BIO EDUCATIO
(*The Journal of Science and Biology Education*)
http: https://jurnal.unma.ac.id/index.php/BE
p-ISSN : 2541-2280
e-ISSN : 2541-4097
DOI: http://doi.org/10.31949/be.v10i2.17940

Digital E-Modules in Elementary Science Education: A Systematic Review on Supporting Education for Sustainable Development

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Article Info
Article History
Received: 20-07-2025
Revised: 13-08-2025
Accepted: 10-09-2025

Keywords:

E-modules,
Elementary science education,
Education for sustainable development,
sustainability literacy,
Higher-order thinking skills,
Digital learning

ABSTRACT

This study aims to systematically analyze the role of e-modules in elementary science education within the framework of Education for Sustainable Development (ESD). A systematic literature review (SLR) was conducted by examining 13 empirical studies published between 2016 and 2025, selected through predefined inclusion and exclusion criteria. The analysis focused on the characteristics, effectiveness, and pedagogical contributions of e-modules in enhancing learning outcomes and sustainability-related competencies. The findings indicate that e-modules significantly improve students' conceptual understanding, learning outcomes, and higher-order thinking skills (HOTS), particularly when designed using interactive, inquiry-based, and contextual approaches. Furthermore, e-modules integrating sustainability contexts and environmental issues contribute to the development of sustainability literacy, environmental awareness, and responsible behavior. The incorporation of local knowledge and ethnoscience also enhances the relevance and effectiveness of learning by connecting scientific concepts with students' real-life experiences. The study highlights that the effectiveness of e-modules is strongly influenced by instructional design, offering practical implications for educators and policymakers in designing meaningful, effective, and ESD-aligned e-modules. However, limitations remain, including the predominance of short-term studies and limited exploration of advanced sustainability competencies such as systems thinking. This study contributes to the theoretical development of digital learning in sustainability education and provides practical implications for educators and policymakers in designing meaningful and future-oriented science learning in elementary education.

INTRODUCTION

The rapid transformation of education in the digital era has not only introduced new technological tools into classrooms but has also fundamentally reshaped how knowledge is constructed, accessed, and applied. This transformation is increasingly aligned with global sustainability agendas, where education is expected to foster not only cognitive achievement but also environmentally responsible and socially aware individuals. Within this paradigm, Education for Sustainable Development (ESD) emerges as a critical framework that integrates knowledge,

skills, values, and attitudes necessary to address complex environmental and societal challenges (Sihombing et al., 2024; Zhang et al., 2024). The integration of sustainability into education reflects a broader shift toward preparing learners to respond to real-world ecological and social issues through informed and responsible decision-making.

Elementary education plays a foundational role in this transformation, as it represents a critical stage for developing early scientific understanding and environmental awareness. At this level, students begin to form basic conceptions about natural systems and human–environment interactions, making science education a strategic domain for embedding sustainability principles (Rico et al., 2021; Triyandana et al., 2024). Topics such as ecosystems, environmental pollution, and natural resource management provide meaningful contexts for integrating ESD into classroom practices. However, the abstract nature of many scientific concepts often presents challenges for young learners, necessitating instructional approaches that can connect theoretical knowledge with real-life sustainability issues in accessible and engaging ways (Laksana et al., 2019).

In response to these challenges, digital learning resources, particularly electronic modules (e-modules), have gained increasing attention as innovative instructional tools. E-modules offer interactive, flexible, and multimedia-rich learning environments that can support students' engagement and conceptual understanding (So et al., 2019; Hasanah et al., 2023). Through the integration of visual, auditory, and interactive elements, e-modules enable learners to explore complex scientific phenomena that are otherwise difficult to observe directly. From a theoretical perspective, this aligns with principles of multimedia learning and cognitive processing, where well-designed digital content can enhance understanding by optimizing information presentation and reducing cognitive overload. In the context of ESD, e-modules are particularly valuable for visualizing dynamic environmental processes such as the hydrological cycle and ecological systems (Santa et al., 2024).

Empirical studies further indicate that e-modules contribute significantly to improving learning outcomes and higher-order thinking skills in elementary science education. For instance, e-modules based on Science, Environment, Technology, and Society (SETS) approaches have been shown to enhance students' critical thinking and learning interest (Yevira, 2023). Similarly, ethnoscience-based and sustainability-oriented e-modules have demonstrated effectiveness in improving science literacy and fostering cultural and environmental awareness (Fauziah & Ihsan, 2024; Budiati et al., 2022). In addition, digital and multimedia-based instructional designs have been associated with improvements in conceptual understanding, argumentation skills, and problem-solving abilities (Chen et al., 2020). These findings suggest that e-modules not only support cognitive development but also play a role in shaping students' sustainability-related competencies.

Beyond cognitive outcomes, e-modules also contribute to affective and behavioral dimensions of learning, which are central to ESD. Learning designs that integrate sustainability contexts have been found to enhance environmental awareness, promote eco-friendly behavior, and strengthen students' engagement with real-world issues (Khofi, 2024; Lestari et al., 2023). Furthermore, the integration of green curriculum and sustainability-oriented instruction in elementary science classrooms has been shown to cultivate ecological literacy and responsible behavior among students (Triyandana et al., 2024). These findings reinforce the idea that

effective science learning should not only focus on knowledge acquisition but also on developing values and attitudes that support sustainable living.

