Shibyana

Jurnal Pendidikan Dasar

10.24952/shibyana.v1i1.17698

Integrating STEM Digital Media on the Readiness of Elementary School Students to Face the Challenges of the 2030 SDGs

Nur Choiro Siregar[1], Rahmadani Siregar[2], Herlina[3]

[1]*Universitas Muhammadiyah Tangeran, Indonesia*

[2]*Universitas Islam Negeri Syekh Ali Hasan Ahmad Addary Padangsidimpuan, Indonesia*

[3]*Universitas Negeri Jakarta, Indonesia*

Corresponding author e-mail: nur.choiro@umt.ac.id

Keywords:

Digital Media; STEM; Student Readiness; SDGs2030; SmartPLS

Abstract

The importance of integrating technology and 21st century learning to prepare young people to face global issues such as climate change, educational equity, and sustainable innovation. This study aims to analyze the influence of the use of STEM (Science, Technology, Engineering, and Mathematics) based digital media on the readiness of elementary school students to face the challenges of the 2030 Sustainable Development Goals (SDGs). This study uses a quantitative approach with an explanatory survey method. The research sample consisted of 100 elementary school (SD) students selected by purposive sampling who had applied STEM-based digital learning media. The research instrument was in the form of a closed questionnaire with a five-point Likert scale to measure three main variables, namely the intensity of STEM digital media use, critical and collaborative thinking skills, and readiness to face the 2030 SDGs. Data analysis was carried out using SmartPLS 3.0 with the Partial Least Squares Structural Equation Modeling (PLS-SEM) model to test the relationship between variables. The results of the study show that the use of STEM digital media has a positive and significant effect on students' readiness to face the challenges of the 2030 SDGs, both directly and through improving critical thinking skills. These findings confirm that the integration of STEM-based digital media can be an effective strategy in basic education to support the achievement of sustainable development goals. This study recommends increasing digital literacy and teacher training in the application of interactive STEM media at the elementary school level.

INTRODUCTION

Background of the Study

The rapid acceleration of social, economic, and environmental transformations over the past decade has fundamentally reshaped the aims and orientations of contemporary education. Educational systems are no longer expected to focus solely on the transmission of conventional academic knowledge; instead, they are increasingly required to equip younger generations with a set of 21st-century competencies that are aligned with the Sustainable Development Goals (SDGs) 2030. These competencies include critical thinking, creativity, collaboration, digital literacy, and socio-environmental awareness, all of which are essential for navigating complex global challenges such as climate change, social inequality, and technological disruption (Fung & Hosseini, 2023; Singh et al., 2024). Within this broader context, basic education occupies a strategic and foundational position in driving educational transformation. Elementary education serves as a critical stage for shaping students' values, strengthening cognitive and affective development, and cultivating early habits of inquiry, problem-solving, and cooperative learning. At this level, students begin to develop the dispositions and skills necessary for responsible and active citizenship, enabling them to engage meaningfully with social and environmental issues in their communities and beyond (Robles-Moral, 2021; Shutaleva, 2023). Consequently, the integration of sustainability-oriented perspectives at the elementary level is not merely supplementary but constitutes a fundamental investment in long-term societal resilience.

In this regard, embedding sustainability literacy and higher-order thinking skills into the elementary school curriculum becomes imperative. Sustainability literacy enables students to understand the interconnections between environmental, social, and economic systems, while higher-order thinking skills empower them to analyze problems, evaluate alternative solutions, and make informed decisions. Together, these competencies prepare students to engage with real-world issues in ways that are consistent with the SDGs 2030 agenda, fostering a generation capable of contributing to sustainable development at local and global levels (Naz et al., 2025; Sugandi & Ruhimat, 2021).

One pedagogical innovation that holds significant promise in advancing these objectives is the integration of STEM (Science, Technology, Engineering, and Mathematics) education with digital media. This integrated approach promotes contextual and inquiry-based learning by encouraging students to explore authentic problems through scientific reasoning, technological tools, and collaborative activities. By leveraging digital media, STEM learning becomes more interactive and accessible, allowing students to visualize complex concepts, engage in simulations, and work collaboratively across diverse contexts. Such learning experiences not only strengthen conceptual understanding but also cultivate essential competencies—such as problem-solving, creativity, and teamwork—that are critical for understanding and addressing sustainability challenges in an increasingly digital and interconnected world (Siregar et al., 2024; Zainil et al., 2024).

