# Enhancing Digital Literacy and 4Cs Skills through Project-Based Deep Learning in Kurikulum Merdeka

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**Abstract:** This study examines the implementation of Deep Learning within the Merdeka Curriculum as a response to educational transformation in the digital age, which demands 21st-century competencies, namely critical thinking, creativity, collaboration, communication, digital literacy, and Pancasila-based character among elementary students. The study aims to evaluate the effectiveness of a project-based approach in integrating technological skills while strengthening national identity. A mixed-method design was employed, combining phenomenology and a one-group pretest-posttest model involving teachers, principals, and fifth-grade students from SD Negeri Sondakan and SD Negeri Tegalrejo in Surakarta. Data were gathered through in-depth interviews, observation, documentation, pretests, and posttests, then analyzed using triangulation, descriptive statistics, and ANOVA. The findings indicate improved students' technology mastery, with success rates of 93.33% in Sondakan and 84.62% in Tegalrejo. Supporting factors included school leadership, teacher collaboration, and parental involvement. These results show that Deep Learning effectively strengthens digital literacy, the 4Cs, and students' national character in diverse elementary school contexts.

**Abstrak**: Penelitian ini menganalisis implementasi Pembelajaran Mendalam dalam Kurikulum Merdeka sebagai respons atas tuntutan transformasi pendidikan abad ke-21, khususnya penguatan 4C, literasi digital, dan karakter Pancasila pada siswa sekolah dasar. Tujuan penelitian ini ialah menilai efektivitas pendekatan berbasis proyek dalam mengintegrasikan kemampuan teknologi sekaligus membangun identitas kebangsaan. Penelitian menggunakan desain mixed method dengan pendekatan fenomenologi dan one-group pretest-posttest pada guru, kepala sekolah, serta siswa kelas V di SD Negeri Sondakan dan SD Negeri Tegalrejo, Surakarta. Data diperoleh melalui wawancara mendalam, observasi, dokumentasi, pretest, dan posttest, lalu dianalisis secara triangulasi, statistik deskriptif, dan ANOVA. Hasil menunjukkan peningkatan penguasaan teknologi siswa, dengan capaian 93,33% di Sondakan dan 84,62% di Tegalrejo. Faktor pendukung meliputi kepemimpinan sekolah, kolaborasi guru, serta keterlibatan orang tua. Temuan ini menegaskan bahwa Pembelajaran Mendalam efektif memperkuat literasi digital, 4C, dan karakter nasional siswa. Secara praktis, model ini memberikan rujukan implementatif bagi sekolah dasar dalam merancang pembelajaran kontekstual, kolaboratif, dan berorientasi hasil berkelanjutan di era digital.

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## A. Introduction

21st-century Education cannot be separated from the impact of globalization and rapid technological advancements, which require a transformation toward a more adaptive and flexible learning paradigm. The traditional educational model that positions teachers as the sole source of knowledge and students as passive recipients is increasingly inadequate in equipping learners with the competencies required in today's modern world (Cadis et al., 2023; Xu & Ouyang, 2022). There is an urgent need to shift toward a student-centered approach in which students are not merely learning objects but active participants who contribute meaningfully to the learning process. This transformation encourages the development of critical, creative, collaborative, and communicative (4C) skills through interactive, participatory, and contextual learning experiences (Mavluda, 2025; Mujiono et al., 2024). Such an approach aligns with the demands of the 21st century, which require individuals not only to possess broad knowledge but also to apply that knowledge effectively to solve problems, innovate, and adapt to rapid change. Consequently, the role of teachers has shifted from information transmitters to facilitators, motivators, and guides who support students in exploring and constructing knowledge (Kamada et al., 2021; Yu et al., 2022). Educators are therefore expected to design learning experiences that are engaging, relevant to students' lives, and enriched by technology as an essential educational tool. The transformation required in 21st-century Education is not limited to teaching roles alone, but also includes the redesign of learning methodology, assessment, and the overall educational environment (Carroll et al., 2021; Mullabayev, 2021).