Despite these promising developments, the effectiveness of e-modules is not automatically ensured. Research highlights that the impact of digital learning tools is highly dependent on instructional design quality, pedagogical alignment, and meaningful integration into classroom practices (Rodríguez-Loinaz et al., 2024). Without careful design, digital modules risk functioning merely as technological substitutions rather than transformative learning tools. Additionally, challenges such as limited technological infrastructure, unequal access to digital resources, and variations in teachers' competencies remain significant barriers to implementation (Zhang et al., 2024). These constraints indicate that the successful integration of e-modules within ESD requires not only technological innovation but also systemic support and pedagogical readiness.

From an ESD perspective, these challenges underscore the need to critically examine the broader role of e-modules beyond improving academic performance. In particular, there is a need to explore how digital learning tools contribute to the development of sustainability literacy, systems thinking, critical thinking, and responsible decision-making. Previous studies have often focused on isolated learning outcomes, resulting in fragmented evidence regarding the comprehensive impact of e-modules in sustainability-oriented education contexts (Munkebye & Gericke, 2022). This fragmentation highlights the importance of synthesizing existing research to obtain a more integrated understanding of their educational potential. Therefore, a systematic literature review (SLR) is essential to map the current trends, characteristics, effectiveness, and challenges of e-module implementation in elementary education within the framework of ESD. By employing a structured and transparent approach, SLR enables the identification of consistent patterns, gaps, and future research directions across multiple studies. This study adopts a cross-study synthesis approach to provide a comprehensive analysis of how e-modules can support both learning effectiveness and sustainability-oriented competencies in elementary education.

Specifically, this study aims to (1) examine the development trends and characteristics of e-modules in elementary science education, (2) analyze their effectiveness in enhancing learning outcomes and higher-order thinking skills, and (3) explore their contribution to fostering sustainability-related competencies within the ESD framework. The findings are expected to advance theoretical discourse on digital learning in sustainability education while also offering practical insights for educators, curriculum developers, and policymakers in designing meaningful, future-oriented learning environments.

METHOD

Research Design

This study employed a Systematic Literature Review (SLR) design to comprehensively identify, evaluate, and synthesize empirical research related to the use of e-modules in elementary education within the framework of Education for Sustainable Development (ESD). The SLR approach was selected due to its rigor in providing a transparent, replicable, and evidence-based synthesis of existing studies, enabling the identification of patterns, trends, and research gaps across diverse educational contexts. Previous research has emphasized that systematic reviews play a critical role in consolidating methodological knowledge and advancing evidence-based

practices in education (Matos et al., 2023). In addition, the use of structured review approaches has been recognized as essential for ensuring methodological clarity and consistency in educational research synthesis (Tinoca et al., 2022). Accordingly, the review process in this study followed established guidelines for systematic reviews, incorporating structured stages of identification, screening, eligibility assessment, and inclusion to ensure methodological consistency and reliability. These stages were designed to minimize bias, enhance transparency, and support the reproducibility of the review process, thereby strengthening the overall validity of the findings.

Data Sources and Search Strategy

A systematic search was conducted across three major academic databases: Scopus, Google Scholar, and ProQuest. These databases were selected to ensure comprehensive coverage of peer-reviewed journal articles and high-quality academic publications in education, science education, and digital learning.

The search process utilized combinations of keywords and Boolean operators related to the research focus, including:

1. *"e-module" OR "digital module" OR "electronic module"*
2. *"elementary school" OR "primary education"*
3. *"science education" OR "biology education"*
4. *"education for sustainable development" OR "ESD" OR "sustainability literacy"*

The search was limited to publications between 2016 and 2025 to capture recent developments in digital learning and sustainability-oriented education.

Inclusion and Exclusion Criteria

Table 1. Inclusion and Exclusion Criteria

Criteria Type	Description
Inclusion Criteria	
Study design	Empirical studies published in peer-reviewed journals
Focus of study	Studies focusing on e-modules or digital learning materials
Educational level	Research conducted in elementary or primary education contexts
Outcome variables	Studies addressing at least one of the following: learning outcomes, conceptual understanding, higher-order thinking skills, or sustainability-related competencies
Language	Articles published in English or Indonesian
Exclusion Criteria	
Study type	Non-empirical studies (e.g., opinion papers, editorials, conceptual papers)
Irrelevant focus	Studies not focusing on e-modules or digital instructional media
Educational mismatch	Research conducted outside elementary or primary education contexts

Study Selection Process

The study selection process followed a structured multi-stage procedure:

1. Identification: Initial search results were collected from all databases
2. Screening: Titles and abstracts were reviewed to remove irrelevant studies
3. Eligibility: Full-text articles were assessed based on inclusion criteria
4. Inclusion: Final studies were selected for analysis

Through this process, a total of 13 empirical studies were identified as meeting all criteria and included in the final analysis.

Data Extraction

Data from the selected studies were systematically extracted using a structured coding framework. The extracted information included:

1. author(s) and publication year
2. research design and methodology
3. subject area (e.g., science, mathematics, language)
4. characteristics of the e-module
5. learning outcomes and measured variables
6. key findings
7. relevance to ESD (e.g., environmental awareness, sustainability literacy)

This process ensured consistency and comparability across studies.

Data Analysis

The data were analyzed using a thematic synthesis approach combined with cross-study analysis. The analysis involved several stages:

1. Familiarization: Reading and re-reading all selected studies
2. Coding: Identifying key concepts and recurring findings
3. Theme Development: Grouping codes into broader thematic categories
4. Synthesis: Interpreting relationships across studies

The main themes identified in this study included:

1. development trends and characteristics of e-modules
2. effectiveness on learning outcomes
3. enhancement of higher-order thinking skills
4. student engagement and motivation
5. contribution to sustainability-related competencies
6. challenges in implementation

Trustworthiness and Rigor

To ensure the validity and reliability of the findings, several strategies were employed:

1. Triangulation: Comparing findings across multiple studies
2. Systematic coding procedures to minimize bias
3. Transparent reporting of selection and analysis processes
4. Cross-study verification to ensure consistency of themes

These steps enhance the credibility and robustness of the review.

