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Effectiveness of Climate-Integrated STEM E-Modules on Students' Environmental Awareness

Hana Kesumalia[1]

[1] Universitas Sarjanawiyata Tamansiswa, Yogyakarta, Indonesia

Abstract

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This study aims to analyze the effectiveness of Science, Technology, Engineering, and Mathematics-based e-learning modules integrated with climate change contexts in improving students' competence and environmental awareness. The research employed a Systematic Literature Review of peer-reviewed publications published over the last five years. The findings indicate that the implementation of Science, Technology, Engineering, and Mathematics-based e-modules positively contributes to the development of critical thinking skills, conceptual mastery, and environmental responsibility among students. The integration of sustainability issues and digital technology promotes more contextual, interactive, and participatory learning experiences. Furthermore, Science, Technology, Engineering, and Mathematics e-modules effectively cultivate sustainability-oriented attitudes and environmentally conscious character. Overall, the study highlights that developing Science, Technology, Engineering, and Mathematics-based e-learning modules combined with climate change education represents an innovative strategy to strengthen scientific literacy, foster ecological awareness, and advance a sustainable digital learning framework for future education.

1. Introduction

Climate change has become an increasingly real global challenge in the last two decades. The impact extends to various sectors of life, including education, which is now required to prepare a young generation that is not only academically intelligent but also has ecological awareness and social responsibility towards the environment. One of the educational approaches that is considered effective to answer these challenges is the integration of Science, Technology, Engineering, and Mathematics (STEM) with environmental sustainability and climate change issues. This approach not only equips students with critical thinking and problem-solving skills, but also fosters concern for the sustainability of the earth (Saengkhattiya, 2024).

In the context of 21st century education, the use of digital technology in the learning process is becoming increasingly dominant. The digitalization of education has encouraged the emergence of various innovations, including the development of electronic modules or e-modules that allow students to learn independently, flexibly, and interactively. STEM-based e-modules have great potential in facilitating contextual learning relevant to global issues such as climate change and environmental degradation (Khalid et al., 2024). Through this e-module, students can relate science and technology concepts to real phenomena such as global warming, pollution, and environmental mitigation efforts.

The massive digital transformation in the field of education demands learning that is not only adaptive to technology but also emphasizes the sustainability aspect. The results of a systematic study show that well-designed STEM-based online

learning can increase student engagement and the effectiveness of learning outcomes (Meylani, 2024). In addition, the integration of Education for Sustainable Development (ESD) into the STEM framework strengthens students' understanding of the interconnectedness between technology, the environment, and the global society. Thus, STEM-based e-modules are not only a learning medium, but also a vehicle for building characters to care about the environment.

Previous research has shown that the development of STEM-based interactive digital teaching materials can improve learning outcomes, high-level thinking skills, and students' ecological awareness (Darmawan et al., 2023). This is in line with the findings of Widiyatmoko et al. (2023) who emphasized that STEM technology plays an important role in building students' sustainability skills and resilience skills to global environmental challenges. Project-based and contextual learning encourages students to apply physics and science concepts in solving real-life environmental problems (Silfiyani & Suyatna, 2024).

Furthermore, Prayogi and Verawati (2024) research highlights the effectiveness of the STEAM approach (adding art elements to STEM) in supporting the Sustainable Development Goals (SDGs), especially in the aspects of quality education and action on climate change. This approach not only enriches learning from the cognitive side but also fosters aesthetic appreciation and social empathy for environmental problems. Thus, the integration of STEM-STEAM in e-module-based learning becomes relevant to face the complex challenges of the 21st century.

In practice, the development of STEM-based e-modules needs to pay attention to elements of communication technology and interactivity in order to

answer the needs of the digital generation. Recent research trends show that ICT-based STEM teaching materials are able to increase learning effectiveness and provide a more meaningful learning experience for learners (Ramnarain & Ndlovu, 2023). With the right design, e-modules are not only a means of knowledge transfer, but also a tool to build ecological awareness and an attitude of responsibility towards the environment (Saragih & Tanjung, 2023).

Therefore, the urgency of research on the effectiveness of STEM-based learning e-modules integrated with climate change materials has become very relevant in the post-pandemic era. Through the integration of learning technology, STEM approaches, and sustainability values, education is expected to be able to produce students who have high scientific competence while behaving in an environmentally friendly manner. This research seeks to make an empirical contribution to the development of a holistic and sustainable 21st century learning model, as well as strengthen the direction of education towards an environmentally conscious society that is resilient to global change (Abdurrahman & Dewi Lengkana, 2022).