Within the Indonesian educational context, the Kurikulum Merdeka emphasizes deep learning as an important framework for strengthening meaningful learning experiences. However, challenges remain, particularly in developing students' literacy skills in schools (Muvid, 2024; Komalasari & Apriani, 2023). Deep learning in the Kurikulum Merdeka is designed to provide students with valuable learning experiences through hands-on and project-based activities (Bouilheres et al., 2020; Minsih et al., 2023). This approach not only supports cognitive development, but also fosters positive character traits aligned with the Pancasila student profile, including creativity, innovation, critical thinking, global awareness, collaboration, and commitment to universal virtues. In this sense, deep learning is increasingly relevant to contemporary educational demands because it equips students with the competencies needed to succeed in a rapidly changing world. At the elementary school level, this relevance becomes even more important, as primary education serves as the foundation for students' long-term academic growth, character formation, and competence development. Therefore, the implementation of deep learning in elementary schools deserves serious attention, especially in relation to how it can support 21st-century learning outcomes and strengthen the values embedded in the Kurikulum Merdeka.

According to Entwistle (2023), the application of deep learning has largely emphasized theoretical and conceptual dimensions, while its practical implementation at the elementary level remains limited and mostly concentrated in primary education settings. This indicates that more comprehensive empirical studies are needed to examine how deep

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learning can be integrated into elementary school practices, what barriers are faced by teachers and students, and how this approach contributes to the development of 21st-century skills. Supporting this view, Cahyanto (2025) highlights that research on deep learning at the primary school level can provide important insights for advancing the Kurikulum Merdeka and refining the deep learning framework itself, thereby serving as an essential foundation for improving the quality of elementary education (Lubis et al., 2023; Sulasmi & Akrim, 2020). In addition, the relationship between deep learning and the development of 21st-century skills has become increasingly important in Indonesia because schools are expected not only to deliver academic content but also to cultivate digital literacy, collaboration, and character formation. This makes deep learning more than a pedagogical trend; it becomes a strategic educational approach that can bridge school learning with the demands of modern life.

The Kurikulum Merdeka and deep learning have emerged as important topics in educational discourse in Indonesia, yet existing studies still leave several critical gaps. While many studies have discussed deep learning at a general level, most research has focused on theoretical explanation or broad curriculum implementation rather than on the concrete practices of implementing deep learning in elementary schools, especially in relation to the development of 21st-century learning skills (Avdiu et al., 2025; González-Salamanca et al., 2020). Moreover, the effectiveness of deep learning in supporting digital literacy, teacher collaboration, and student character formation in real school contexts has not been extensively examined. Research also remains limited in explaining how supporting factors such as school leadership, parental involvement, resource availability, and teacher readiness interact to shape implementation quality (Cahyono et al., 2024; Sumardi et al., 2020). As a result, there is still insufficient empirical evidence on how deep learning is experienced, adapted, and sustained in elementary school settings, particularly within the Merdeka Curriculum. This gap shows the need for a study that does not only describe the concept of deep learning, but also examines its actual implementation, supporting conditions, and practical outcomes in schools.

The novelty of this research lies in its emphasis on best practices for implementing deep learning in basic education and its relationship to the evolution of learning in the 21st century (Hadiyanto et al., 2021; Yan, 2020). Unlike previous studies that tend to discuss deep learning at the conceptual or policy level, this study examines deep learning as a lived educational practice in elementary schools, focusing on how it operates through project-based activities, digital literacy development, and the strengthening of Pancasila-based character. In addition, this research brings together qualitative insights from teachers, principals, and students with measurable evidence of student technology mastery, allowing a more comprehensive understanding of how deep learning functions in real classroom contexts. The study also highlights the interplay between pedagogical competence, school leadership, learning resources, and parental support as part of the implementation process. In this way, the present study contributes a more contextual and practice-oriented model of

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deep learning that can be used as a reference for other elementary schools seeking to implement meaningful learning aligned with the Kurikulum Merdeka.

