

Analysis of Digital Literacy Needs as the Main Foundation in Education for Sustainable Development (ESD)

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ABSTRACT

Digital literacy is critical in supporting Education for Sustainable Development (ESD) by providing access to information, raising awareness, and encouraging engagement with environmental, social, and economic issues through technology. As part of 21st-century skills, digital literacy empowers educators and learners to utilize digital platforms for interactive and practical learning while fostering critical thinking, collaboration, communication, and creativity to address sustainability challenges. Digital literacy also supports innovation in sustainable practices such as renewable energy, precision agriculture, and responsible resource management. This study aims to analyze the digital literacy needs of prospective science teacher students in order to strengthen their capacity to integrate technology into ESD-oriented learning. The study employed a quantitative descriptive survey design, utilizing the Rasch Rating Scale Model, to systematically analyze students' digital literacy competence. A total of 140 second-semester students from two universities completed a 20-item closed-ended questionnaire on a 4-point scale. The results indicated deficiencies in several areas, including information retrieval, scientific writing, participation in digital platforms, collaboration, and digital ethics, often due to the lack of supportive learning models and limited opportunities for real-life application. The findings contribute to science education by providing empirical evidence on specific digital literacy gaps, informing the design of instructional models, training programs, and curriculum innovations to enhance digital literacy for ESD in science education.

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INTRODUCTION

Education for Sustainable Development (ESD); also often referred to as Education for Sustainability (EfS), is a key driver of the United Nations Sustainable Development Goals, which emphasize the need for everyone to have the knowledge and skills to meet the challenges of creating a more sustainable world (Impedovo & Cederqvist, 2024; Nasibulina, 2015; Ssossé et al., 2021). ESD aims at an interdisciplinary, holistic approach to education that can integrate the various perspectives of the three pillars of SD, the pressures and contingencies of their interactions, in time and space, and at the local, regional, and global levels. ESD is a dynamic concept taught through education with noble values to realize a sustainable future. There are three primary perspectives in ESD: socio-cultural, environmental, and economic. Education for Sustainable Development (ESD) is defined as education that enables learners to acquire the knowledge, skills, attitudes, and values necessary to shape a sustainable future (Rieckmann, 2018; Rieckmann & Barth, 2022). Education for Sustainable Development (ESD) is an educational concept that aims to prepare individuals to contribute to

realizing sustainable development ([Anggraini & Nugraheni, 2024](#); [Faizah & Nugraheni, 2024](#); [Putri & Chusni, 2024](#); [Vioresa et al., 2023](#)). ESD integrates global issues such as climate change, poverty, and environmental concerns into the educational curriculum. In the context of global warming material, the implementation of ESD aims to increase students' awareness of the impacts of global warming and provide the knowledge and skills needed to take responsible action ([Badiah et al., 2024](#); [Hilyati et al., 2023](#); [Putri & Chusni, 2024](#)).

The primary goal of ESD is to educate individuals to be more aware of environmental issues, including climate change, biodiversity loss, pollution, and the conservation of natural resources. It also helps students develop critical thinking and problem-solving skills essential for navigating the complexities of the modern world, and inspires individuals to take concrete actions that support their desires, both in their daily lives and at the community and global levels ([Padmanabhan, 2016](#); [Pradipta & Hariyono, 2021](#)). ESD applies not only in formal educational contexts, such as schools and universities, but also in informal and non-formal education, including on-the-job training and community awareness programs. ESD is considered essential to achieving the United Nations' Sustainable Development Goals (SDGs). Society 5.0 is a concept developed in Japan that describes a future society in which advanced technologies, such as artificial intelligence (AI), big data, the Internet of Things (IoT), and robotics, are integrated with human life to enhance quality of life and social well-being. Society 5.0 aims to address social challenges through technological innovation while ensuring that technological development remains human-centered. Society 5.0 aims to strike a balance between economic progress and social well-being by harnessing technology.

On the other hand, ESD teaches the importance of permanence through a holistic approach that encompasses environmental, economic, and social dimensions. Both emphasize the importance of balanced and sustainable solutions to global problems. Education in ESD can help shape a critical understanding of how technology can be used ethically and effectively to achieve desired goals. Technology is at the heart of Society 5.0, which leverages AI, IoT, and big data to address pressing social issues, including urbanization, climate change, and inequality. ESD can integrate an understanding of how these technologies can be used responsibly to support sustainable development, ensuring that technology makes a positive contribution to society and the environment. ESD and Society 5.0 are closely linked in shaping a sustainable and inclusive future society, where advanced technologies are utilized to enhance the quality of human life while protecting the environment and promoting social well-being ([Ariastika, 2022](#); [Redhana, 2024](#); [Rusilowati et al., 2016](#)).