2. Methods

This study uses a Systematic Literature Review (SLR) approach which aims to identify, analyze, and synthesize various previous studies relevant to the topic of effectiveness of STEM Education-based learning e-modules that are integrated with climate change and environmental awareness issues. The SLR approach was chosen because it is able to provide a comprehensive understanding of the latest research

developments, as well as map trends, research gaps, and scientific contributions that have been made in a certain period of time. Through this method, the research is focused on reviewing the literature published in the period 2020 to 2024 so that the results remain up-to-date and in accordance with the policy direction and dynamics of 21st century education.

The research stage begins with the planning process, namely determining the focus of the study and formulating research questions related to the effectiveness of STEM-based e-modules, the integration of climate change materials, and its impact on students' competence and environmental awareness. Once the focus is set, the next stage is a literature search using academic databases such as Google Scholar, ScienceDirect, SpringerLink, and ResearchGate. The search process was carried out using relevant keywords, such as "STEM Education", "e-learning module", "climate change education", "environmental awareness", and "digital learning". The search results are then filtered based on predetermined inclusion criteria, namely English or Indonesian articles published between 2020–2024, are peer-reviewed, and explicitly discuss the integration of STEM with environmental or sustainability issues.

The next stage is the selection and evaluation process of articles that meet the criteria. Each article is systematically analyzed by considering the research design, implementation context, learning methods, and key outcomes and findings. The collected data is then coded and grouped based on key themes such as the effectiveness of digital learning, the development of interactive e-modules, and the influence of STEM learning on environmental care attitudes. The analysis was

conducted descriptively and thematically to identify consistent patterns of findings among the studies reviewed.

The last stage is the synthesis of the results of the study, which is to summarize various relevant research findings to produce a complete understanding of the effectiveness of STEM e-modules in the context of continuing education. The results of this synthesis are the basis for providing recommendations for the development of innovative learning models, adaptive to digital technology, and oriented towards strengthening ecological awareness in the educational environment.

3. Results and Discussion

The results of this systematic literature review show that the development and implementation of STEM Education-based e-modules that are integrated with the context of climate change have a significant impact on improving learning outcomes, scientific literacy, and environmental awareness of students at various levels of education. Most of the studies analyzed confirm that the integration between STEM approaches and environmental issues not only enriches learning content, but also fosters 21st-century competencies such as the ability to think critically, collaboratively, and reflective of global issues. STEM-based learning that utilizes interactive e-modules is considered to be able to facilitate students to understand scientific concepts through real-life contexts, so that the learning process becomes more meaningful and sustainable (Saengkhattiya, 2024; Darmawan et al., 2023).

Based on the results of the thematic analysis of eleven main articles, three major dominant themes were found, namely: the pedagogical effectiveness of STEM e-modules on improving learning competence, the relevance of integrating climate change issues in science learning, and the contribution of digital technology to student participation and engagement. In the first theme, various studies show that STEM-based e-modules are effective in improving cognitive and affective learning outcomes. This is because the design of the e-module allows for student-centered learning, where students can access virtual materials, simulations, and experiments independently. For example, research by Khalid et al. (2024) confirms that digital learning in STEM strengthens conceptual understanding because it combines science visualization with project-based exploration. With interactive features, e-modules are able to encourage active participation and create an immersive learning experience.

In addition to cognitive effectiveness, the application of STEM e-modules also has an effect on increasing environmental awareness. Some research highlights that when learning materials are contextualized with real issues such as air pollution, global warming, and land degradation, students show increased pro-environmental attitudes and a sense of ecological responsibility. Widiyatmoko et al. (2023) emphasized that learning that instills sustainability values through digital media can build awareness of environmental crises while training students' resilience skills in facing climate uncertainty. These findings are in line with Prayogi and Verawati (2024) who show that the STEAM approach in physics learning can increase

motivation and awareness of the Sustainable Development Goals (SDGs), especially goal 13 on action on climate change.

Meanwhile, the second theme focuses on the integration of climate change issues in the context of STEM learning. Saengkhattiya (2024) found that students who engaged in problem-solving activities related to environmental sustainability issues showed significant improvements in systemic thinking skills and evidence-based decision-making. This is due to the holistic nature of the STEM approach which requires students to combine scientific, technological, and engineering principles in finding solutions to environmental problems. Similar findings were put forward by Abdurrahman and Dewi Lengkana (2022), who designed an interactive e-module with the context of climate change and found a substantial improvement in aspects of scientific literacy and students' reflective thinking skills.