The Problem of The Study

Despite the increasing scholarly and practical interest in STEM-based learning and the broader digital transformation of education, empirical evidence explaining how STEM digital media contributes to students' readiness to face the challenges of the Sustainable Development Goals (SDGs) remains limited. Existing research has primarily focused on measuring learning outcomes or general skill development, without sufficiently examining students' preparedness to engage with sustainability-related issues in a holistic and systematic manner. Although several studies have reported positive impacts of digital-based STEM learning on the development of so-called "6C skills"—namely character, citizenship, critical thinking, creativity, collaboration, and communication—particularly among elementary school students (Hu et al., 2024; Zainil et al., 2024), these findings are often context-specific and lack explanatory depth regarding how such skills translate into concrete readiness for achieving the SDGs.

Moreover, the implementation of STEM digital media in educational settings continues to face a range of structural and pedagogical challenges. Persistent issues such as unequal access to digital devices and internet connectivity, disparities in teachers' digital competence and pedagogical readiness, as well as inconsistencies in the quality and alignment of instructional design, frequently limit the effectiveness and sustainability of STEM-based digital interventions (Khalid et al., 2024; Mhlongo et al., 2023). These constraints not only affect learning outcomes but also risk widening educational inequalities, particularly in under-resourced or remote learning contexts.

In addition, most existing studies have yet to explore the underlying mechanisms through which STEM digital media influences students' readiness for the SDGs. Specifically, there is a lack of empirical analysis examining whether the use of STEM digital media exerts a direct effect on SDGs readiness or whether this influence operates indirectly through mediating variables such as critical thinking ability, digital literacy, or collaborative problem-solving skills. The absence of such analytical depth limits the theoretical contribution of prior research and hampers the development of evidence-based instructional models. Therefore, these gaps highlight the need for more rigorous quantitative investigations employing advanced methodological frameworks—such as mediation or structural equation modeling—that are capable of capturing complex intervariable relationships and providing a more comprehensive understanding of how STEM digital media can effectively support sustainability-oriented education.

Research's State of the Art

Recent empirical and theoretical studies provide valuable insights into the potential of STEM and digital media integration. Research has shown that interactive and digital-based STEM environments can enhance critical thinking, problem-solving, and sustainability-related awareness (Fior et al., 2025; Song & Cai, 2024). Digital platforms such as virtual labs, modeling applications, and online collaborative environments create meaningful, contextual, and action-oriented learning experiences that align with the principles of Education for Sustainable Development (ESD) (Chaleta et al., 2021; Boltsi et al., 2024). However, despite these advances, few studies explicitly connect STEM digital media interventions with students' multidimensional readiness for SDGs, which includes cognitive (knowledge of SDGs), affective (awareness and care for sustainability), and conative (ability to act collaboratively and responsibly) components (Mawonde & Togo, 2021). Methodologically, the use of PLS-SEM in educational technology studies has recently gained traction as it allows the modeling of complex relationships among latent variables (Zainil et al., 2024; Aryasandy et al., 2025), but its application in assessing SDG-oriented readiness among elementary students remains underexplored.

Novelty, Research Gap, & Objective

This research is among the first to empirically examine the influence of STEM digital media on elementary students' readiness to face the SDGs, combining educational technology and sustainability education frameworks. Unlike previous studies that focus narrowly on academic or cognitive outcomes, this study integrates three readiness dimensions cognitive, affective, and conative into one holistic model.

Although prior research confirms the benefits of STEM and digital learning separately, there is still a lack of evidence about their combined impact on sustainable development readiness. Moreover, existing studies often overlook the mediating roles of critical thinking and digital literacy, as well as contextual variables such as teacher preparedness and digital infrastructure, which may significantly affect outcomes. This study aims to analyze the effect of STEM digital media use on the readiness of elementary school students to face the challenges of the 2030 SDGs, both directly and indirectly through mediating variables like critical and collaborative thinking skills. Using the PLS-SEM approach, the research seeks to map the structural relationships among these variables, providing empirical evidence and policy-relevant insights to strengthen elementary education's role in achieving SDG 4 (Quality Education).

