate solutions (Mahanal et al., 2022; Shanta & Wells, 2022; Sholihah & Lastariwati, 2020). Deep learning provides opportunities for students to engage in such processes through inquiry-based and problem-centered activities (Gomez, 2025). These learning experiences allow students to develop systematic approaches to solving complex problems. Previous research has demonstrated that problem-based learning and inquiry-based learning significantly improve problem-solving performance. These approaches share similar characteristics with deep learning, particularly in terms of active engagement and reflection. In addition, students who engage in deep learning are more likely to transfer knowledge across different contexts. This transferability is essential for effective problem-solving in real-life situations. The findings of this study are consistent with earlier studies that emphasize the role of deep learning in enhancing cognitive flexibility (Ma et al., 2025; Sandbrink & Summerfield, 2024). Furthermore, deep learning environments encourage students to explore multiple solutions to a given problem.

In addition to problem-solving skills, the deep learning approach also demonstrates a significant relationship with digital literacy. This finding indicates that students who engage in deep learning tend to utilize digital technologies more effectively. Digital literacy involves not only technical skills but also the ability to evaluate and manage information critically (Falloon, 2020; Nikou et al., 2022; Tinmaz et al., 2022). Deep learning environments require students to interact with various digital resources, which enhances their digital competencies (Braßler, 2024; Lee & Chang, 2025). Previous studies have reported that technology-integrated learning environments significantly improve students' digital literacy. These environments encourage students to explore, analyze, and synthesize information from multiple sources (Martin et al., 2020). Furthermore, digital literacy supports independent learning and self-regulation. Students with strong digital literacy are better equipped to manage their learning processes. The findings of this study are consistent with research showing that meaningful learning experiences enhance digital engagement. In addition, the integration of technology in deep learning promotes collaborative and interactive learning.

However, the relationship between the deep learning approach and learning outcomes, as well as between other variables and learning outcomes, is relatively weak despite being statistically significant. This finding suggests that learning outcomes are influenced by multiple factors beyond instructional approaches and cognitive skills. Academic achievement is a complex construct that involves both internal and external variables. Internal factors such as motivation, prior knowledge, and self-efficacy play a crucial role in determining learning outcomes. External factors such as teaching quality, learning environment, and assessment methods also significantly influence academic performance (Brink et al., 2021). Previous studies have similarly reported that learning outcomes cannot be explained by a single variable. In addition, traditional assessment systems may not fully capture the depth of understanding developed through deep learning. This mismatch between learning approach and assessment method may explain the weaker correlations observed in this study. Furthermore, the effects of deep learning on academic performance may require longer periods to become evident. Short-term studies may not fully reflect the long-term benefits of meaningful learning approaches.

Overall, the findings of this study demonstrate that the deep learning approach, problem-solving skills, and digital literacy are interconnected variables that play an important role in the learning process. The results indicate that deep learning is more strongly associated with cognitive and digital competencies than with immediate academic outcomes. This finding supports the view that meaningful learning processes contribute to the development of transferable skills. Previous research has emphasized the importance of integrating cognitive and technological competencies in education. The strong relationship between problem-solving skills and digital literacy further highlights the synergy between these competencies. This synergy is particularly relevant in the context of 21st-century education, where students are required to navigate complex digital environments. The use of a nonparametric approach in this study also contributes methodologically by providing a more flexible analysis of educational data. Many previous studies rely on parametric methods, which may not always be suitable for ordinal data. Therefore, this study provides a more robust analysis by using Spearman's Rho correlation. The findings also suggest that educators should design learning environments that integrate deep learning, problem-solving, and digital literacy.