Digital literacy is essential in Education for Sustainable Development (ESD). Digital literacy is vital for achieving ESD goals because it enables individuals to understand, access, and use digital technologies wisely and responsibly. Digital literacy empowers individuals to access a wide range of information and resources relevant to sustainability, including data on climate change, sustainable agricultural practices, and environmental policies. With digital literacy skills, learners can search for, evaluate, and utilize this information to support better decisions and more effective actions. In ESD, digital technology can be used for interactive learning, such as environmental simulations, educational videos, or online learning platforms ([Estrada et al., 2022](#); [Febliza & Okatariansi, 2020](#)). Digital literacy encompasses the ability to evaluate information found online critically. This is important in ESD, where learners must evaluate the accuracy and reliability of information on environmental and sustainability issues. These skills help combat misinformation and ensure decisions are based on valid data. Digital literacy is also important for fostering global collaboration and innovation in sustainability. With these skills, individuals can engage in global discussions, share ideas, and collaborate on sustainability projects that involve communities from different parts of the world through digital platforms. In the context of ESD, digital literacy encompasses an understanding of the

impacts of digital technologies on the environment and society. This includes understanding the carbon footprint of technology use, privacy issues, and the ethics of using digital data and information. These skills are essential to ensure that technology is used in a way that supports sustainability. Digital literacy enables individuals to innovate and adapt to new technologies that can help achieve sustainability goals. This includes understanding green technologies, smart cities, and other digital solutions that can reduce environmental impacts. Digital literacy is a crucial skill in ESD, as it empowers individuals to utilize technology effectively and responsibly in support of environmental, social, and economic sustainability (Neto & Carvalho, 2022; Redhana, 2024; Terttiaavini & Saputra, 2022).

Literacy is not just reading or writing; digital literacy encompasses the knowledge and skills necessary to use digital media, communication tools, or networks in finding, evaluating, using, creating, and utilizing information in a healthy, wise, intelligent, careful, precise, and effective manner. Digital literacy can also be used to enhance language skills, critical thinking, and acting under prevailing societal norms, as well as to increase legal awareness, thereby fostering effective communication and interaction in everyday life (Maulida & Sunarti, 2022; Suherdi, 2021; Suherman, 2020). In Indonesia, there has been limited research examining digital literacy. Previous studies have focused more on information literacy, media literacy, and ICT literacy among specific community groups in various regions of Indonesia. Digital literacy competency is essential for navigating information from various digital sources that continue to evolve in tandem with the development of information and communication technology, driven by the phenomenon of media convergence (Giovanni & Komariah, 2019; Muliani et al., 2021; Restianty, 2018).

The level of digital literacy of prospective teacher students in Indonesia still shows worrying results. Terttiaavini and Saputra (2022) found that most science education students have not been able to utilize digital technology to support learning that is oriented toward sustainability issues, especially in terms of critical thinking and digital collaboration. Meanwhile, Redhana (2024) noted that students' understanding of digital ethics and personal data security in online learning activities is still low. In addition, Faizah and Nugraheni (2024) revealed that many students have been unable to utilize digital technology productively to convey scientific ideas or participate in discussions that support sustainable development. The results of a preliminary study conducted by researchers on 30 second-semester students from two Science Education study programs showed that more than 65% of students had difficulty searching for, evaluating, and scientifically conveying digital information. They also demonstrated low participation in the digital space and lacked an understanding of the importance of maintaining ethics and privacy in the use of technology. These findings indicate a real gap between students' digital literacy skills and the demands of Education for Sustainable Development (ESD) competencies, which emphasize systemic, collaborative, and reflective thinking skills in a digital context.

The indicators used to measure digital literacy are modifications based on the digital literacy indicators proposed by Hague and Payton (2022) and Techataweewan and Prasertsin (2018), which have been tested for validity and reliability. These indicators were selected because they reflect not only technical competencies but also cognitive, communicative, and ethical dimensions of digital literacy, which are highly relevant to the context of Education for Sustainable Development (ESD). The indicators have been tested for validity and reliability to ensure that they appropriately measure the digital competencies of prospective science teachers. The eight indicators used include (1) the ability to convey product results using digital technology; (2) the ability to communicate effectively through digital media, (3) the ability to communicate scientific ideas or concepts clearly and coherently, and (4) the ability to actively participate in digital spaces such as forums, learning platforms, or collaborative tools. In addition, they include (5) the ability to engage in productive discussions about

ideas or concepts with peers; (6) the ability to assess and re-evaluate information retrieved from the internet quickly, accurately, and critically; (7) the ability to use technology with consideration for social and cultural contexts; and (8) the ability to ensure safety and privacy when using digital technologies by ethical and legal standards. These indicators comprehensively represent the core competencies that must be developed to prepare future educators to integrate digital technology within sustainable and responsible educational practices.