METHOD

Type and Design

This study employs a quantitative approach with an explanatory survey design to examine the causal relationship between the use of STEM-based digital media and the readiness of elementary school students to face the challenges of the 2030 SDGs. The explanatory survey was selected because it allows for the identification of direct and indirect effects among variables through statistical modeling. The research was conducted in several elementary schools (SD) in the Tangerang City area that have implemented STEM-based digital learning media in their instructional processes. The study design includes three main constructs: Independent Variable: Intensity of STEM digital media use, Mediator Variable: Critical thinking skills, Dependent Variable: Readiness to face the 2030 SDGs. This design allows testing of both direct and mediated influences using structural equation modeling with the PLS approach.

Data and Data Sources

The data in this study consist of responses to a closed-ended questionnaire measured on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). Data were obtained from 100 fifth-grade elementary school students who met specific inclusion criteria: Students have participated in STEM-based digital learning for at least one semester; Students have received written permission from parents or guardians to participate; Students are able to read the questionnaire independently or with assistance.

A purposive sampling technique was employed to ensure that all respondents had direct experience using STEM-based digital media, thereby strengthening the validity of causal inference. The questionnaire items were validated by three experts (basic education and educational technology specialists), and a pilot test was conducted on 30 non-sample respondents to assess item clarity, content validity, and initial reliability. The three main constructs and their indicators are as follows: STEM Digital Media Use: Frequency of use, duration per session, variety of applications/simulations, involvement in digital STEM projects. Critical Thinking Skills: Problem analysis, data-based decision-making, and scientific communication. Readiness to Face the 2030 SDGs: Knowledge of SDGs, social responsibility, intention to act, and ability to apply sustainable solutions.

Data Collection Technique

The data collection process was carried out systematically through several structured stages to ensure methodological rigor, ethical compliance, and data reliability. First, administrative preparation was undertaken by obtaining formal permission from the school authorities and securing ethical clearance from the relevant institutional ethics committee. This step ensured that the research procedures aligned with institutional regulations and ethical standards governing research involving children. Second, informed consent procedures were implemented prior to data collection. Written consent was obtained from parents or legal guardians, while verbal assent was sought from the participating students. This dual consent process was intended to respect both parental authority and the autonomy of the students, in accordance with ethical guidelines for research with minors.

Third, survey administration was conducted by distributing questionnaires to students in their respective classrooms under the supervision of trained research personnel. To minimize response bias and ensure consistency, enumerators followed standardized instructions during questionnaire administration. For students with limited reading fluency, enumerators provided assistance by reading the questionnaire items aloud in a neutral and non-directive manner, without offering interpretations or influencing students' responses. Fourth, demographic data recording was performed by collecting basic information such as students' age and gender to support descriptive and contextual analysis of the findings. This information was used solely for analytical purposes and did not include any personally identifiable details. Throughout the data collection process, participation was entirely voluntary, and students were informed of their right to withdraw at any time without any consequences. Anonymity and confidentiality of all data were strictly maintained, and the collected data were managed in accordance with institutional data protection and privacy standards to ensure the ethical integrity of the study.

Data Analysis

Data were analyzed using SmartPLS 3.0 software, applying the PLS-SEM technique. The analysis followed two main phases: (a) Measurement model testing indicator loading: Acceptable if ≥ 0.708; indicators between 0.40–0.70 retained if theoretically relevant and overall reliability is sufficient. Internal consistency reliability: Cronbach's Alpha, rho_A, and Composite Reliability (CR) with threshold > 0.70. Convergent Validity: Average Variance Extracted (AVE) > 0.50. Discriminant Validity: Heterotrait-Monotrait Ratio (HTMT) < 0.90. Multicollinearity: Variance Inflation Factor (VIF) < 5 (ideally < 3.3). (b) Structural Model (Inner Model) Testing Coefficient of Determination (R^2): 0.75 (substantial), 0.50 (moderate), 0.25 (weak). Effect Size (f^2): 0.02 (small), 0.15 (medium), 0.35 (large). Predictive Relevance (Q^2):

Tested using blindfolding; $Q^2 > 0$ indicates predictive power. Hypothesis Testing: Conducted via bootstrapping to assess the significance of path coefficients. All analyses were performed to determine both direct and indirect effects of STEM-based digital media use on students' readiness for the 2030 SDGs through mediating variables such as critical thinking.