Ethical Considerations

This study did not directly involve human participants, as it relied solely on previously published research. All sources were properly cited in accordance with academic standards to ensure ethical integrity and avoid plagiarism.

RESULTS

Study Selection Process

The study selection process followed a systematic approach using predefined inclusion and exclusion criteria. An initial search across selected databases yielded a substantial number of records, which were subsequently screened through title and abstract review. After removing duplicates and irrelevant studies, full-text articles were assessed for eligibility. A total of **13 studies** met all inclusion criteria and were included in the final synthesis. The selection process is illustrated in **Figure 1**, which presents the PRISMA flow diagram of study identification, screening, eligibility, and inclusion.

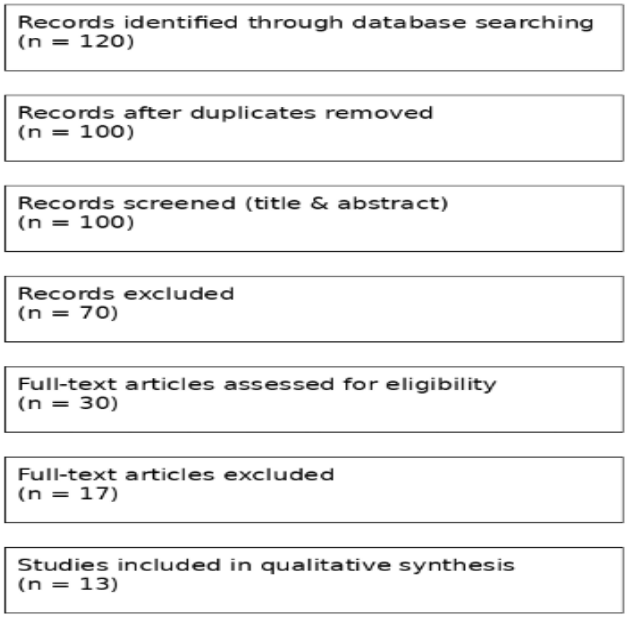

Figure 1. PRISMA Diagram Flow

Characteristics of Selected Studies

The characteristics of the selected studies were systematically analyzed to identify patterns in research focus, pedagogical approaches, and learning outcomes. As presented in **Table 2**, the studies predominantly focus on **elementary science education**, with particular emphasis on biology-related and environmental topics.

Table 2. Analytical Matrix of Selected Studies (n = 13)

No	Author(s)	Domain	Pedagogical Approach	E-Module Features	Outcome Variables	Key Effects	ESD Dimension
1	Adri (2023)	Science	Scientific reasoning	Structured, inquiry-based	Reasoning skills	Significant improvement	Cognitive
2	Syahfitri &	Biology	Interactive	Multimedia,	Critical	Moderate–	Cognitive–

	Safitri (2024)		learning	digital	thinking, motivation	high improvement	Affective
3	Sintawati & Margunayasa (2021)	Science	Developmental	Interactive, structured	Validity, feasibility	High feasibility	Technical
4	Sari et al. (2024)	Science	Multimedia learning	Flipbook, visual	Learning outcomes	Significant improvement	Cognitive
5	Syafitri & Hamdu (2023)	Science	ESD-based	Sustainability content	Sustainability awareness	Positive impact	Sustainability literacy
6	Lestari et al. (2022)	Science	RADEC (ESD)	Contextual, active learning	Sustainability consciousness	Significant improvement	Sustainability literacy
7	Handayani et al. (2024)	Science	Project-based (ESD)	Ecoliteracy module	Environmental care	Strong improvement	Behavior
8	Uslan et al. (2024)	Science	Local knowledge	Contextual module	Scientific literacy	Moderate improvement	Cognitive–Contextual
9	Liana & Sarong (2024)	Biology	Problem-based	Android-based	Science literacy	Significant improvement	Sustainability
10	Al-Muhdhar et al. (2021)	Science	Experiential	Environmental exploration	Environmental literacy	Strong improvement	Sustainability literacy
11	Putri & Aznam (2019)	Science	Contextual	Local integration	Critical thinking, problem solving	Moderate improvement	Cognitive
12	Syahmani et al. (2022)	Science	Ethnoscience	Inquiry-based	Problem solving	High improvement	Contextual–ESD
13	Winangun et al. (2024)	Science	Local wisdom	Case-based module	Concept understanding	Positive improvement	Contextual–Sustainability

The analysis indicates that most studies employ experimental and development (R&D) designs, reflecting a strong emphasis on the creation and validation of e-modules, as well as on their effectiveness in classroom implementation. In terms of pedagogical orientation, a clear trend toward student-centered approaches, including inquiry-based learning, problem-based learning, ethnoscience integration, and ESD-oriented instruction, emerges. From a technological perspective, the e-modules are characterized by the integration of multimedia elements, such as animations, interactive tasks, and visual simulations. These features support active engagement and facilitate the understanding of abstract scientific concepts. Furthermore, several studies incorporate contextual and local knowledge, highlighting the importance of relevance and cultural connection in elementary science learning.

