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The Impact of Digital Literacy on STEM Competencies among High School Students

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ABSTRACT

This study analyses the influence of digital literacy on the STEM (Science, Technology, Engineering, and Mathematics) competencies of high school students. Digital literacy is one of the key 21st-century competencies that plays a role in helping students access, evaluate, and utilize digital information to support STEM learning. The study employed a quantitative approach using a survey design that involved 133 high school students as respondents. Data were collected using digital literacy and STEM competency questionnaires that met validity and reliability criteria. Data analysis was conducted using descriptive statistics, Pearson's correlation, and linear regression. The results indicate that students' digital literacy levels fall into the high category (M = 3.968; α = 0.890), and their STEM competencies also fall into the high category (M = 3.618; α = 0.899). Correlation analysis showed a positive and significant relationship between digital literacy and STEM competencies ($r = 0.661$; $p < 0.001$). Regression results indicate that digital literacy has a positive and significant effect on STEM competencies ($\beta = 0.694$; $t = 10.078$; $p < 0.001$), contributing 43.7% ($R^2 = 0.437$). These findings suggest that strengthening the digital literacy can be an effective strategy for improving students' STEM competencies and supporting their readiness to face 21st-century challenges.

1. Introduction

Advances in digital technology have driven significant transformations in the 21st-century education system. The Fourth Industrial Revolution and Society 5.0 require students not only to master academic knowledge but also to possess critical thinking skills, creativity, collaboration, communication, and the ability to effectively utilize digital technology in their daily lives and careers (Samala & Amanda, 2023; Tsarava et al., 2022). These changes require schools to prepare students with a range of competencies relevant to the development of science and technology so that they can adapt to the demands of an increasingly complex world (Chu et al., 2023). In this context, digital

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literacy and STEM competencies have become two key competencies receiving widespread attention in various global education policies.

Digital literacy is generally defined as an individual's ability to access, understand, evaluate, create, and communicate information through digital technologies (Eshet-Alkalai, 2004.; Gilster, 1997; Martin, 2006). Contemporary perspectives further emphasize that digital literacy encompasses not only technical skills but also critical thinking, information evaluation, and responsible technology use (Bentri et al., 2022; Ng, 2012). In the era of digital learning, students with strong digital literacy tend to find it easier to access scientific information, utilize various digital learning resources, and develop the independent learning skills required in modern education.

STEM education has been widely recognized as a strategic approach for preparing students to face future challenges in science, technology, engineering, and mathematics (Bybee, 2013). STEM integrates multiple disciplines into meaningful learning experiences that encourage inquiry, innovation, and problem-solving (Chu et al., 2023; Tan et al., 2023). The integration of STEM into learning has been shown to enhance students' higher-order thinking skills, creativity, innovation, and problem-solving abilities—all of which are essential components of 21st-century skills (Çiftçi & Topçu, 2023; Zainil et al., 2022). Consequently, the development of STEM competencies has become a top priority in educational reforms across many countries.

Nevertheless, various indicators suggest that Indonesian students' STEM competencies still face significant challenges. Results from the Programme for International Student Assessment (PISA) indicate that Indonesian students' performance in science and mathematics remains below the average of OECD countries (OECD, 2023). This condition suggests that many students continue to experience difficulties in understanding scientific concepts, integrating interdisciplinary knowledge, and applying their understanding to solve real-world problems. Such challenges are particularly concerning because STEM education requires students to connect knowledge across multiple disciplines and utilize higher-order thinking skills to address complex issues (Chu et al., 2023; Tan et al., 2023). Previous studies have also emphasized that the development of STEM competencies depends not only on content knowledge but also on students' ability to engage in critical thinking, problem-solving, and technology-supported learning processes (Roehrig et al., 2021). Therefore, these persistent gaps highlight the importance of identifying factors that can support the enhancement of students' STEM competencies, particularly at the secondary school level, which represents a critical stage for the development of academic skills, technological proficiency, and future career readiness (OECD, 2023).