Implications

The findings of this study provide important implications for both educational practice and research in the context of 21st-century learning. The significant association between the deep learning approach and both problem-solving skills and digital literacy suggests that instructional strategies should prioritize meaningful engagement and active learning processes. Teachers are encouraged to design learning environments that promote critical thinking, reflection, and knowledge integration. In addition, the moderate relationships identified in this study indicate that deep learning can effectively support the development of higher-order cognitive skills. The integration of digital tools within deep learning environments can further enhance students' ability to access and evaluate information. This highlights the need for educators to incorporate technology in a purposeful and structured manner. However, the relatively weak relationship between deep learning and learning outcomes suggests that academic performance is influenced by multiple factors. Therefore, educators should consider combining deep learning strategies with other supportive elements such as motivation, feedback, and assessment alignment. The findings also imply that assessment practices need to be adapted to better capture the outcomes of meaningful learning processes. Traditional evaluation methods may not fully reflect students' conceptual understanding and critical thinking abilities. From a methodological perspective, the use of nonparametric analysis demonstrates the importance of selecting appropriate statistical techniques based on data characteristics. Consequently, future research should adopt more flexible analytical approaches and explore additional variables to provide a more comprehensive understanding of student learning outcomes.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting the findings. First, the use of a correlational research design limits the ability to establish causal relationships among the variables. The results only indicate the presence and strength of associations rather than direct effects. Second, the study was conducted within a single school context, which may limit the generalizability of the findings to other educational settings. Differences in institutional characteristics, teaching practices, and student backgrounds may influence the applicability of the results. Third, the data were collected using self-reported questionnaires, which may introduce response bias and subjectivity. Students' perceptions may not always accurately reflect their actual competencies or behaviors. Fourth, several items in the instruments did not meet the validity threshold, yet were retained, which may affect the precision of measurement. Fifth, the relatively weak correlations with learning outcomes suggest that additional variables were not included in the analysis. Factors such as motivation, prior knowledge, learning environment, and teacher effectiveness may play a significant role in shaping academic performance. Sixth, the study relied on cross-sectional data collected within a limited time frame, which may not capture long-term learning effects. Based on these limitations, future research is recommended to employ experimental or longitudinal designs to examine causal relationships and learning development over time. Researchers are also encouraged to involve larger and more diverse samples to enhance the generalizability of findings. In addition, future studies should refine measurement instruments by removing invalid items and incorporating multiple data sources such as observations or performance-based assessments. Finally, integrating additional variables and advanced analytical models is suggested to provide a more comprehensive understanding of the factors influencing student learning outcomes.

CONCLUSION

This study concludes that the deep learning approach is positively and significantly associated with problem-solving skills, digital literacy, and students' learning outcomes. The findings indicate that learning environments emphasizing meaningful understanding, active engagement, and reflective thinking contribute to the development of higher-order cognitive abilities. In particular, the deep learning approach demonstrates a moderate relationship with both problem-solving skills and digital literacy, suggesting its effectiveness in fostering critical and analytical thinking. However, the relationship between the deep learning approach and learning outcomes is relatively weak, indicating that academic achievement is influenced by multiple factors beyond instructional strategies alone. The results also reveal that problem-solving skills and digital literacy have a stronger association with each other, highlighting the interconnected nature of cognitive and technological competencies. These findings suggest that enhancing students' learning experiences requires an integrated approach that combines cognitive skill development and digital competence. The use of nonparametric analysis in this study provides a more appropriate methodological approach for handling ordinal and non-normally distributed data. This contributes to the robustness and validity of the research findings. Furthermore, the study emphasizes the importance of aligning instructional practices with the demands of 21st-century education. Educators are encouraged to implement deep learning strategies that promote active participation and meaningful learning experiences. In addition, integrating digital literacy and problem-solving activities into the curriculum can enhance students' readiness for complex learning environments. Overall, this study contributes to the growing body of knowledge on effective learning strategies and provides practical insights for improving educational outcomes.

AUTHOR CONTRIBUTIONS STATEMENT

Eviana designed the study, developed the research framework integrating deep learning approach, problem-solving skills, digital literacy, and learning outcomes, and led the data collection and nonparametric statistical analysis using Spearman's Rho. Achmadi contributed to the conceptualization of the study, refined the theoretical background and literature review, and supported the interpretation of the relationships among variables within the context of 21st-century science education. Afandi provided methodological expertise, supervised the validation and reliability testing of instruments, and contributed to the interpretation and contextualization of the findings. All authors contributed to writing, reviewed the manuscript critically for important intellectual content, and approved the final version.

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