Effects on Learning Outcomes and Conceptual Understanding

Across the reviewed studies, e-modules demonstrate a **consistently positive effect on cognitive learning outcomes**, particularly in improving conceptual understanding and science literacy. Experimental findings indicate that students who engage with e-modules achieve significantly higher performance than those using conventional learning materials. The effectiveness of e-modules can be attributed to their ability to present scientific concepts through multimodal representations, enabling students to process information more effectively. In particular, e-modules support the understanding of abstract and dynamic processes, such as environmental systems and biological phenomena, which are often challenging for elementary learners.

Enhancement of Higher-Order Thinking Skills

A substantial body of evidence across the selected studies indicates that e-modules significantly foster higher-order thinking skills (HOTS) among elementary students, particularly in the domains of critical thinking, problem-solving, and scientific reasoning. These cognitive gains are consistently reported in studies employing interactive, inquiry-based, and contextualized e-module designs, suggesting that the pedagogical structure embedded within the modules is a key determinant of their effectiveness. More specifically, e-modules that incorporate problem-based and inquiry-oriented tasks require students to engage in identifying problems, formulating hypotheses, analyzing evidence, and drawing conclusions. For instance, modules grounded in contextual science learning and ethnoscience approaches demonstrate that students are not only able to understand concepts but also apply them in interpreting real-world phenomena and solving authentic problems. This indicates a shift from surface-level learning toward deep cognitive processing, where learners actively construct knowledge rather than passively receive information.

Furthermore, interactive features such as simulations, guided questions, and embedded tasks enable iterative thinking processes, allowing students to revisit, refine, and extend their understanding. These design elements support the development of analytical and evaluative thinking, which are central components of HOTS. In this context, e-modules function as cognitive scaffolding tools, providing structured support that gradually guides learners from basic comprehension toward more complex reasoning and decision-making processes. Another important finding is the role of contextualization and real-world relevance in enhancing HOTS. E-modules that integrate environmental issues, local knowledge, or sustainability contexts encourage students to connect abstract scientific concepts with everyday experiences. This not only increases engagement but also strengthens students' ability to transfer knowledge across contexts, a key indicator of higher-order thinking. For example, when students are exposed to environmental problem scenarios, they are required to evaluate multiple perspectives, consider consequences, and propose solutions, thereby engaging in systems-oriented and reflective thinking.

In addition, the integration of ESD principles within e-modules further amplifies the development of HOTS by promoting decision-making and value-based reasoning. Students are not only trained to think critically but are also encouraged to make responsible judgments regarding environmental and societal issues. This aligns with the broader goal of education: developing learners capable of addressing complex, interdisciplinary challenges. The findings

suggest that the effectiveness of e-modules in enhancing HOTS is not merely a result of technological integration but is strongly influenced by instructional design quality, task complexity, and contextual relevance. E-modules that combine interactive features with inquiry-based and sustainability-oriented approaches are more likely to produce meaningful improvements in students' higher-order thinking skills. However, the extent of these improvements varies across studies, indicating the need for more consistent measurement frameworks and longitudinal investigations to capture the long-term impact of e-modules on cognitive development.

Contribution to Sustainability Literacy and Environmental Awareness

From an ESD perspective, the findings consistently indicate that e-modules contribute not only to cognitive outcomes but also to the development of sustainability literacy and environmental awareness. ESD-oriented e-modules, particularly those that integrate ecoliteracy and environmental problem contexts, enable students to move beyond understanding concepts to recognize the implications of human activities for ecological systems. Several studies show that students exposed to sustainability-based e-modules demonstrate improved awareness of environmental issues alongside the emergence of more responsible attitudes and behaviors. This effect is largely driven by the inclusion of real-world environmental scenarios, which require learners to interpret, evaluate, and respond to authentic ecological challenges. Importantly, these modules facilitate a shift from knowledge acquisition to value-oriented learning, in which students develop a sense of responsibility toward the environment. By explicitly linking scientific concepts to sustainability issues, e-modules serve as integrative tools that embed environmental values into elementary science learning in meaningful, practical ways.

Integration of Contextual and Local Knowledge

An important pattern emerging from the analysis is the integration of contextual and local knowledge within e-module design, particularly through ethnoscience and local wisdom approaches. This integration enhances both engagement and conceptual understanding by situating learning within students' immediate cultural and environmental contexts. Contextualized e-modules enable students to connect abstract scientific concepts with familiar experiences, thereby improving comprehension and relevance. At the same time, the incorporation of local environmental issues fosters place-based learning, strengthening students' awareness of their surroundings and encouraging more meaningful engagement with sustainability topics. This approach aligns closely with ESD principles, as it promotes not only cognitive understanding but also cultural relevance and ecological responsibility. By bridging scientific knowledge with local practices and environmental conditions, e-modules support the development of learners who are both scientifically literate and socially responsive.

Synthesis of Findings and Emerging Patterns

The synthesis of the 13 selected studies reveals a coherent pattern indicating that integrating e-modules into elementary science education yields multidimensional learning benefits. Across the studies, e-modules consistently improve students' learning outcomes and conceptual understanding, particularly in addressing abstract and process-oriented scientific content. This improvement is closely associated with the interactive and multimodal nature of e-modules, which enables learners to engage more deeply with scientific concepts.

In addition to cognitive gains, the findings demonstrate that e-modules significantly promote higher-order thinking skills. Through the incorporation of inquiry-based, problem-oriented, and contextual learning tasks, students are encouraged to analyze information, evaluate evidence, and construct solutions, thereby fostering critical and reflective thinking processes. This indicates that e-modules function not merely as instructional media but as pedagogical tools that support deeper cognitive engagement. Another prominent pattern is the increasing integration of sustainability principles within e-module design. Many studies reflect a shift toward embedding Education for Sustainable Development (ESD) by incorporating environmental contexts, ecoliteracy components, and real-world issues. This integration enables students to develop awareness of sustainability challenges while simultaneously building scientific understanding, thus linking knowledge with values and responsible action.