This study aims to analyze the need for digital literacy as the primary foundation in Sustainable Development Education (ESD). Despite the growing attention to digital literacy in education, there have been limited studies that specifically analyze how digital literacy competencies support the integration of Education for Sustainable Development (ESD) within pre-service science teacher training. Therefore, this study aims to fill this gap by examining the digital literacy needs of science education students about the key competencies required for advancing sustainability goals. The framework of this study is based on the intersection between digital literacy and the competencies required for ESD. According to [Hague and Payton \(2022\)](#), digital literacy includes not only technical proficiency but also critical thinking and ethical considerations in using digital media. These dimensions align with the ESD competencies outlined by [Rieckmann \(2018\)](#), which emphasize systems thinking, anticipatory skills, and collaborative problem solving. The integration of these two frameworks is essential in preparing future science educators to address sustainability challenges in the digital age.

METHOD

This study employed a qualitative descriptive research design. Qualitative descriptive research is used to provide an accurate and systematic description of a phenomenon, event, or social condition through the collection and interpretation of qualitative data. In the context of this study, this approach was chosen to explore the digital literacy needs of pre-service science teacher students in detail, especially in their ability to integrate digital competencies into Education for Sustainable Development (ESD). This method allows researchers to capture students' perceptions, challenges, and readiness in utilizing digital tools for sustainability-related learning.

The objective of this research was to analyze the digital literacy competence of science education students and the required competencies for supporting ESD. This research aims to provide a foundation for improving instructional models, training programs, and curriculum design that integrate digital technology in science education by identifying specific strengths and weaknesses in digital literacy. The study also aims to determine whether students have acquired the necessary skills to access, evaluate, and utilize digital information effectively, promoting sustainable practices.

The research was conducted at two institutions: the Faculty of Mathematics and Natural Sciences (FMIPA) at Universitas Negeri Semarang and the Faculty of Tarbiyah and Teacher Training at UIN Salatiga. The subjects were second-semester students in the Science Education Study Program, with 140 respondents. The primary data collection instrument was a closed-ended questionnaire consisting of 20 items, based on eight validated digital literacy indicators adapted from [Hague and Payton \(2022\)](#) and [Techataweewan and Prasertsin \(2018\)](#). The questionnaire employed a four-point Likert scale (Strongly Agree, Agree, Disagree, Strongly Disagree), with all items phrased positively to reflect digital competency levels.

The data collected were analyzed using the Rasch Rating Scale Model with the help of Winsteps version 5.9.2. This analysis included evaluating item reliability and person reliability to assess the internal consistency of the instrument. Additionally, item fit statistics were examined through infit and outfit Mean Square (MNSQ) and Z-standard (ZSTD) values. Items outside the acceptable range (MNSQ 0.5–1.5) were further reviewed and refined. The results of the Rasch analysis were then

interpreted and presented in the form of descriptive graphs and narrative explanations to highlight trends in students' digital literacy levels across the defined indicators.

RESULTS AND DISCUSSION

Education for Sustainable Development (ESD) is an educational approach that aims to equip individuals with the knowledge, skills, attitudes, and values necessary to address global challenges, including climate change, social inequality, and environmental degradation. In this context, digital literacy serves as the primary foundation supporting the achievement of ESD goals. Digital literacy allows students to access information on global issues relevant to sustainable development. They can learn from trusted sources and develop broader insights into environmental, social, and economic issues. By combining digital skills with sustainable education, we can create a generation that faces global challenges and contributes to achieving the Sustainable Development Goals. The study employed a questionnaire comprising 20 questions that covered eight indicators of digital literacy. The distribution of questions in the questionnaire, based on indicators, is presented in Table 1.

Table 1. Indicators and Distribution of Digital Literacy Question Items

Indicator	Question Item Number
Deliver product results by utilizing digital technology	1 and 2
Communicate through digital media	3
Communicate ideas or concepts	4 and 5
Participate in digital spaces	6 and 7
Discuss ideas or concepts with friends	8 and 9
Assess and re-evaluate information found through the internet quickly and accurately	10, 11, 12, 13, and 14
Use technology according to the context of social and cultural understanding	15, 16, and 17
Ensure security when using digital technology	18, 19, and 20

The number of items in each digital literacy indicator was not designed evenly, considering the concept's scope, skill complexity level, and the need for proportional measurement for each indicator. Indicators with a more specific and measurable scope, such as "communicate through digital media," are represented by a single item because it clearly describes the measured competency. Meanwhile, indicators such as "assess and re-evaluate information found through the internet quickly and accurately" require a larger number of items because this competency involves higher-level digital literacy skills, such as the ability to sort information, assess the credibility of sources, and speed in processing information, which require more aspects to be measured comprehensively. Therefore, the distribution of the number of items is adjusted to the depth and scope of competencies to be achieved in each indicator, ensuring that the measurement remains valid, efficient, and able to provide a comprehensive picture of the digital literacy level of prospective science teacher students.