RESULTS AND DISCUSSIONS

Descriptive Statistics of Respondents

A total of 100 respondents provided complete data that could be analyzed. In terms of demographic characteristics, 54% of respondents were female and 46% were male. The age of students ranges from 10–12 years, with an average age of 10.8 years (SD = 0.78). Based on location, 60% came from schools in urban areas and 40% from suburban schools. As many as 87% of students stated that they have access to digital devices at home, both in the form of laptops, tablets, or smartphones. The data distribution shows that students have experience using a variety of STEM digital media, from the use of simple science simulation applications to virtual lab-based experiments and robotics for kids projects.

The average score of this variable was 4.12 (SD = 0.61), indicating a high level of digital media use among respondents. The item with the highest score was "I use digital media to understand difficult science concepts" (mean = 4.35), while the item with the lowest score was "I often work with digital STEM tools at home" (mean = 3.88). This variable shows an average score of 4.08 (SD = 0.55). Students feel capable enough to think logically and cooperate with friends. The item with the highest score was "I can discuss with a friend to find the best solution to a problem" (mean = 4.26). The student readiness variable had an average score of 4.22 (SD = 0.58), indicating a good level of readiness. The items with the highest scores were "I want to help keep the environment cleaner and healthier" (mean = 4.41), and the lowest "I know how to help reduce social inequality" (mean = 3.97).

Evaluation of Measurement Models

Evaluation is carried out to ensure that each construct is measured validly and reliably before structural analysis is carried out. All indicators have an outer loading above 0.70, indicating that each item represents its construct well. The Average Variance Extracted (AVE) values for each construct were: (1) STEM digital media = 0.71, (2) Critical thinking skills = 0.74, and (3) SDGs 2030 readiness = 0.78. All AVE values > 0.50, indicating adequate convergent validity. Cronbach's Alpha values range from 0.84-0.91, and Composite Reliability (CR) ranges from 0.87–0.93. Thus, all constructs have high internal reliability. HTMT (Heterotrait-Monotrait Ratio) testing shows values between 0.62–0.85 (< 0.90). This indicates that each construct is discriminatory and there is no overlap between variables.

Before testing the hypothesis, an examination of multicollinearity between latent variables was carried out by looking at the VIF value. All IF was below 3.3, indicating no multicollinearity problems. The R^2 and Q^2 values for the endogenous model are presented in Table 1.

Table 1. R^2 and Q^2 values

Endogenous Variable	R^2	Q^2
Critical Thinking Skills	0.64	0.38
SDGs 2030 Readiness	0.71	0.42

R^2 value of 0.71 indicates that 71% of variations in student readiness can be explained by the use of STEM digital media and critical thinking skills. A positive Q^2 value confirms that the model has good predictive capabilities.

Hypothesis Testing

All influence bands showed a value of $p < 0.05$ and $t > 1.96$, so the hypothesis was accepted (Table 2).

Table 2. Hypothesis results

Influence Path	Coefficient β	t-statistic	p-value	Result
STEM digital media → Critical thinking skills	0.802	13.54	0.000	Significant
Critical thinking skills → SDGs 2030 readiness	0.458	6.72	0.000	Significant
STEM digital media → SDGs 2030 readiness	0.376	5.21	0.000	Significant

The Use of STEM Digital Media on Critical Thinking Skills

The value of the coefficient $\beta = 0.802$ signifies a strong and positive influence. This shows that the more intensively students use STEM-based digital media, the more their critical and collaborative thinking skills will increase. These findings are consistent with the research of Fior et al. (2025) which states that STEM-based digital learning environments provide wider opportunities for exploration and discussion, trigger higher-level thinking skills, and improve scientific communication skills. The use of digital media such as interactive simulations, virtual experiments, or simple design applications helps students understand cause-and-effect relationships visually and empirically (Pang et al., 2024; Wahidin et al., 2025). This experience fostered the habit of testing hypotheses, observing results, and communicating findings with group mates.