Furthermore, the inclusion of contextual and local knowledge emerges as a key strength in enhancing the relevance and effectiveness of learning. By connecting scientific concepts to students' immediate environments and cultural contexts, e-modules facilitate more meaningful learning experiences and support the development of place-based understanding. This alignment between content, context, and learner experience reinforces both engagement and comprehension. Despite these positive trends, several limitations are evident. The majority of studies rely on short-term experimental designs, limiting insights into the long-term impact of e-modules on learning and sustainability competencies. Moreover, while improvements in general environmental awareness are frequently reported, there remains limited exploration of more complex sustainability skills, such as systems thinking and informed decision-making. These gaps highlight the need for future research to adopt more comprehensive and longitudinal approaches in evaluating the role of e-modules within the broader framework of sustainable education.

DISCUSSION

The findings of this systematic review provide strong evidence that e-modules play a transformative role in elementary science education, particularly when aligned with the principles of Education for Sustainable Development (ESD). Across the selected studies, consistent improvements in learning outcomes, conceptual understanding, and higher-order thinking skills indicate that e-modules function as pedagogically meaningful learning environments rather than mere technological tools. This transformation is closely associated with integrating structured instructional design and interactive features to promote active engagement. Previous research supports this interpretation, demonstrating that digital learning environments can significantly enhance students' conceptual understanding and engagement in science learning when aligned with pedagogical goals (Ristanto et al., 2022; Fadillah et al., 2024). Furthermore, structured instructional approaches embedded in digital modules have been shown to improve learning outcomes by facilitating active participation and cognitive involvement (Nikmah et al., 2024). Therefore, the effectiveness of e-modules lies not only in their technological affordances but also in their ability to integrate pedagogy, content, and learner interaction in a coherent instructional framework.

From a theoretical perspective, the effectiveness of e-modules can be explained through multimedia learning theory, which emphasizes the integration of visual and verbal representations to enhance cognitive processing and knowledge construction. Empirical evidence

grounded in cognitive load theory suggests that well-designed multimedia instruction reduces extraneous cognitive load while supporting deeper conceptual understanding (Al Atiyat, 2018; Dervić & Mešić, 2019). This is particularly relevant in elementary science education, where students often encounter abstract and process-oriented concepts that are difficult to visualize. Studies on digital and multimedia learning environments further indicate that interactive simulations and visual representations significantly improve comprehension of complex scientific phenomena (Girwidz & Kohnle, 2021; Ginting et al., 2021). The reviewed studies reinforce these findings by showing that e-modules incorporating multimedia elements enable learners to engage with content more effectively. Consequently, e-modules can be understood as cognitive tools that optimize information processing while simultaneously supporting meaningful learning experiences.

In addition, the findings strongly support the role of e-modules in fostering higher-order thinking skills (HOTS), including critical thinking, problem-solving, and analytical reasoning. E-modules that integrate inquiry-based, problem-based, and contextual learning approaches require students to actively engage in identifying problems, analyzing data, and generating solutions. This aligns with constructivist learning theory, which emphasizes that knowledge is constructed through active engagement and interaction with meaningful tasks (Romdhon et al., 2024). Empirical studies further demonstrate that STEM-based and inquiry-oriented digital learning environments significantly enhance students' higher-order thinking abilities (Pertiwi et al., 2024; Zainil et al., 2023). Additionally, inquiry science learning has been shown to promote deeper cognitive engagement and conceptual reasoning among elementary learners (Lee et al., 2020). The inclusion of real-world scenarios and contextual tasks further enables students to transfer knowledge across situations, reflecting deeper learning processes. Thus, e-modules serve as cognitive scaffolding tools that facilitate not only understanding but also the application and evaluation of knowledge.

A particularly significant contribution of this study lies in highlighting the alignment between e-modules and ESD principles. The integration of sustainability contexts, ecoliteracy components, and environmental problem scenarios within e-modules supports the development of sustainability literacy, environmental awareness, and responsible behavior among students. This is consistent with research showing that contextual and culturally relevant science learning enhances students' engagement with environmental issues and promotes awareness of sustainability challenges (Wardani et al., 2024). By embedding real-world environmental problems into instructional design, e-modules enable learners to connect scientific knowledge with practical implications, thereby fostering value-oriented learning. Moreover, the incorporation of local knowledge and ethnoscience strengthens this alignment by linking global sustainability issues with local contexts, enhancing both relevance and cultural responsiveness. As a result, e-modules not only support cognitive development but also contribute to the formation of environmentally responsible attitudes and behaviors, which are central goals of ESD.

Despite these strengths, the findings also reveal several limitations in the current body of research. Most studies rely on short-term experimental designs, which restrict the ability to assess the long-term impact of e-modules on students' cognitive and behavioral development. This limitation is consistent with broader findings in digital learning research, which emphasize the

need for longitudinal studies to capture sustained learning effects (Fadillah et al., 2024). Furthermore, while improvements in environmental awareness are widely reported, there is limited exploration of more complex sustainability competencies, such as systems thinking and decision-making. Variations in research design, measurement instruments, and implementation contexts also create challenges in comparing and generalizing findings across studies. These limitations indicate that although current evidence supports the effectiveness of e-modules, further research is required to establish a more comprehensive understanding of their long-term and multidimensional impact.