Based on the issues above, this study is guided by three research questions: how is deep learning implemented in elementary schools within the Kurikulum Merdeka, *what factors support its success; and what challenges arise during its implementation?* This research aims not only to identify and understand best practices for deep learning in elementary schools, but also to analyze the supporting factors and obstacles that influence its effectiveness (Cahyono et al., 2024; Sumardi et al., 2020). Specifically, this study explores how teacher knowledge and skills, resource availability, stakeholder support, and school climate affect implementation quality (Henukh et al., 2024; Cahyono et al., 2023). The contribution of this study is threefold. Theoretically, it enriches the discussion on deep learning within the Kurikulum Merdeka by linking it to 21st-century skills and character education. Practically, it offers an implementation model that can assist teachers and school leaders in designing more contextual, collaborative, and technology-oriented learning. Policy-wise, the findings provide evidence that may inform decision-making for the broader adoption of deep learning in elementary education. Thus, this study is expected to serve as a valuable reference for educators, school leaders, supervisors, and policymakers in improving the quality of 21st-century education and strengthening the educational transformation agenda in Indonesia (Firdausih, 2024; Milicevic, 2015; Prihatin et al., 2025; Sari & Arta, 2025).

## B. Method

This study employed a mixed-method approach, integrating a qualitative phenomenological framework with a quantitative quasi-experimental design to obtain a comprehensive understanding of the implementation of deep learning within the Kurikulum Merdeka (McKim, 2017). The qualitative component aimed to explore the socio-contextual experiences of students, teachers, and school principals, while the quantitative component utilized a one-group pretest–posttest design to measure students' digital literacy improvement after the intervention. The research was conducted through several stages: (1) preliminary observation and needs analysis, (2) instrument development and validation, (3) pretest administration, (4) implementation of project-based deep learning intervention, (5) posttest administration, (6) data analysis, and (7) interpretation of findings.

The study was conducted at SD Negeri Sondakan and SD Negeri Tegalrejo, located in Laweyan District, Surakarta City. These schools were selected purposively due to their active implementation of the Kurikulum Merdeka and deep learning practices. The participants consisted of school principals, fifth-grade teachers, and fifth-grade students. At SD Negeri Sondakan, the participants included one principal, one teacher, and 15 students, while at SD Negeri Tegalrejo, the participants included one principal, one teacher, and 13 students. Thus, the total number of student participants was 28 students, supported by two principals and two teachers. Table 1 presents the distribution of respondents involved in this study.

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**Table 1.** Deep Learning Respondents

| Number | Institution | Principal | Fifth grade of the home teacher | Fifth grade of the home teacher |
|---|---|---|---|---|
| 1 | SDN Sondakan | 1 | 1 | 15 |
| 2 | SDN Tegalrejo | 1 | 1 | 13 |
| | Total | 2 | 2 | 28 |

Data were collected using multiple instruments to support methodological triangulation. The qualitative data were obtained through in-depth interviews, observations, and document analysis, while quantitative data were collected using structured questionnaires and pretest–posttest instruments designed to measure students' digital literacy and technology mastery. To ensure instrument quality, validity and reliability testing were conducted. Content validity was established through expert judgment involving education and curriculum specialists. Construct validity was examined using item correlation analysis, where items with correlation coefficients above 0.30 were considered valid. Reliability testing was performed using Cronbach's Alpha, with a coefficient greater than 0.70 indicating acceptable internal consistency.

Data collection was conducted in several stages. First, preliminary observations were carried out to identify students' initial digital literacy levels. Second, the pretest was administered to measure baseline competencies in digital literacy and basic technological skills. Third, the intervention was implemented through project-based deep learning activities focusing on digital literacy development. During the intervention, qualitative data were collected through interviews with principals and teachers, classroom observations, and documentation. Finally, a posttest was administered using the same instrument to measure students' improvement after the intervention.

Data analysis was conducted by integrating qualitative and quantitative techniques. Qualitative data from interviews, observations, and documents were analyzed using thematic analysis and triangulation to ensure credibility and consistency (Aspers & Corte, 2019). The analysis focused on identifying patterns related to implementation practices, supporting factors, and challenges.

Quantitative data from questionnaires and pretest–posttest results were analyzed using descriptive statistics (mean and percentage) and inferential statistics. A one-way ANOVA test was employed to determine differences in students' digital literacy outcomes (Smith, 2023). Prior to conducting ANOVA, statistical assumptions were tested. Normality was examined using the Shapiro–Wilk test, and homogeneity of variance was assessed using Levene's Test. Data were considered suitable for ANOVA when $p > 0.05$. The significance level was set at $\alpha = 0.05$, where $p < 0.05$ indicates a statistically significant difference.