Furthermore, STEM digital media serves as an effective platform to engage students in problem-based learning, where they are encouraged to identify problems, analyze data, and formulate logical conclusions. By integrating multimedia elements such as animations, videos, and real-time data visualization students are able to construct conceptual understanding that goes beyond rote memorization. For example, when students engage with virtual laboratories or digital engineering simulations, they can manipulate variables, make predictions, and observe direct outcomes. This active learning process nurtures the essential elements of critical thinking: interpretation, analysis, evaluation, inference, and explanation. In addition, digital media within STEM education promotes autonomy and self-regulated learning. Students can access materials anytime and anywhere, revisit complex concepts, and explore different problem-solving strategies at their own pace. This independence builds metacognitive awareness students become more conscious of how they think and learn.

Research by Liu and Chen (2024) also supports this idea, showing that digital STEM tools not only increase motivation and engagement but also empower learners to make decisions and reflect on their learning progress. Such reflection is a critical component of developing higher-order thinking skills. Collaborative learning through STEM-based digital platforms also enhances communication and teamwork. Many applications allow for real-time collaboration, idea sharing, and group projects that simulate authentic scientific inquiry. When students engage in online discussions or joint design projects, they are required to justify their reasoning, critique peer arguments, and integrate diverse perspectives. This process naturally cultivates both critical and creative thinking. The digital environment, therefore, becomes a social learning space where ideas are negotiated and refined through interaction.

Moreover, the integration of STEM digital media aligns with 21st-century educational goals, emphasizing the need for innovation, adaptability, and technological literacy. In a rapidly changing world, students must be prepared to navigate complex problems that require multidisciplinary solutions. By using digital tools that mimic real-world scientific and engineering processes, students can connect theoretical concepts to practical applications. For instance, simulation software allows learners to experiment with scientific phenomena that may be too costly or dangerous in a traditional classroom, such as chemical reactions or structural stress testing. These experiences make learning more meaningful and contextually relevant. The positive impact of STEM digital media is also linked to the way it supports inquiry-based learning. Students are not merely passive consumers of information; instead, they become active investigators who construct knowledge through exploration. Inquiry-driven digital learning encourages curiosity and persistence, qualities that are essential for critical thinking. As students pose questions, gather evidence, and derive conclusions, they engage in cognitive processes similar to those of scientists and engineers.

Finally, the integration of STEM digital media also encourages educators to shift from teacher-centered instruction to learner-centered pedagogy. Teachers act as facilitators who guide exploration and provide feedback, while students take responsibility for their own learning. This shift promotes a classroom culture that values reasoning, evidence, and open discussion. As a result, the combination of STEM pedagogy and digital media not only enhances academic performance but also prepares students for the cognitive demands of higher education and professional life.

Critical Thinking Skills for Readiness to Face the 2030 SDGs

The coefficient of $\beta = 0.458$ shows a positive and significant influence between the ability to think critically-collaboratively on students' readiness to face the 2030 SDGs. This means that students who have good critical and collaborative thinking skills are better prepared to actively participate in efforts to achieve sustainable development goals (Uddin et al., 2020; Warsah et al., 2025). These skills are at the core of ESD competencies, where students need to be able to objectively assess socio-environmental issues, think systemically, and work together to create innovative and ethical solutions. The ability to think critically allows students to analyze complex global issues such as poverty, climate change, and inequality through multiple perspectives, while collaborative skills enable them to engage productively in team-based projects that mirror real-world problem-solving scenarios.