In theory, digital literacy has the potential to support the development of STEM competencies. Students with strong digital literacy skills tend to be better able to access technology-based learning resources, utilize digital simulations, conduct scientific research, process data, and use various digital applications to solve problems (Roehrig et al., 2021; Willard et al., 2023). These abilities are an essential part of STEM competencies, which require the integration of conceptual knowledge, technological skills, and analytical thinking. Thus, digital literacy can serve as a factor that strengthens students' ability to understand and apply STEM concepts more effectively.

A number of previous studies have shown that digital literacy contributes to the development of various 21st-century skills. Bentri et al., (2022) found that digital competence plays a crucial role in supporting effective learning processes. Tsarava et al., (2022) demonstrated that the use of digital technology can enhance students' computational thinking skills. Additionally, research by Zainil et al., (2022) found that the integration of technology in learning contributes to the development of students' 21st-century skills. Meanwhile, STEM learning has been shown to strengthen students' critical thinking, analytical reasoning, and problem-solving skills (Halpern & Dunn, 2021; Hidayat et al., 2024; Perdana et al., 2021; Richardo et al., 2023).

Although research on digital literacy and STEM has advanced significantly, most studies still examine these two constructs separately. Digital literacy research generally focuses on learning outcomes, critical thinking skills, or students' digital competencies, whereas STEM research more often highlights the implementation of STEM learning models on various learning outcomes and 21st-century skills (Roehrig et al., 2021; Tan et al., 2023). Research specifically examining the influence of digital literacy on the STEM competencies of secondary school students remains relatively limited, particularly in the context of Indonesian education. This limitation indicates a research gap that needs to be addressed to gain a more comprehensive understanding of the relationship between these two variables.

Based on the above discussion, this study aims to analyze the influence of digital literacy on the STEM competencies of high school students. This study is expected to make a theoretical contribution to the field of digital literacy and STEM education, as well as provide practical implications for schools and teachers in designing learning experiences that integrate digital literacy to enhance students' STEM competencies, thereby equipping them to face the challenges of the 21st century.

2. Methodology

This study employs a quantitative approach with an explanatory survey design to analyze the influence of digital literacy on the STEM competencies of high school students. This approach was chosen because it allows the researcher to identify relationships and influences among variables based on data obtained from respondents through a structured research instrument. The study was conducted at SMA Negeri 1 Matur, Agam Regency, West Sumatra, Indonesia. The study participants consisted of 133 students in grades 10, 11, and 12 who were selected using purposive sampling. This technique was used considering that the respondents already had experience using digital technology in learning activities. The involvement of students from various grade levels is expected to provide a more comprehensive picture of the state of digital literacy and STEM competencies at the high school level.

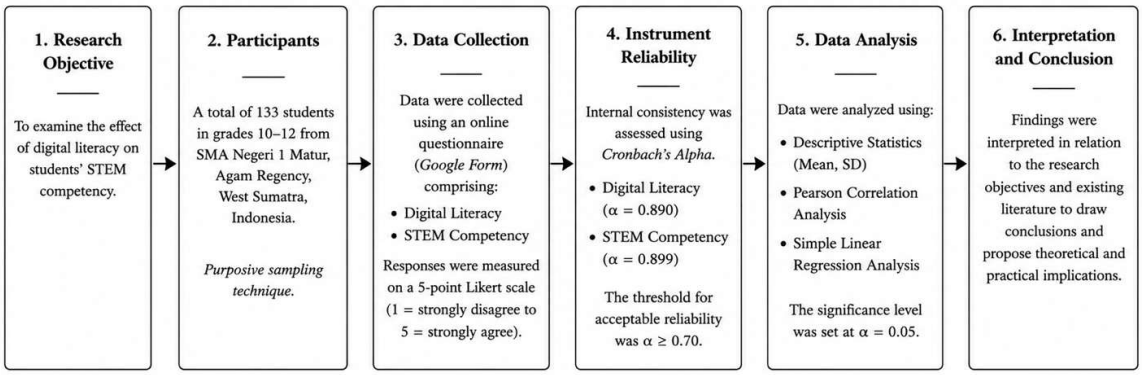

Fig 1. Research procedure

Research data were collected using a questionnaire consisting of two main constructs: digital literacy and STEM competencies. Digital literacy refers to students' ability to access, evaluate, manage, create, and communicate information effectively through digital technologies while demonstrating critical thinking and responsible technology use (Eshet-Alkalai, 2004.; Ng, 2012; Van Laar et al., 2017). Meanwhile, STEM competencies refer to students' ability to integrate knowledge and skills in science, technology, engineering, and mathematics to investigate problems, generate solutions, and make informed decisions in real-world contexts (Bybee, 2013; Roehrig et al., 2021). All