The context of education digitalization also has an important influence on the effectiveness of STEM e-modules. Meylani (2024) explained that designing a good online learning environment in STEM education requires a balance between scientific content, digital collaboration, and authentic learning experiences. E-modules that adopt the principles of the 21st century online learning environment have been proven to increase student participation and retention. Thus, the development of e-modules is not only concerned with the content aspect, but also with the design of the user interface, interactivity, and technological support that suits the needs of modern learners.

In addition, the results of the review show that the use of information and communication technology (ICT) in the development of STEM e-modules has a

positive impact on the effectiveness of learning in various contexts. Ramnarain and Ndlovu (2023) suggest that ICT-based teaching materials that integrate STEM approaches are able to increase student involvement in scientific exploration and optimize the learning outcome evaluation process. The integration of multimedia such as simulations, experimental videos, and digital worksheets in the e-module makes learning more engaging and challenging. In this context, technology serves not only as an aid, but also as a catalyst for pedagogical transformation towards more adaptive and data-driven learning.

Thethematically, the majority of research confirms that the effectiveness of STEM-based e-modules is not only measured through improved academic scores, but also through changes in students' learning behavior and ecological attitudes. The results of Saragih and Tanjung's (2023) research show that the use of STEM e-modules associated with local environmental problems can increase students' empathy for ecological issues and encourage real action in daily life. This strengthens the argument that STEM learning integrated with environmental education serves as a medium for character formation and sustainability awareness, not just a means of scientific knowledge transfer.

Although these results show a positive trend, some limitations have also been identified. Most of the research still focuses on the context of secondary education, so the application of STEM e-modules at the primary and tertiary education levels still needs to be further explored. In addition, many studies use experimental designs of relatively short duration, so the long-term impact on behavioral change and ecological awareness has not been fully measured. Darmawan et al. (2023) highlight

the importance of follow-up research with a longitudinal approach to understand the consistency of the effects of e-modules on the development of scientific competence and students' environmental care attitudes in the long term.

Several studies also emphasized the importance of teacher training in implementing STEM-based e-modules so that they can be implemented effectively. Listiana et al. (2023) emphasized that teacher capacity building through digital module development training is a key factor in the successful implementation of innovative and sustainable STEM learning. Teachers need to understand the basic principles of digital learning design, interactive media management, and strategies for integrating sustainability values in teaching and learning activities. Thus, improving the professionalism of educators is an integral part of efforts to strengthen the implementation of STEM Education in the digital era.

In terms of learning outcomes, the research of Widiyatmoko et al. (2023) underlines that the development of STEM e-modules that prioritize cross-disciplinary collaboration is able to hone high-level thinking skills such as analysis, evaluation, and creation. Project-based learning packaged in e-modules provides space for students to design solutions to environmental problems with appropriate scientific and technological approaches. This strategy has been proven to improve problem-solving skills while fostering students' intrinsic motivation to learn independently.

Based on the overall results, the results of the study show that STEM-based e-modules that are integrated with climate change issues make a real contribution to improving the quality of learning and strengthening sustainability values in

education. The integration between scientific approaches and environmental contexts creates a synergy between students' cognition and affection. With the support of digital technology, learning becomes more adaptive, contextual, and relevant to global challenges. Therefore, the development of STEM e-modules not only needs to be developed from the technical and design side, but also from the pedagogical side in order to really be able to foster ecological awareness of the younger generation. In the long term, this learning model is expected to contribute to the formation of a scientifically knowledgeable, socially responsible, and planet-oriented society.

4. Conclusion

Based on the results of the study conducted through the Systematic Literature Review (SLR) approach, it can be concluded that STEM Education-based e-modules that are integrated with climate change issues have proven to be effective in improving students' knowledge competencies, critical thinking skills, and environmental awareness. E-module-based learning provides high flexibility and independence of learning, while being able to provide contextual learning experiences through the integration of digital technology and sustainability issues. The interactive, applicative, and project-oriented design of e-modules encourages students to relate scientific concepts to real-life phenomena, so that learning becomes more meaningful and sustainable.

In addition to improving cognitive aspects, STEM e-modules also play an important role in fostering an attitude of caring for the environment and shaping the

character of students who are aware of the importance of planet sustainability. The use of digital technology in the development of e-modules allows for a more interesting, participatory, and relevant learning process to the needs of the 21st century generation. Therefore, the development of STEM-based e-modules that integrate the context of climate change needs to be encouraged and expanded at various levels of education in order to build an adaptive, innovative, and sustainable development-oriented learning system.

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