These findings reinforce the results of Robles-Moral (2021), who emphasized that education which encourages discussion, collaboration, and critical reflection from an early age increases awareness and responsibility for SDGs-related issues. In this sense, fostering critical and collaborative thinking is not merely an academic exercise but a foundational element of transformative education that prepares young people to become global citizens. Students trained to engage critically with knowledge are more capable of identifying biases, questioning assumptions, and seeking evidence-based conclusions. When this is combined with the ability to collaborate listening to others, negotiating differences, and integrating diverse viewpoints the outcome is a generation of learners who can meaningfully contribute to sustainable societies.

Furthermore, the positive relationship indicated by the coefficient highlights how educational strategies focusing on inquiry-based and participatory learning can enhance SDGs readiness. When students are involved in projects that simulate real-world sustainability challenges such as managing resources, reducing waste, or designing community initiatives they apply their critical and collaborative thinking skills in practical contexts. This experiential learning bridges theory and practice, motivating students to act rather than merely understand. It aligns with UNESCO's (2023) framework for ESD, which asserts that achieving the 2030 Agenda requires education systems to develop competencies that combine cognitive, socio-emotional, and behavioral dimensions.

Additionally, the correlation between these competencies and SDGs readiness suggests that schools and universities must adopt interdisciplinary curricula that integrate sustainability across subjects. Rather than treating SDGs as isolated topics, embedding them in discussions about science, economics, ethics, and culture helps students grasp their interdependence. Teachers play a pivotal role in facilitating this process by designing collaborative activities such as debates, case studies, and community service projects that require students to use critical analysis while working collectively toward shared goals.

STEM Digital Media for SDGs Readiness 2030

The coefficient of $\beta = 0.376$ shows that STEM digital media directly affects students' readiness to face the SDGs. This means that in addition to strengthening critical thinking skills, direct exposure to STEM digital content such as renewable energy topics, recycling, and environmentally friendly technology has fostered students' awareness and motivation to contribute to sustainability (Hoque et al., 2022; Purwaningsih & Wulandari, 2024). Digital media allows for the visualization of global issues (e.g., simulating the impacts of climate change or digital experiments on clean water), so that students better understand the relationship between science and real life. These results are in line with research by Zainil et al. (2024) who showed that digital STEM integration improves sustainability literacy and "6C skills" in elementary school students. Overall, the results of this study reinforce the theory that STEM digital media is an important catalyst in building 21st century competencies and sustainability readiness since primary education. Third, the variables of STEM digital media, the ability to think critically and collaboratively, and the readiness of the SDGs are significantly connected and form a learning system that strengthens each other.

These results are in line with the concept of transformative learning for sustainability (Mezirow, 2020) which emphasizes the importance of technology-based reflective learning experiences and real-world contexts to change students' perspectives on the world. Through STEM digital media, students not only learn science, but also learn to be agents of change for sustainability. In addition, these empirical findings are relevant to the SDG 4.7 policy direction which emphasizes the integration of sustainability values and technology literacy into the basic curriculum. With a high R^2 result (0.71), this research model shows that learning technology factors have a substantial role in students' readiness for the global agenda.

However, there are still a number of important implications for the role of teachers as digital learning facilitators. Teachers need to understand digital STEM learning designs that focus on real-world problem-solving, not just app usage. The infrastructure and digital divide whereschools in the suburbs need the support of tools and training so that the integration of digital STEM can be evenly distributed. Increasing sustainability literacy, namely STEM materials, needs to be designed contextually with local issues such as waste management, water conservation, or alternative energy so that students feel directly relevant to the SDGs.

CONCLUSION

The ability to think critically has a significant effect on students' readiness to face the 2030 SDGs. Students who are able to think reflectively, assess problems logically, and work together tend to have higher awareness and motivation towards sustainability issues. STEM digital media also has a direct influence on readiness to face the SDGs. Exposure to STEM digital materials that are oriented towards solving real problems (e.g. energy, environmental, and green technology issues) increases students' global awareness and social responsibility. There is an indirect influence through the mediation of critical and collaborative thinking skills. This means that the effectiveness of digital media in shaping sustainability readiness does not only come from the use of technology itself, but especially from how it stimulates students' thinking processes and social interactions. Conceptually, the results of this study support the theory of transformative learning and the principles of ESD which emphasize the importance of contextual, reflective, and action-oriented learning.