The research followed a systematic flow consisting of observation, instrument preparation, pretest, intervention, posttest, data analysis, and conclusion. This structured process ensures the reliability and replicability of the study.

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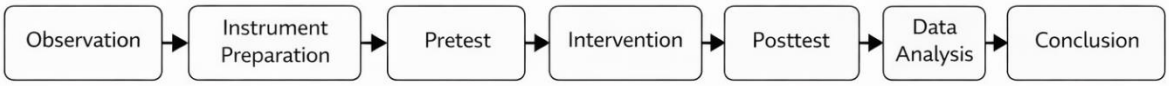


**Figure 1.** Research Flow of the Study

## C. Result

### Baseline Students' Digital Literacy

To establish students' initial level of digital literacy, a pretest was administered prior to the implementation of project-based deep learning. The assessment focused on students' ability to operate basic computer functions, understand simple programming logic, and apply digital tools in learning activities. The baseline results are presented in Table 1.

**Table 1.** Baseline Digital Literacy (Pretest Results)

| No | School | Number of Students | Competent | Incompetent | Percentage (%) |
|---|---|---|---|---|---|
| 1 | SDN Sondakan | 15 | 5 | 10 | 33.33% |
| 2 | SDN Tegalrejo | 13 | 4 | 9 | 30.77% |

As shown in Table 1, students' initial digital literacy levels were relatively low in both schools. In SD Negeri Sondakan, only 33.33% of students were categorized as competent, while 66.67% were still classified as incompetent. Similarly, in SD Negeri Tegalrejo, only 30.77% of students demonstrated competence, whereas the majority (69.23%) had not yet mastered basic digital literacy skills.

These findings indicate that most students had limited experience in using computer devices and applying digital concepts in learning contexts prior to the intervention. The results also confirm that the implementation of project-based deep learning was necessary to improve students' technological understanding and digital literacy competence at the elementary level.

### Post-Intervention Digital Literacy Outcomes

After the intervention, students' digital literacy skills were reassessed using the same instrument to determine changes in competence. The post-intervention results are presented in Table 2.

**Table 2.** Results of In-Depth Learning Activities for Fifth-Grade Students

| No | School | Number of Respondent Students | Competent | Incompetent | Success Percentage (%) |
|---|---|---|---|---|---|
| 1 | SDN Sondakan | 15 | 14 | 1 | 93.33% |
| 2 | SDN Tegalrejo | 13 | 11 | 2 | 84.62% |

As shown in Table 2, the number of competent students increased substantially after the implementation of project-based deep learning. In SD Negeri Sondakan, 14 out of 15

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students were categorized as competent, resulting in a success rate of 93.33%. In SD Negeri Tegalrejo, 11 out of 13 students achieved competence, with a success rate of 84.62%. These results indicate a clear improvement in students' digital literacy performance after the intervention. Taken together, the baseline and post-intervention data suggest a notable shift in students' digital literacy competence. Before the intervention, most students were still in the incompetent category, whereas after the intervention, the majority had moved into the competent category. This change provides the quantitative basis for the subsequent statistical analysis and supports the qualitative findings on the implementation process.

### ANOVA Results

To further examine whether the observed improvement in students' digital literacy was statistically significant, a one-way ANOVA test was conducted. The results of the analysis are presented in Table 3.

**Table 3.** One-Way ANOVA Test Results

| Source of Variation | Number of Squares (SS) | Free Degree (df) | Mean Square (MS) | F Calculate | p-value |
|---|---|---|---|---|---|
| Intergroup | 0,073 | 1 | 0,073 | 0,524 | 0,476 |
| In a Group | 3,735 | 26 | 0,144 | | |
| Total | 3,808 | 27 | | | |

As shown in Table 3, the ANOVA test produced an F value of 0.524 with a p-value of 0.476. Since the p-value is greater than the significance level of 0.05 ($p > 0.05$), the difference in students' digital literacy outcomes is not statistically significant. This result indicates that, statistically, the variation in students' digital literacy performance does not show a significant difference between the measured conditions. The statistical findings presented in this section provide a quantitative basis for understanding the outcomes of the intervention, which are further elaborated through qualitative findings in the following section.