These limitations suggest important directions for future research. There is a clear need for longitudinal and large-scale studies that examine the sustained impact of e-modules on both cognitive and sustainability-related outcomes. Future research should also incorporate more comprehensive assessment frameworks that capture not only cognitive gains but also affective and behavioral dimensions of learning. Additionally, integrating interdisciplinary approaches and leveraging emerging digital technologies, such as adaptive learning systems and immersive environments, may further enhance the effectiveness of e-modules. By addressing these gaps, future studies can contribute to a more robust and holistic understanding of how digital learning tools can support transformative education within the framework of sustainability.

CONCLUSION

This study provides a comprehensive synthesis of empirical evidence on the use of e-modules in elementary science education within the framework of Education for Sustainable Development. The findings demonstrate that e-modules are effective in improving learning outcomes, enhancing conceptual understanding, and promoting higher-order thinking skills. More importantly, they contribute to the development of sustainability literacy and environmental awareness, indicating their potential as tools for fostering responsible and informed future citizens. Theoretically, this study contributes to the growing body of literature by positioning e-modules as integrative learning tools that bridge digital pedagogy, science education, and sustainability education. It highlights the importance of aligning instructional design with ESD principles to achieve not only cognitive but also transformative learning outcomes. Practically, the findings suggest that educators should move beyond using e-modules as supplementary materials and instead design them as contextual, interactive, and sustainability-oriented learning environments. Curriculum developers are encouraged to integrate local knowledge, environmental issues, and real-world contexts into e-module design to enhance relevance and engagement. Policymakers should also support the implementation of digital learning by improving infrastructure, providing teacher training, and promoting sustainability-oriented curricula. However, the study is not without limitations. The reliance on a limited number of studies and variations in research design may affect the generalizability of the findings. Therefore, future research should expand the scope of analysis and employ more robust methodological approaches. In conclusion, e-modules hold significant potential to transform elementary science education by integrating technology, pedagogy, and sustainability. When designed and implemented effectively, they can support not only academic achievement but also the development of critical, reflective, and environmentally responsible learners, who are essential for addressing the challenges of the 21st century.

ADDITIONAL INFORMATION

Section	Description
Funding	This research received no external funding.
Conflict of Interest	The authors declare no conflict of interest regarding the publication of this paper.
Author Contributions	All authors contributed significantly to this study. The first author was responsible for conceptualization, methodology, data analysis, and writing the original draft. The second author contributed to data validation, analysis, and manuscript review. The third author was responsible for supervision, critical revision, and editing of the manuscript. All authors have read and approved the final version of the manuscript.
Data Availability	The data supporting the findings of this study are available from the corresponding author upon reasonable request.
Ethical Approval	This study was conducted in accordance with ethical research standards. As this research is based on a systematic literature review, it does not involve direct participation of human subjects and therefore does not require formal ethical approval.
AI Usage Statement	The authors declare that artificial intelligence (AI) tools were used only to assist in language refinement and grammatical editing. All conceptual development, data analysis, interpretation, and scientific conclusions were conducted solely by the authors. The authors take full responsibility for the content and integrity of this manuscript.

REFERENCES

Adri, H. T. (2023). Developing science e-modules based on scientific reasoning skills for primary education course. *Jurnal Penelitian Pendidikan IPA, 9*(8), 6480–6486. https://doi.org/10.29303/jppipa.v9i8.4727

Al Atiyat, A. M. (2018). The effect of multimedia instructional design based on Sweller's theory on reducing cognitive load and developing scientific concepts among deaf primary students. *Journal of Educational and Psychological Studies, 12*(4), 672–685. https://doi.org/10.53543/jeps.vol12iss4pp672-685

Al-Muhdhar, M. H. I., Basaroh, A. S., Prasetyo, T. I., Sumberartha, I. W., Mardiyanti, L., & Fanani, Z. (2021). Improvement of creative thinking skills and environmental literacy through the e-module of surrounding nature exploration. *AIP Conference Proceedings, 2330*(1), 030003. https://doi.org/10.1063/5.0043102

Budiati, A. N. S. L., Hernani, H., & Amprasto, A. (2022). Teaching students about education for sustainable development through e-module of Indonesian traditional fermented food. *Jurnal Pendidikan MIPA, 23*(2), 540–553. https://doi.org/10.23960/jpmipa/v23i2.pp540-553

Chen, C. Y., Huang, H. J., Lien, C. J., & Lu, Y. L. (2020). Effects of multi-genre digital game-based instruction on students' conceptual understanding, argumentation skills, and learning experiences. *IEEE Access, 8*, 110643–110655. https://doi.org/10.1109/ACCESS.2020.3000659

Dervić, D., & Mešić, V. (2019). Cognitive load in multimedia learning: An example from teaching about lenses. *Journal of Education in Science, Environment and Health, 5*(1), 102–118. https://doi.org/10.21891/jeseh.481698

Fadillah, M. A., Asrizal, A., Festiyed, F., & Usmeldi, U. (2024). The effect of e-modules on physics learning in senior high school: A meta-analysis. *Indonesian Journal of Science and Mathematics Education, 7*(3), 574–589. https://doi.org/10.24042/ijsme.v7i3.21641

Fauziah, N., & Ihsan, M. S. (2024). Science literacy profile and students' cultural character taught using science e-modules based on ethnoscience oriented towards green chemistry. *Jurnal Penelitian Pendidikan IPA, 10*(10), 8276–8281. https://doi.org/10.29303/jppipa.v10i10.9259