The study analyzed the digital literacy needs of different study programs and universities. However, this study was not limited and did not differentiate the analysis results of the two study programs. The study focused on the digital literacy needs at the tertiary level. The results were obtained from a questionnaire that could measure digital literacy and were analyzed descriptively. The questions asked in the questionnaire were phrased as positive questions, meaning that respondents who answered "strongly agree" would receive a high score. The results of the descriptive analysis of the digital literacy questionnaire data, consisting of 20 items, show that most students fall into the score category 3 (agree) on almost all items, as seen in Table 2. This indicates that students

tend to feel quite confident with their digital literacy abilities in the aspects measured. Table 2 shows the frequency distribution of students' scores on each item in the digital literacy questionnaire. This table lists the number of students who selected each score category (4 = strongly agree, 3 = agree, 2 = disagree, and 1 = strongly disagree) for each item, making it easier to identify trends in student responses and areas of digital literacy competency that still need improvement.

Table 2. Distribution of Student Scores Across Digital Literacy Items

Indicator	Item Number	Item score			
		4	3	2	1
Deliver product results by utilizing digital technology	1	0	37	75	28
	2	9	72	58	1
Communicate through digital media	3	22	89	29	0
	4	0	19	56	65
Communicate ideas or concepts	5	14	82	39	5
	6	0	21	81	38
Participate in digital spaces	7	6	57	54	23
	8	12	91	36	1
Discuss ideas or concepts with friends	9	10	88	37	5
	10	8	77	47	8
Assess and re-evaluate information found through the internet quickly and accurately	11	7	79	50	4
	12	5	98	35	2
	13	6	80	52	2
	14	15	105	20	0
Use technology according to the context of social and cultural understanding	15	6	89	35	10
	16	4	74	49	13
	17	1	70	64	5
	18	3	67	53	17
Ensure security when using digital technology	19	4	73	59	4
	20	0	71	63	6

To provide a visual representation of the trends in student responses to each questionnaire item, Figure 1 presents a graph of the distribution of student scores on the digital literacy instrument used in this study. It also illustrates the overall pattern of student responses to each measured indicator, facilitating an analysis of areas of competence that have been mastered and those that still require improvement.

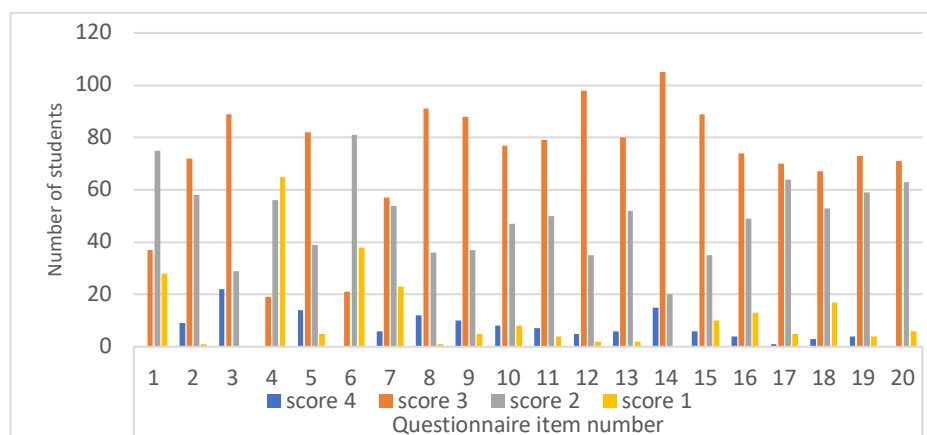


Figure 1. Analysis of Digital Literacy Needs Questionnaire

Based on Figure 1, five indicators have low values, specifically the acquisition of Disagree answers, which have a higher number compared to the other indicators. These results can be seen in questions number 1 (Deliver product results by utilizing digital technology), 4 (Participate in digital spaces), 6 (Assess and re-evaluate information found through the internet quickly and accurately), 7 (Use technology according to the context of social and cultural understanding), and 8 (Ensure security when using digital technology). The five indicators with low scores reflect a consistent pattern of deficiency in higher-order digital competencies, particularly those related to creative output (digital product creation), critical expression, idea communication, and socio-ethical awareness (digital ethics and cultural context). These weaknesses suggest that current educational practices may be focusing more on basic digital usage rather than critical and transformative digital engagement aligned with ESD values.