### Qualitative Findings on Deep Learning Implementation

To complement the quantitative findings, qualitative data were analyzed to explore how deep learning was implemented in classroom practices. The results of the coding analysis are presented in Table 4.

**Table 4.** Coding Analysis Results

| Theme Code | Sub-Theme | Frequency | Description |
|---|---|---|---|
| Implementation of Digital Literacy | Use of Computer Devices | 18 | Students actively practice digital literacy through computers |
| 4C Development | Critical thinking | 15 | Students demonstrate analytical skills in simple programming |

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| Theme Code | Sub-Theme | Frequency | Description |
|---|---|---|---|
| 4C Development | Creativity | 14 | Students design programs based on their own ideas |
| 4C Development | Collaboration | 12 | Group work is evident in completing assignments |
| 4C Development | Communication | 10 | Student interaction increases during project discussions |
| Supporting Factors | Teacher Capacity | 16 | Teachers provide support with training and guidance |
| Supporting Factors | Learning Facilities | 13 | Computer availability influences success |
| Supporting Factors | Stakeholder Support | 11 | The active role of the principal and parents is identified |
| Obstacle | Teacher Understanding | 9 | Teachers' limited knowledge is a barrier |
| Obstacle | Time and Resources | 8 | Lack of time and tools hinders the process |

As shown in Table 4, the most dominant theme is the use of computer devices (frequency = 18), indicating that students were actively engaged in hands-on digital literacy practices during the learning process. In addition, the development of 21st-century skills is reflected through critical thinking (15), creativity (14), collaboration (12), and communication (10), suggesting that students participated in various interactive and higher-order learning activities. The findings also highlight that teacher capacity (16), learning facilities (13), and stakeholder support (11) played important roles in facilitating the implementation of deep learning. These themes demonstrate that the learning process was supported by both pedagogical and environmental factors.

## Supporting Factors and Barriers

To further understand the implementation of deep learning, qualitative findings were analyzed to identify key supporting factors and barriers influencing the learning process. These findings are summarized in Table 4 based on thematic coding of interview, observation, and documentation data.

**Table 4.** Coding Analysis Results

| Theme Code | Sub-Theme | Frequency | Description |
|---|---|---|---|
| Supporting Factors | Teacher Capacity | 16 | Teachers provide support with training and guidance |
| Supporting Factors | Learning Facilities | 13 | Computer availability influences success |
| Supporting Factors | Stakeholder Support | 11 | The active role of the principal and parents is identified |
| Barriers | Teacher Understanding | 9 | Teachers' limited knowledge is a barrier |

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| Theme Code | Sub-Theme | Frequency | Description |
|---|---|---|---|
| Barriers | Time and Resources | 8 | Lack of time and tools hinders the process |

As shown in Table 4, the most dominant theme is the use of computer devices (frequency = 18), indicating that students actively practiced digital literacy through hands-on activities. This theme is followed by teacher capacity (16), critical thinking (15), creativity (14), learning facilities (13), collaboration (12), stakeholder support (11), communication (10), teacher understanding (9), and time and resources (8). The distribution of these frequencies shows that deep learning implementation was not limited to digital tool use, but also involved the development of 21st-century competencies and the presence of contextual school support.

The qualitative findings also show that students were not only learning how to operate computer devices, but were also developing critical thinking, creativity, collaboration, and communication during project-based activities. These themes indicate that deep learning created opportunities for students to engage actively in learning tasks that required analysis, idea generation, teamwork, and discussion. The pattern observed in the coding results suggests that the implementation of digital literacy was closely connected to the development of 4C skills.

The supporting factors identified in the data were teacher capacity, learning facilities, and stakeholder support. Teacher capacity emerged as the strongest supporting factor, showing that teacher readiness and pedagogical guidance played a central role in facilitating the learning process. The availability of computers also influenced the success of learning activities, while the involvement of principals and parents helped strengthen the implementation process. These findings suggest that the success of deep learning depended not only on students' participation, but also on the readiness of the school ecosystem to provide academic and material support.

On the other hand, the main barriers were limited teacher understanding and constraints related to time and resources. The frequency of these themes shows that some teachers still faced difficulty in integrating digital technology into project-based learning, while limited time and tools made the learning process more difficult to implement optimally. These barriers indicate that deep learning requires continuous teacher development and adequate infrastructure to be implemented effectively in elementary schools.