Ginting, D., Barella, Y., Linarsih, A., & Woods, R. (2021). Emergency remote teaching practices in the perspective of cognitive load of multimedia learning theory. In *Proceedings of the 1st International Conference of Education, Social and Humanities (INCESH 2021)* (pp. 96–106). Atlantis Press. https://doi.org/10.2991/assehr.k.211028.100

Girwidz, R., & Kohnle, A. (2021). Multimedia and digital media in physics instruction. In H. E. Fischer & R. Girwidz (Eds.), *Physics education: Challenges in physics education*. Springer. https://doi.org/10.1007/978-3-030-87391-2_11

Handayani, T., Yufiarti, & Solihatin, E. (2024). The effectiveness of project-based blended learning ecoliteracy e-module to improve environmental care character. *AIP Conference Proceedings, 3148*(1), 040029. https://doi.org/10.1063/5.0242374

Hasanah, U., Astra, I. M., & Sumantri, M. S. (2023). Exploring the need for using science learning multimedia to improve critical thinking of elementary school students: Teacher perception. *International Journal of Instruction, 16*(1), 417–440. https://e-iji.net/ats/index.php/pub/article/view/199

Khofi, M. B. (2024). The green school concept in elementary schools as an effort to form sustainable behavior and environmental awareness. *Al-Adzka: Jurnal Ilmiah Pendidikan Guru Madrasah Ibtidaiyah, 14*(2), 206–225. https://doi.org/10.18592/aladzkapgmi.v14i2.14412

Laksana, D. N. L., Dasna, I. W., & Degeng, I. (2019). The effects of inquiry-based learning and learning styles on primary school students' conceptual understanding in multimedia learning environments. *Journal of Baltic Science Education, 18*(1), 51–62. https://doi.org/10.33225/jbse/19.18.51

Lee, Y. C., Lee, C. K. P., & Lam, I. C. M. (2020). Inquiry science learning and teaching: A comparison between the conceptions and attitudes of pre-service elementary teachers in Hong Kong and the United States. *Research in Science Education, 50*, 227–251. https://doi.org/10.1007/s11165-017-9687-2

Lestari, H., Ali, M., Sopandi, W., & Wulan, A. R. (2022). The ESD-oriented RADEC model: To improve students' sustainability consciousness in elementary schools. *Pegem Journal of Education and Instruction, 12*(2), 113–122. https://doi.org/10.47750/pegegog.12.02.11

Lestari, H., Rahmawati, I., Ali, M., Sopandi, W., & Wulan, A. R. (2023). An innovative approach to environmental literacy: The sustainable RADEC learning model for elementary schools. *Al Ibtida: Jurnal Pendidikan Guru MI, 10*(2), 189–210. http://dx.doi.org/10.24235/al.ibtida.snj.v10i2.13123

Liana, T., & Sarong, A. (2024). Development of Android-based e-modules in biology learning on water environmental pollution to enhance science literacy. *Jurnal Penelitian Pendidikan IPA, 10*(9), 644–654. https://doi.org/10.29303/jppipa.v10i9.8097

Munkebye, E., & Gericke, N. (2022). Primary school teachers' understanding of critical thinking in the context of education for sustainable development. In B. Puig & M. P. Jiménez-Aleixandre (Eds.), *Critical thinking in biology and environmental education* (pp. xx–xx). Springer. https://doi.org/10.1007/978-3-030-92006-7_14

Nikmah, U., Andriani, V., Zuliastuti, V., Ruhansah, V. I., & Chasanah, U. (2024). Implementation of discovery learning method to improve student learning outcomes in science learning at MI Tarbiyatul Islamiyah Winong. *Darussalam: Scientific Journal of Islamic Education, 1*(2), 213–224. https://doi.org/10.62945/darussalam.v1i2.698

Pertiwi, N. P., Saputro, S., Yamtinah, S., & Kamari, A. (2024). Enhancing critical thinking skills through STEM problem-based contextual learning: An integrated e-module education website with virtual experiments. *Journal of Baltic Science Education, 23*(4), 739–766. https://doi.org/10.33225/jbse/24.23.739

Putri, A. S., & Aznam, N. (2019). The effect of the science web module integrated on batik's local potential towards students' critical thinking and problem solving (thinking skill). *Journal of Science Learning, 2*(3), 92–96. https://doi.org/10.17509/jsl.v2i3.16843

Rico, A., Agirre-Basurko, E., Ruiz-González, A., Palacios-Agundez, I., & Zuazagoitia, D. (2021). Integrating mathematics and science teaching in the context of education for sustainable development: Design and pilot implementation of a teaching-learning sequence about air quality with pre-service primary teachers. *Sustainability, 13*(8), 4500. https://doi.org/10.3390/su13084500

Ristanto, R. H., Kristiani, E., & Lisanti, E. (2022). Flipped classroom–digital game-based learning (FC-DGBL): Enhancing genetics conceptual understanding of students in bilingual programme. *Journal of Turkish Science Education, 19*(1), 332–352. https://doi.org/10.36681/

Rodríguez-Loinaz, G., Ametzaga-Arregi, I., & Palacios-Agundez, I. (2024). ICT tools and citizen science: A pathway to promote science learning and education for sustainable development in schools. *Journal of Biological Education, 58*(3), 609–625. https://doi.org/10.1080/00219266.2022.2092192

Romdhon, J., Masrifah, M., Shiyama, N. M., & Suharyati, H. (2024). Applying constructivist learning theory to enhance student learning outcomes in elementary schools. *International Journal of Sustainable Development & Future Society, 2*(2), 62–69. https://doi.org/10.62157/ijsdfs.v2i2.73