The low ability of students to deliver product results by utilizing digital technology can be attributed to the fact that not all students have adequate access to technological devices, such as computers, tablets, or stable internet. This can cause difficulties in practicing and developing the digital skills needed to deliver product results (Lee, 2024; OECD, 2019). In addition, it can also be caused by the learning that has been used so far, not placing enough emphasis on the use of digital technology for presentations or not integrating digital skills in daily learning, such as the absence of learning with the use of presentation software, video editing, or other digital tools effectively. Internal factors within students can also be one of the influences on students' low ability to utilize technology. Students who do not see the relevance of digital skills or direct benefits become less motivated to learn and practice, and as a result, they are reluctant to develop these digital skills (Abulibdeh et al., 2024; Eden et al., 2024; Suherman, 2020). This requires an integrated approach that involves increasing access, developing curriculum, training teachers, and encouraging student motivation and confidence in using digital technology.

The indicator in question number 4 shows that students' ability to communicate ideas or concepts tends to be low. Various factors, including limitations in communication, teaching, and training, a lack of self-confidence, and an in-depth understanding of the material, as well as social, cultural, and technological influences, can contribute to this. In many educational institutions, oral and written communication skills are not always the main focus of the curriculum (Chassignol et al., 2018). Students may not receive adequate training to formulate and convey ideas effectively. Students are often less exposed to communication exercises, such as presentations, debates, or group discussions. They tend to feel less confident and less skilled in conveying ideas without sufficient practice. Many students fear criticism or mistakes when conveying ideas, so they hesitate or choose not to speak. These feelings often relate to previous experiences or an overly critical academic environment. Students who rarely speak in public may feel nervous or anxious, which hinders their ability to communicate ideas effectively. Students who do not fully understand the material or topic they want to communicate tend to struggle with conveying their ideas. They may feel unsure or confused, which affects their ability to explain ideas well. With limited practical experience in applying the theories or concepts they have learned, students may struggle to connect these ideas to real-world contexts, making their communication less relevant and clear. Reliance on Digital Communication (text messages, social media) can make one less skilled in communicating orally or in formal written form. This short and informal communication style can make it difficult for students to convey ideas in a structured and in-depth manner. Therefore, a comprehensive approach is needed, including curriculum revision, increased practical exercises, and greater support for developing student communication skills.

Students' low ability to participate in digital spaces (indicators in question number 6) can be caused by a combination of factors such as limited digital literacy, inadequate access to technology,

lack of motivation, discomfort with digital interactions, low understanding of ethics, technical challenges, and an academic culture that is not yet supportive. Some students have limited technical skills in using digital tools and platforms. This can include basic skills, such as managing accounts and understanding online privacy and security, as well as more complex skills, such as utilizing social media for academic discussions or collaboration. According to [Tinmaz et al. \(2022\)](#), the digital environment is also full of distractions, such as social media and games, that can reduce students' focus and motivation to participate in more productive activities, such as online academic discussions or project collaboration. Students are more comfortable with direct interactions and feel awkward or less confident communicating in digital spaces. Digital spaces are often perceived as less personal and more vulnerable to criticism or verbal attacks, which can lead to discomfort with digital media. The risk of negative comments or online bullying can also deter students from actively participating in digital spaces.

The indicator in question number 7, students' ability to use technology in the context of social and cultural understanding, tends to be low. This can be caused by educational limitations that integrate technology with socio-cultural aspects, a lack of socio-cultural literacy, gaps between global technology and local practices, a lack of practical experience, and the influence of globalization. Education often separates technology teaching from its social and cultural context, resulting in students lacking a holistic understanding of how technology interacts with social and cultural dynamics ([Farias-Gaytan et al., 2022](#)). Students may master technology technically, but they are not taught how to use it in consideration of social and cultural aspects. A curriculum that fails to link the use of technology to local social and cultural realities can render students less able to understand the implications of technology in various social and cultural contexts. Teaching that focuses on a single discipline (for example, technology alone or socio-cultural studies alone) without interaction between disciplines can limit students' understanding of how technology can be used contextually and in an interdisciplinary manner. A more holistic and contextual approach to education is needed to overcome this challenge, combining technology teaching with social and cultural awareness.