Overall, the findings indicate that the implementation of project-based deep learning contributed to improvements in students' digital literacy, as reflected in the increase in the number of competent students across both schools. The quantitative results show a shift from low baseline competence to higher post-intervention outcomes, while the statistical analysis indicates that the differences were not statistically significant. In addition, the qualitative findings reveal that the implementation process was supported by teacher capacity, learning facilities, and stakeholder involvement, although several challenges related to teacher readiness and resource limitations were still identified. These results

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provide a comprehensive overview of the implementation process and serve as a foundation for further discussion of the findings in the next section.

## D. Discussion

The findings of this study indicate that the implementation of project-based deep learning contributes to improving students' digital literacy and 21st-century skills. This is evidenced by the increase in students' technological proficiency, which reached 93.33% at SD Negeri Sondakan and 84.62% at SD Negeri Tegalrejo. These results suggest that integrating digital literacy into project-based activities enables students to engage actively in meaningful learning processes that combine conceptual understanding with practical application. This improvement reflects the fundamental characteristics of deep learning, where students are not only passive recipients of knowledge but active participants who construct understanding through experience. The project-based approach provides opportunities for students to directly interact with digital tools, thereby enhancing both technical competence and cognitive engagement.

The findings of this study are consistent with previous research highlighting the effectiveness of project-based and interactive learning in developing 21st-century skills. The development of critical thinking, creativity, collaboration, and communication observed in this study aligns with the results of Adnyani & Suniasih (2023), Dilekçi & Karatay (2023), and Kim et al (2019), which emphasize the importance of student-centered learning in fostering higher-order thinking skills. Furthermore, this study supports the argument that contextual and interactive learning approaches are essential in enhancing student engagement and competence development (Intaratat et al., 2024; González-Salamanca et al., 2020). The integration of digital literacy within project-based deep learning provides a concrete learning environment where students can apply knowledge in real-world contexts, thereby strengthening both cognitive and practical skills.

The effectiveness of deep learning implementation in this study can be explained by several key factors identified in the findings. First, teacher pedagogical competence plays a central role in facilitating meaningful learning experiences. Teachers who received training were able to design and implement technology-based projects that enhanced students' engagement and digital literacy mastery. Second, the availability of infrastructure, such as computers and internet access, supported the learning process by providing students with opportunities for hands-on practice. The role of school leadership in facilitating these resources also contributed to creating a conducive learning environment. These findings are consistent with studies emphasizing the importance of teacher competence and infrastructure in improving learning outcomes (Xing & Feng, 2023; Entwistle, 2023; Zainil et al., 2024; Bouilheres et al., 2020; Nhlumayo, 2024; Prihatin et al., 2025).

However, despite the observed improvement, the statistical analysis showed that the results were not statistically significant ($p > 0.05$). This condition may be influenced by the relatively small sample size and the limited duration of the intervention. Therefore, while the practical outcomes indicate improvement, the statistical evidence remains limited,

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suggesting the need for further investigation with broader research designs. The implementation of deep learning also faced several challenges related to human resource readiness and technical limitations. One of the main barriers identified was limited teacher understanding, reflecting gaps in integrating digital technology into project-based learning. In addition, time constraints and limited resources hindered the optimal implementation of learning activities. These findings are consistent with Mullabayev (2021), who states that inadequate infrastructure can be a major barrier to digital education transformation, particularly in resource-constrained environments. Similarly, Muvid (2024) emphasizes that teacher readiness is a key determinant of successful curriculum implementation. This study reinforces these arguments by providing empirical evidence of the challenges encountered in real classroom settings.

Furthermore, limitations in computer availability and inconsistent internet access also affected the implementation process, supporting previous findings that resource constraints remain a major issue in technology-based education (Yeganeh et al., 2025; Prasetiyo et al., 2023). In addition to improving technical skills, the implementation of the "Technology Engineering" project also contributed to the development of students' character. Through collaborative and contextual activities, students demonstrated values such as cooperation, responsibility, and discipline. This finding supports previous studies showing that project-based learning can foster both cognitive and character development (Ritter, 2018; Mebert et al., 2020). Moreover, the integration of Pancasila values within the learning process aligns with research emphasizing the importance of character education in strengthening students' identity and social responsibility (Natalia et al., 2021).