STEM digital media has proven to be not only a means of learning science, but also a vehicle to instill global awareness and social responsibility from an early age. In practical terms, this study provides empirical evidence that the integration of digital media in STEM learning in elementary schools can increase students' readiness to face the global challenges of the 2030 SDGs. Thus, schools and teachers are advised to: develop project-based STEM learning that uses interactive digital media; train students in critical and collaborative thinking through real problem-solving activities; and aligning the core curriculum with global sustainability values. This research also emphasizes the need for education policy support that encourages the strengthening of digital infrastructure, teacher training, and the provision of digital learning resources that are relevant to local and global contexts. By strengthening the integration of STEM and digital technology from the elementary school level, Indonesia can prepare a young generation that is not only academically capable, but also resilient, adaptive, and competitive in realizing the 2030 SDGs agenda.

REFERENCES

Aryasandy, N., Arwizet, A., Ambiyar, A., Sukardi, S., & Rozi, F. (2025). Analyzing the Influence of critical thinking skills, self-efficacy, digital literacy, and industrial internship on students' work readiness: SEM-PLS approach. *Jurnal Pendidikan MIPA*, *26*(1), 721-735. http://dx.doi.org/10.23960/jpmipa/v26i1.pp721-735

Boltsi, A., Kalovrektis, K., Xenakis, A., Chatzimisios, P., & Chaikalis, C. (2024). Digital tools, technologies, and learning methodologies for education 4.0 frameworks: A STEM oriented survey. *Ieee Access*, *12*, 12883-12901. https://doi.org/10.1109/ACCESS.2024.3355282

Chaleta, E., & rekan. (2021). *Higher education and sustainable development goals (SDG)—Potential contribution of the undergraduate courses of the School of Social Sciences of the University of Évora*. *Sustainability, 13*(4), 1828. https://doi.org/10.3390/su13041828

Fior, G., Fonda, C., & Canessa, E. (2025). Hands-on STEM learning experiences using digital technologies. *STEM Education*, *5*(2), 171–186. https://doi.org/10.3934/steme.2025009

Fung, J. M., & Hosseini, S. (2023). Reimagining education and workforce preparation in support of the UN's Sustainable Development Goals. *Augmented Education in the Global Age*, 30-47. https://doi.org/10.4324/9781003230762-4

Hoque, F., Yasin, R. M., & Sopian, K. (2022). Revisiting education for sustainable development: Methods to inspire secondary school students toward renewable energy. *Sustainability*, *14*(14), 8296. https://doi.org/10.3390/su14148296

Hu, X., Fang, Y., & Liang, Y. (2024). Roles and effect of digital technology on young children's STEM education: A scoping review of empirical studies. *Education Sciences*, *14*(4), 357. https://doi.org/10.3390/educsci14040357

Khalid, I. L., Abdullah, M. N. S., & Fadzil, H. M. (2024). A systematic review: Digital learning in STEM education. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, *51*(1), 98-115. https://doi.org/10.37934/araset.51.1.98115

Liu, J., Zhang, Y., Luo, H., Zhang, X., & Li, W. (2024). Enhancing high school students' stem major intention through digital competence: A large-scale cross-sectional survey. *Sustainability*, *16*(24), 11110. https://doi.org/10.3390/su162411110

Mawonde, A., & Togo, M. (2021). Challenges of involving students in campus SDGs-related practices in an ODeL context: The case of the University of South Africa (Unisa). *International Journal of Sustainability in Higher*