The ability to ensure security when using digital technology tends to be low among students (item indicator number 18). In many educational institutions, digital security is often not a core part of the curriculum. Students learn to use digital technology for academic purposes. Still, they are not taught how to protect themselves online, so they do not understand basic concepts such as encryption, two-factor authentication, or strong password management. This can leave them vulnerable to phishing, malware, or identity theft threats. The ability to ensure digital technology security can also be compromised by low awareness of risks, poor digital habits, limited tools and resources, and increasingly sophisticated attacks. Better education, increased awareness, and broader access to effective security tools and resources are needed to improve this ability ([Şirin & Ketrez, 2023](#); [Yaras & Öztürk, 2022](#)).

The low ability among students to use digital technology effectively, including conveying product results, communicating ideas or concepts, participating in digital spaces, utilizing technology in social and cultural contexts, and ensuring digital security, indicates a significant gap in digital literacy. Factors such as a lack of holistic education and training, limited awareness of digital risks and ethics, and low access to adequate tools and resources all contribute to this condition ([Gutiérrez-Ángel et al., 2022](#); [Wang & Si, 2023](#)). Without effective intervention, these gaps can hinder students from harnessing the full potential of digital technologies to support learning, collaboration, and active participation in the digital age. Therefore, a comprehensive and integrated effort is needed to improve digital literacy, which encompasses technical instruction, social and cultural awareness, and an understanding of digital security ([Eden et al., 2024](#); [Estrada et al., 2022](#)). The results of this study align with those of [Jaya and Sucipto \(2023\)](#), who demonstrated that students have a low ability to ensure

digital technology security due to a lack of integrated education and training within the curriculum. This study, indicator item 18, reveals that many students lack an understanding of practical steps to maintain digital security, including the use of two-factor authentication, strong password management, and protection against phishing. This indicates that digital security literacy has not yet become a primary focus in science education at the higher education level.

Furthermore, these results are consistent with the findings of [Gutiérrez-Ángel et al. \(2022\)](#) and [Wang and Si \(2023\)](#), who found digital literacy gaps in the use of technology to deliver products, communicate ideas, actively participate in digital spaces, and use technology in social and cultural contexts. This study confirms that student science teachers continue to face limitations in these areas, which hinder their ability to utilize digital technology to support learning and collaboration optimally. Low awareness of digital risks and ethics in technology use also contributes to these findings, consistent with previous research. However, this study provides an additional contribution by specifically mapping areas of digital literacy that are still low based on measurable instrument items, which can serve as a basis for designing more targeted learning interventions in science education to support Education for Sustainable Development (ESD). Thus, the results of this study not only reinforce previous findings but also highlight the need to design digital literacy training that focuses not only on technical aspects but also on digital security, active participation, and socio-cultural understanding in an integrated manner.

The novelty of this study lies in its specific integration of validated digital literacy indicators within the context of Education for Sustainable Development (ESD) for pre-service science teachers. This area remains underexplored in prior research. While previous studies have generally focused on digital literacy or sustainability education in isolation, this research provides empirical evidence on how digital competencies, particularly those related to higher-order thinking and socio-cultural awareness, remain insufficiently developed among science education students. The emphasis on the Rasch Model for instrument validation further adds methodological rigor and contributes to a reliable tool for future digital literacy assessments in similar contexts. This study contributes to science education by highlighting the critical gaps between technological proficiency and pedagogical readiness for sustainability education. It offers practical implications for curriculum developers, teacher educators, and policymakers to prioritize technical digital skills, as well as ethical, collaborative, and culturally relevant digital literacy. The findings support the development of a more holistic ESD-oriented digital literacy framework that addresses cognitive and affective domains. This contributes significantly to the ongoing discourse on preparing future educators capable of navigating complex, digital, and sustainability-driven educational environments in the era of Society 5.0. These findings have important implications for curriculum designers and teacher educators. Integrating project-based learning that incorporates digital content creation, critical digital storytelling, and collaborative online problem-solving can significantly enhance students' digital literacy. Furthermore, teacher training programs should incorporate modules on digital ethics, data privacy, and the application of technology in culturally sensitive ways to equip future educators with holistic digital literacy for sustainability.

CONCLUSION

The research results indicate that prospective science teacher students still have low levels of digital literacy, particularly in ensuring digital security, actively participating in digital spaces, conveying ideas or products, and using technology appropriately in social and cultural contexts. This situation highlights a digital literacy gap that can hinder their participation in Education for Sustainable Development (ESD), despite ESD's demand for integrating digital skills to support sustainable learning and practice. The application of this research finding can serve as a reference for

curriculum developers and educators in designing targeted learning, such as collaborative digital projects or contextual digital literacy training, so that students can use technology effectively, ethically, and relevantly to sustainability. This effort is crucial to equip prospective teachers to integrate technology into science learning that supports ESD in the future. This research is still limited to descriptive analysis and does not examine causal relationships or differences between student groups. Further research is recommended to test the effectiveness of specific learning strategies in sustainably improving students' digital literacy.