This study provides several important implications. Practically, it highlights the need for continuous professional development for teachers to enhance their ability to design and implement technology-based learning. Institutionally, it emphasizes the importance of providing adequate infrastructure and strengthening stakeholder support to ensure effective implementation. From a policy perspective, the findings suggest that broader support is needed to facilitate the integration of deep learning within the Kurikulum Merdeka, including equitable access to digital resources and structured training programs for educators (Prihatin et al., 2025). Theoretically, this study contributes to the literature by providing empirical evidence on how deep learning is implemented in elementary school contexts, particularly in integrating digital literacy, 21st-century skills, and character education. The implementation model derived from this study offers a practical reference for educational transformation aligned with the demands of the digital era and the principles of the Kurikulum Merdeka (Muvid, 2024; Efendi & Suastra, 2023).

Overall, this study demonstrates that deep learning is not merely a pedagogical approach, but a comprehensive educational strategy that integrates cognitive, technological, and character development. The success of its implementation depends on the synergy between teachers, school leadership, students, and stakeholders. Therefore, deep learning has the potential to serve as a strategic framework for preparing students to face the challenges of the 21st century while maintaining strong national values.

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## E. Implication

This study implies that the successful implementation of project-based deep learning requires a comprehensive and sustained effort involving multiple stakeholders. Continuous professional development for teachers is essential to enhance their capacity in designing and implementing meaningful, technology-integrated learning, while the replication of this model in other elementary schools can support broader educational transformation. In addition, stronger policy support is needed to promote innovation in digital-based learning and ensure equitable access to technological infrastructure across diverse educational contexts. The findings also highlight that effective implementation depends on the synergy between school leadership, teachers, and students, where principals play a strategic role in program management, teachers act as facilitators of contextual and creative learning, and students actively engage in developing digital literacy, 21st-century skills, and Pancasila-based character. Therefore, deep learning should be positioned not merely as an instructional approach, but as a strategic framework for advancing national education in line with the demands of the digital era and the principles of the Kurikulum Merdeka.

## F. Limitation and Suggestion for Further Research

This study has several limitations that need to be acknowledged. The implementation of project-based deep learning at SD Negeri Sondakan and SD Negeri Tegalrejo was constrained by limited teacher readiness, particularly in integrating digital technology into learning activities. In addition, restricted access to technological infrastructure, such as computers and stable internet connections, affected the effectiveness of learning implementation. The relatively short duration of the project also limited the depth of student learning outcomes and reduced the ability to capture long-term impacts. These limitations indicate that both pedagogical capacity and resource availability remain critical challenges, especially in schools with limited facilities.

Based on these limitations, future research is recommended to focus on several key aspects. First, continuous professional development programs should be designed to strengthen teachers' technological and pedagogical competencies. Second, longitudinal studies are needed to examine the long-term effects of deep learning on students' digital literacy, 21st-century skills, and character development. Third, further studies should explore the implementation of this model in more diverse educational settings to improve its generalizability. Finally, efforts to expand equitable access to digital infrastructure and extend the duration of project-based learning are essential to optimize the effectiveness of deep learning and support sustainable educational transformation in the 21st century.

## G. Conclusion

This study concludes that project-based deep learning within the Kurikulum Merdeka provides a meaningful framework for strengthening elementary students' digital literacy, 21st-century skills, and Pancasila-based character. The findings show that students'

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digital competence improved substantially after the intervention, with 93.33% success in SD Negeri Sondakan and 84.62% in SD Negeri Tegalrejo, while the ANOVA result indicated that the difference was not statistically significant. Nevertheless, the qualitative evidence confirms that the implementation was supported by teacher capacity, learning facilities, school leadership, and parental involvement, although challenges related to teacher readiness, time constraints, and limited resources remained. Overall, the study demonstrates that deep learning is not only relevant to the digital transformation of education but also serves as a practical and contextual model for elementary schools seeking to integrate technology, collaboration, and character formation in line with the goals of the Kurikulum Merdeka.

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