Santa, S., Lathifah, S. S., Aulia, D. N., & Meyradhia, A. G. (2024). Development of a smart module on hydrological cycle based on SDGs as a source of science studies for primary school students. *Jurnal Penelitian Pendidikan IPA, 10*(3), 1492–1499. https://doi.org/10.29303/jppipa.v10i3.6515

Sari, I. P., Rohmani, R., & Nisa, K. (2024). Analysis of the effectiveness of using flipbook-based e-modules in science learning in elementary schools. *International Journal of Recent Educational Research, 5*(6), 1367–1382. https://doi.org/10.46245/ijorer.v5i6.615

Sihombing, R. A., Muslim, M., Rahman, T., & Karimi, A. (2024). Literature study of the e-book based on education for sustainable development (ESD) as the main solution to improving sustainability awareness. *INSECTA: Integrative Science Education and Teaching Activity Journal, 5*(1), 108–120. https://doi.org/10.21154/insecta.v5i1.8616

Sintawati, N. P., & Margunayasa, I. G. (2021). Interactive e-module for science learning content: Validity and feasibility. *International Journal of Elementary Education, 5*(1), 19–29. https://doi.org/10.23887/ijee.v5i1.34281

So, W. W. M., Chen, Y., & Wan, Z. (2019). Multimedia e-learning and self-regulated science learning: A study of primary school learners' experiences and perceptions. *Journal of Science Education and Technology, 28*, 508–522. https://doi.org/10.1007/s10956-019-09782-y

Sormunen, K., Vehmaa, S., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2023). Learning science through a collaborative invention project in primary school. *Disciplinary and Interdisciplinary Science Education Research, 5*(6), 1–15. https://doi.org/10.1186/s43031-023-00074-5

Syafitri, N. F., & Hamdu, G. (2023). Pengembangan e-modul berbasis education for sustainable development untuk kelas IV sekolah dasar. *Jurnal Pendidikan Dasar, 11*(1), 12–25. https://doi.org/10.46368/jpd.v11i1.763

Syahfitri, J., & Safitri, D. (2024). The effect of digital-based interactive modules to improve students' critical thinking skills and learning motivation on biology learning. *Jurnal Penelitian Pendidikan IPA, 10*(5), 2495–2502. https://doi.org/10.29303/jppipa.v10i5.3878

Syahmani, S., Rahmatilah, J., Winarti, A., Kusasi, M., Iriani, R., & Prasetyo, Y. D. (2022). Development of guided inquiry lesson based on ethnoscience e-modules to improve students' problem-solving ability in chemistry class. *Journal of Innovation in Educational and Cultural Research, 3*(4), 670–682. https://doi.org/10.46843/jiecr.v3i4.363

Triyandana, A., Ibrohim, I., Yanuwiyadi, B., Amin, M., & Hajar, M. U. (2024). Strategies to enhance eco-friendly culture and environmental awareness by green curriculum integration in Indonesian elementary science classroom. *International Electronic Journal of Elementary Education, 17*(1), 217–232. https://doi.org/10.26822/iejee.2024.374

Uslan, U., Abdullah, N., Imami, M. K. W., & Aiman, U. (2024). The effectiveness of the local knowledge-based module (LKBM) to improve students' scientific literacy and thinking skills. *Jurnal Pendidikan IPA Indonesia, 13*(1), 147–161. https://doi.org/10.15294/jpii.v13i1.47561

Wardani, R. P., Zahro, K. A., & Alfaroidz, A. S. H. (2024). Integrating Blambangan culture of Banyuwangi into elementary science education: An ethnoscience approach. *International Journal of Elementary Education, 8*(3). https://doi.org/10.23887/ijee.v8i3.84439

Winangun, I. M. A., Suma, K., Subagia, I. W., & Sudiatmika, A. A. I. A. R. (2024). E-modules for basic science and elementary school concepts based on cases in the context of local wisdom. *Revista de Gestão Social e Ambiental, 18*(9), 1–13. https://doi.org/10.24857/rgsa.v18n9-041

Yevira, R. (2023). Development of SETS (science, environment, technology, and society)-based e-modules on environmental pollution materials to increase learning interest and critical thinking ability. *Jurnal Penelitian Pendidikan IPA*. https://doi.org/10.29303/jppipa.v9i8.4229

Zainil, M., Kenedi, A. K., Indrawati, T., & Handrianto, C. (2023). The influence of a STEM-based digital classroom learning model and higher-order thinking skills on the 21st-century skills of elementary school students in Indonesia. *Journal of Education and E-Learning Research, 10*(1), 29–35. https://doi.org/10.20448/jeelr.v10i1.4336

Zhang, J., Shen, X., & Liu, H. (2024). Current situation and training of Chinese elementary school science teachers in the context of education for sustainable development. In H. Fujii & S. K. Lee (Eds.), *Science education for sustainable development in Asia*. Springer. https://doi.org/10.1007/978-981-99-8711-5_16

Matos, J. F., Piedade, J., Freitas, A., Pedro, N., Dorotea, N., Pedro, A., & Galego, C. (2023). Teaching and learning research methodologies in education: A systematic literature review. *Education Sciences*, *13*(2), 173. https://doi.org/10.3390/educsci13020173

Tinoca, L., Piedade, J., Santos, S., Pedro, A., & Gomes, S. (2022). Design-based research in the educational field: A systematic literature review. *Education Sciences*, *12*(6), 410. https://doi.org/10.3390/educsci12060410