REFERENCES

- Abulibdeh, A., Zaidan, E., & Abulibdeh, R. (2024). Navigating the Confluence of Artificial Intelligence and Education for Sustainable Development in the Era of Industry 4.0: Challenges, Opportunities, and Ethical Dimensions. *Journal of Cleaner Production*, 437, 140527.
- Anggraini, D., & Nugraheni, S. (2024). Menuju Pendidikan Berkelanjutan: Implementasi Tujuan Pembangunan Berkelanjutan (SDGs) dalam Mewujudkan Pendidikan Berkualitas di Indonesia. *Jurnal Penelitian Pendidikan Indonesia (JPPI)*, 1(3), 189–197.
- Ariastika, D. (2022). Penerapan Literasi Digital pada Pembelajaran IPA dalam Menghadapi Kesiapan Pendidikan di Era Society 5.0. *Prosiding Seminar Nasional Inovasi Pendidikan*.
- Badiah, S., Saefullah, A., & Antarnusa, G. (2024). Development of Integrated Education for Sustainable Development Digital Teaching Materials on Renewable Energy to Facilitate Students' Critical Thinking Abilities. *EduFisika: Jurnal Pendidikan Fisika*, 9(1), 63–73.
- Chassignol, M., Khoroshavin, A., Klimova, A., & Bilyatdinova, A. (2018). Artificial Intelligence Trends in Education: A Narrative Overview. *Procedia Computer Science*, 136, 16–24.
- Eden, O. N. C., & Idowu, S. A. (2024). Integrating AI in Education: Opportunities, Challenges, and Ethical Considerations. *Magna Scientia Advanced Research and Reviews*, 10(2), 6–13.
- Estrada, F. J. R., George-Reyes, C. E., & Glasserman-Morales, L. D. (2022). Security as an Emerging Dimension of Digital Literacy for Education: A Systematic Literature Review. *Journal of E-Learning and Knowledge Society*.
- Faizah, A. N., & Nugraheni, N. (2024). Pendidikan Berkelanjutan Berbasis Konservasi dan Teknologi sebagai Aksi Nyata dalam Mewujudkan SDGs. *Socius: Jurnal Penelitian Ilmu-Ilmu Sosial*, 1(10), 73–80.
- Farias-Gaytan, S., Aguaded, I., & Ramirez-Montoya, M. S. (2022). Transformation and Digital Literacy: Systematic Literature Mapping. *Education and Information Technologies*, 27(2), 1417–1437.
- Febliza, A., & Okatariyani, O. (2020). Pengembangan Instrumen Literasi Digital Sekolah, Siswa dan Guru. *Jurnal Pendidikan Kimia Unri*.
- Giovanni, F., & Komariah, N. (2019). Hubungan Antara Literasi Digital dengan Prestasi Belajar Siswa SMA Negeri 6 Kota Bogor. *LIBRARIA: Jurnal Perpustakaan*.
- Gutiérrez-Ángel, N., Sánchez-García, J. N., Mercader-Rubio, I., García-Martín, J., & Brito-Costa, S. (2022). Digital Literacy in the University Setting: A Literature Review of Empirical Studies Between 2010 and 2021. *Frontiers in Psychology*, 13.
- Hague, C., & Payton, S. (2022). *Digital Literacy Across the Curriculum*. Futurelab.
- Hilyati, W., Yudha, C. B., & Vioresa, N. (2023). The Implementation of Education for Sustainable for Development (ESD) in Shaping Students' Green Behavior. *Proceeding of International Conference on Education*, 2, 31–40.
- Impedovo, M., & Cederqvist, A. M. (2024). Socio-(Im)Material-Making Activities in Minecraft: Retracing Digital Literacy Applied to ESD. *Research in Science and Technological Education*, 42(1).
- Jaya, F., & Sucipto, S. (2023). Digital Literacy, Academic Self-Efficacy, and Student Engagement: Its Impact on Student Academic Performance in Hybrid Learning. *Journal of Innovation in Educational and Cultural Research*, 4(3), 458–470.