items in the instrument were measured using a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Before being used in the study, the instruments were tested to ensure their reliability. The test results showed that the digital literacy instrument had a Cronbach's Alpha value of 0.890, while the STEM competency instrument had a Cronbach's Alpha value of 0.899. These values were above the minimum threshold of 0.70, so both instruments were deemed to have high reliability and were suitable for data collection. Data collection was conducted online via an electronic questionnaire distributed to respondents. Before completing the questionnaire, students were provided with information regarding the research objectives and the confidentiality of the data provided. Of the 134 data points collected, 133 were deemed complete and suitable for analysis.

Data analysis was conducted using descriptive statistics to describe students' levels of digital literacy and STEM competencies based on mean scores and standard deviations. Furthermore, Pearson's correlation analysis was used to identify the relationship between digital literacy and STEM competencies. To test the effect of digital literacy on STEM competencies, simple linear regression analysis was used at a significance level of 0.05. All analyses were performed using statistical software.

3. Results

3.1 Profile of Students' Digital Literacy and STEM Competencies

The results of the descriptive analysis indicate that the digital literacy levels and STEM competencies of high school students fall into the high category. The average digital literacy score for students was 3.968, while the average STEM competency score was 3.618. These findings suggest that most students have developed fairly strong abilities in utilizing digital technology to support their learning activities, while also possessing relatively adequate STEM competencies.

Table 1. Descriptive Statistics of the Research Variables

Variable	Mean	Category
Digital Literacy	3,968	High
STEM Competencies	3,618	High

The high levels of digital literacy among students indicate that they are accustomed to using digital technology to access information, communicate, and support the learning process. This aligns with the evolution of learning environments that are increasingly integrated with digital technology. Additionally, high levels of STEM competencies suggest that students possess a solid ability to understand concepts in science, technology, engineering, and mathematics and apply them to problem-solving.

These findings support previous research stating that the use of digital technology in learning can help students access a wider range of information, increase learning engagement, and strengthen 21st-century skills . Thus, a learning environment that optimally utilizes technology has the potential to support the development of students' STEM competencies.

3.2 The Impact of Digital Literacy on Students' STEM Competencies

The relationship between digital literacy and STEM competencies was analyzed using Pearson's correlation and simple linear regression. The results of the correlation analysis showed a strong positive relationship between digital literacy and STEM competencies, with a correlation coefficient of 0.661 ($p < 0.001$). These findings indicate that the higher a student's level of digital literacy, the higher their STEM competencies.

Table 2. Results of the Linear Regression Analysis

Variable	β	t	p
Digital Literacy → STEM Competencies	0,694	10,078	<0,001

The coefficient of determination (R^2) of 0.437 indicates that digital literacy accounts for 43.7% of the variation in students' STEM competencies. Meanwhile, 56.3% of the variation in STEM competencies is influenced by other factors not examined in this study, such as learning motivation, the learning environment, learning strategies, and technological support in schools.

Table 3. Coefficient of Determination

Dependen Variable	R^2
STEM Competencies	0,437

These findings indicate that digital literacy is a key factor in the development of STEM competencies among high school students. The ability to access, evaluate, and utilize digital information enables students to access a wider variety of learning resources, gain a deeper understanding of STEM concepts, and develop technology-based problem-solving skills. These results align with the research by Bentri et al., (2022), which shows that digital competencies play a crucial role in supporting the effectiveness of learning. These findings also support the research by (Tsarava et al., 2022), which states that the use of digital technology can enhance students' computational thinking abilities and problem-solving skills. In the context of STEM, these abilities are an essential part of the competencies required to understand and solve problems systematically and data-driven.