Education, *22*(7), 1487-1502. https://doi.org/10.1108/IJSHE-05-2020-0160
Mhlongo, S., Mbatha, K., Ramatsetse, B., & Dlamini, R. (2023). Challenges, opportunities, and prospects of adopting and using smart digital technologies in learning environments: An iterative review. *Heliyon*, *9*(6). https://doi.org/10.1016/j.heliyon.2023.e16348
Naz, B., Ali, S., Haider, Z., Khan, F., & Abbas, S. Z. (2025). Curriculum for a sustainable future: integrating SDGs into teaching and learning. *The Critical Review of Social Sciences Studies*, *3*(4), 629-647.
Pang, S., Lv, G., Zhang, Y., & Yang, Y. (2024). Enhancing students' science learning using virtual simulation technologies: A systematic review. *Asia Pacific Journal of Education*, 1-21. https://doi.org/10.1080/02188791.2024.2441676
Purnama, S., Ulfah, M., Machali, I., Wibowo, A., & Narmaditya, B. S. (2021). Does digital literacy influence students' online risk? Evidence from Covid-19. *Heliyon*, *7*(6). https://doi.org/10.1016/j.heliyon.2021.e07406
Purwaningsih, S., & Wulandari, S. (2024). Analysis of the application of SDGs-Based STEM learning in improving critical thinking abilities and environmental awareness. *Proceedings of the Multidisciplinary Research Community*, *1*(1), 698-704.
Reyna, J., & Meier, P. (2020). Co-creation of knowledge using mobile technologies and digital media as pedagogical devices in undergraduate STEM education. *Research in Learning Technology*, *28*. http://dx.doi.org/10.25304/rlt.v28.2356

Robles-Moral, F. J. (2021). Learning about sustainability and SDG with future primary education teachers in initial training. *Social Sciences*, *10*(11), 409. https://doi.org/10.3390/socsci10110409
Shutaleva, A. (2023). Ecological culture and critical thinking: building of a sustainable future. *Sustainability*, *15*(18), 13492. https://doi.org/10.3390/su151813492
Singh, D., Singh, P., Kumar, P., & Nautiyal, A. K. (2024). Global sustainable educational goals for catering to the needs and challenges of 21st century. *Journal of Mountain Research.* https://doi. org/10.51220/jmr. v19-i1, 56
Siregar, N. C., Warsito, W., Gumilar, A., Amarullah, A., & Rosli, R. (2024). STEM in action: Real-world applications of science, technology, engineering, and math. *Prima: Jurnal Pendidikan Matematika*, *8*(2), 493-507.
Song, H., & Cai, L. (2024). Interactive learning environment as a source of critical thinking skills for college students. *BMC Medical Education*, 24, 270. https://doi.org/10.1186/s12909-024-05247-y
Sugandi, D., & Ruhimat, M. (2021, July). The urgency of HOTS-oriented learning and assessment towards quality of education in facing indonesia sustainable development goals (SDGs) 2030. In *5th Asian Education Symposium 2020 (AES 2020)* (pp. 237-250). Atlantis Press.
Uddin, M. R., Shimizu, K., & Widiyatmoko, A. (2020, June). Assessing secondary level students' critical thinking skills: inspiring environmental education for achieving sustainable development goals. In *Journal of Physics: Conference Series* (Vol. 1567, No. 2, p. 022043). IOP Publishing. https://doi.org/10.1088/1742-6596/1567/2/022043
Wahidin, W., Gutierrez, G., Osman, K., Akkapin, S., & Tan, M. L. T. (2025). Digital simulations in science learning: A student perspective on interactive, engagement, conceptual understanding, and learning

satisfaction. *International Journal of Educational Qualitative Quantitative Research*, *4*(1), 36-46. https://doi.org/10.58418/ijeqqr.v4i1.138
Warsah, I., Morganna, R., Uyun, M., Afandi, M., & Hamengkubuwono, H. (2021). The impact of collaborative learning on learners' critical thinking skills. *International Journal of Instruction*, *14*(2), 443-460.
Wells, J. G., & Van de Velde, D. (2020). Technology education pedagogy: Enhancing STEM learning. In *pedagogy for technology education in secondary schools: Research informed perspectives for classroom teachers* (pp. 219-244). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-41548-8_12
Westheimer, J. (2020). Can education transform our world? Global citizenship education and the UN's 2030 agenda for sustainable development. In *Grading goal four* (pp. 280-296). Brill. https://doi.org/10.1163/9789004430365_013
Zainil, M., Kenedi, A. K., Rahmatina, I., Indrawati, T., & Handrianto, C. (2024). The influence of STEM-based digital learning on 6C skills of elementary school students. *Open Education Studies*, *6*(1), Article 20240039. https://doi.org/10.1515/edu-2024-0039

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be constructed as a potential conflict of interest.