- Lee, H. (2024). Analysis of the Impact of Digital Literacy on Life Satisfaction (2019–2022) for Older Adults in South Korea: A National Community-Based Panel Study. *Scientific Reports*, 14(1), 1–8.
- Maulida, F., & Sunarti, T. (2022). Pengembangan Instrumen Tes Literasi Sains Berbasis Kearifan Lokal di Kabupaten Lamongan. *ORBITA: Jurnal Kajian, Inovasi dan Aplikasi Pendidikan Fisika*.
- Muliani, A., Karimah, F. M., Liana, M. A., & dkk. (2021). Pentingnya Peran Literasi Digital Bagi Mahasiswa di Era Revolusi Industri 4.0 untuk Kemajuan Indonesia. *Journal of Education Technology*.
- Nasibulina, A. (2015). Education for Sustainable Development and Environmental Ethics. *Procedia - Social and Behavioral Sciences*, 214, 1077–1082.
- Neto, N. V. L., & Carvalho, A. B. (2022). Digital Literacy: A Brief Literature Review of in-Between Concepts and of Teachers' Conceptions. *Texto Livre*.
- OECD. (2019). An OECD Learning Framework 2030. In *Future of Education and Skills 2030*. Springer.
- Padmanabhan, J. (2016). Does Integrated Approach to ESD Affect Critical Thinking on Sustainable Development? *Journal of Education and Applied Social Studies*, 7(3), 311–321.
- Pradipta, D. D., & Hariyono, E. (2021). The Effectiveness of Science Learning Tools Based on Education Sustainable Development (ESD) to Improve Problem-Solving Skills. *IJORER: International Journal of Recent Educational Research*, 2(3), 342–353.
- Putri, N. H., & Chusni, M. M. (2024). Analisis Implementasi Education for Sustainable Development (ESD) dalam Pendidikan Pemanasan Global. *BIOCHEPHY: Journal of Science Education*, 4(1).
- Redhana, I. W. (2024). *Literasi Digital: Pedoman Menghadapi Society 5.0*. Samudra Biru.
- Restianty, A. (2018). Literasi Digital, Sebuah Tantangan Baru dalam Literasi Media. *Jurnal Gunahumas*.
- Rieckmann, M. (2018). Learning to Transform the World: Key Competencies in Education for Sustainable Development. *Issues and Trends in Education for Sustainable Development*, 39(1), 39–59.
- Rieckmann, M., & Barth, M. (2022). Educators' Competence Frameworks in Education for Sustainable Development. In *Competences in Education for Sustainable Development: Critical Perspectives*.
- Rusilowati, A., Kurniawati, L., Nugroho, S. E., & Widiyatmoko, A. (2016). Developing an Instrument of Scientific Literacy Assessment on the Cycle Theme. *International Journal of Environmental and Science Education*, 11(12), 5718–5727.
- Şirin, H., & Ketrez, G. (2023). Digital Addiction and Its Reflections on the Individual and Society. In *Handbook of Research on Perspectives on Society and Technology Addiction* (pp. 250–264). IGI Global.
- Ssossé, Q., Wagner, J., & Hopper, C. (2021). Assessing the Impact of ESD: Methods, Challenges, Results. *Sustainability (Switzerland)*, 13(5), 1–26.
- Suherdi, D. (2021). *Peran Literasi Digital di Masa Pandemi*. Pusat Penelitian dan Publikasi Ilmiah LPPM UIN Sunan Gunung Djati Bandung.
- Suherman, A. (2020). Promoting Digital Literacy Skills: An Action Research to People of Kampung Literasi. *Universal Journal of Educational Research*, 8(4), 1372–1386.
- Techataweewan, W., & Prasertsin, U. (2018). Development of Digital Literacy Indicators for Thai Undergraduate Students Using Mixed Method Research. *Kasetsart Journal of Social Sciences*, 39(2).
- Terttiaavini, T., & Saputra, T. S. (2022). Literasi Digital untuk Meningkatkan Etika Berdigital Bagi Pelajar di Kota Palembang. *JMM (Jurnal Masyarakat Mandiri)*.
- Tinmaz, H., Lee, Y. T., Fanea-Ivanovici, M., & Baber, H. (2022). A Systematic Review on Digital Literacy. *Smart Learning Environments*, 9(1).
- Vioreza, N., Hilyati, W., & Lasminingsih, M. (2023). Education for Sustainable Development: Bagaimana Urgensi dan Peluang Penerapannya pada Kurikulum Merdeka? *PUSAKA: Journal of Educational Review*, 1(1), 34–48.
- Wang, C., & Si, L. (2023). A Bibliometric Analysis of Digital Literacy Research from 1990 to 2022 and Research on Emerging Themes During the COVID-19 Pandemic. *Sustainability (Switzerland)*, 15(7).
- Yaras, Z., & Öztürk, F. K. (2022). Society 5.0 in Human Technology Integration: Digital Transformation in Educational Organizations. *International Journal of Progressive Education*, 18(1), 458–474.