Theoretically, the positive relationship between digital literacy and STEM competencies can be explained by the role of technology as a tool for exploration, investigation, and problem-solving. Students with strong digital literacy tend to find it easier to access scientific information sources, use educational software, conduct simulations, and utilize various digital applications to understand STEM concepts (Ng, 2012; Willard et al., 2023). Furthermore, digital literacy supports students' ability to engage in information processing, critical thinking, collaboration, and technology-based problem-solving, which are essential components of STEM learning (Van Laar et al., 2017). Since STEM education emphasizes inquiry, investigation, and the application of interdisciplinary knowledge to solve real-world problems, students with higher levels of digital literacy are more likely to participate effectively in STEM learning activities and achieve better learning outcomes (Roehrig et al., 2021; Tan et al., 2023). Therefore, strengthening digital literacy can be an effective strategy for improving the quality of STEM education in secondary schools.

3.2 Implications of the Research Findings

The results of this study have important implications for the development of 21st-century education, particularly in efforts to improve the STEM competencies of secondary school students. The finding that digital literacy has a positive and significant effect on STEM competencies indicates that students' ability to access, evaluate, and utilize digital information is a key factor supporting successful STEM learning. This finding reinforces the view that digital literacy is no longer viewed as an additional skill but has become an essential competency that supports the learning process and the development of 21st-century skills (GEM Report UNESCO, 2023; Ng, 2012).

From a pedagogical perspective, the results of this study indicate that the integration of digital technology into learning must be designed not only to enhance technological proficiency but also to support the development of critical thinking, problem-solving, and data-driven decision-making—

core characteristics of STEM education (Roehrig et al., 2021; Tan et al., 2023). Students with strong digital literacy tend to be better able to utilize various digital learning resources, independently explore concepts, and use technology to solve complex problems. These conditions enable students to gain more meaningful learning experiences and support the optimal achievement of STEM competencies.

The findings of this study also indicate that schools need to place greater emphasis on developing digital literacy through the curriculum, learning strategies, and the provision of adequate technological infrastructure. According to the (OECD, 2023), mastery of digital competencies is a key prerequisite for students to participate effectively in a knowledge-based society. Therefore, the strengthening of digital literacy must be carried out systematically through various learning activities that encourage students to think critically, evaluate information, and use technology productively and responsibly.

Furthermore, the results of this study have implications for teachers as learning facilitators. Teachers need to develop learning that integrates digital technology with a STEM approach through the use of virtual simulations, technology-based projects, authentic problem-solving, and the utilization of various digital learning resources. This approach has been proven to increase student engagement in the learning process and develop the higher-order thinking skills required in STEM learning (Çiftçi & Topçu, 2023; Tsarava et al., 2022).

This study extends the existing literature on the relationship between digital literacy and STEM competencies in the context of secondary education. Most previous studies have examined digital literacy in relation to student learning outcomes, critical thinking skills, or digital competencies, while STEM research has largely focused on the effectiveness of STEM learning models (Bentri et al., 2022; Zainil et al., 2022). The findings of this study indicate that digital literacy can be positioned as a key predictor of STEM competencies. Consequently, the development of digital literacy can serve as a relevant strategy to enhance the quality of STEM education and prepare students to face educational challenges and the demands of the workforce in the digital age.

4. Conclusions

This study was conducted to analyze the influence of digital literacy on the STEM competencies of high school students. The results indicate that both students' digital literacy and STEM competencies fall into the high category. Statistical analysis reveals that digital literacy has a positive and significant relationship with STEM competencies and significantly influences them, accounting for 43.7% of the variance. These findings indicate that improvements in students' ability to access, evaluate, and utilize digital information contribute to enhanced STEM competencies.

The research findings confirm that digital literacy is a critical factor in the development of secondary school students' STEM competencies. Therefore, strengthening digital literacy should be integrated into the learning process as an effort to support the development of critical thinking, problem-solving, and technology utilization skills—which are the core characteristics of STEM education. Further research is recommended to examine other factors that may influence STEM competencies in order to gain a more comprehensive understanding of the development of students' STEM competencies.

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