



DESIGN OF A STEM-BASED E-MODULE AS A SUSTAINABLE EDUCATION APPROACH TO ENHANCE CRITICAL REASONING SKILLS IN ELEMENTARY SCHOOL

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Abstract

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This study aimed to develop and validate a STEAM-based e-module titled “Bersama Selamatkan Keasrian Bumi” (BERSAKSI) to enhance elementary school students' critical reasoning skills within sustainable education. Using the Research and Development (R&D) 4D model-Define, Design, Develop, and Disseminate-the e-module was meticulously crafted and evaluated by experts in content, media, and language, achieving excellent validation ratings (91.6%, 93.7%, and 93.7%, respectively). The module effectively integrated science, technology, engineering, arts, and mathematics to provide a multidisciplinary and interactive learning experience, fostering critical reasoning and ecological awareness. The findings demonstrated alignment with the Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education) and SDG 13 (Climate Action), by promoting quality education and environmental awareness. While the module demonstrated significant potential in enhancing students' skills and awareness, challenges such as teacher training and infrastructure readiness were identified as critical factors for effective implementation. This research underscores the importance of innovative educational tools in supporting sustainable education and offers a pathway for future studies to explore broader applications and long-term impacts. These findings suggest that the module can inform curriculum design and teacher training for STEAM–SDG integration; however, the evidence is based on expert validation and limited piloting, so broader, longitudinal classroom trials are needed to test its impact and scalability.

Keywords: Critical Reasoning; E-Module; Elementary School; STEAM, SDGs

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INTRODUCTION

Climate change and environmental degradation have become pressing global issues, affecting various aspects of human life and ecosystems worldwide (Hassan et al., 2023). These phenomena not only pose significant ecological impacts but also threaten the social and economic well-being of communities (Ricoy & Sánchez-Martínez, 2022).

According to the Intergovernmental Panel on Climate Change (IPCC) report in 2023, increasing global temperatures, melting polar ice caps, and increasing frequency and intensity of natural disasters are clear indicators of our environmental crisis (Trudeau, 2024). In this context, education becomes crucial to mitigate and adapt to climate change (Whitburn et al., 2023).

As the largest archipelago in the world with abundant biodiversity, Indonesia faces serious environmental conservation challenges (Zulaeha, 2019). Deforestation, water and air pollution, and loss of natural habitats threaten Earth's beauty (Guo et al., 2022). Data from the Ministry of Environment and Forestry (KLHK) for 2024 shows that Indonesia's deforestation rate is still high despite various conservation efforts (Nofrizal et al., 2024). This condition demands strategic action in education to form a young generation with ecological awareness and critical reasoning skills in dealing with environmental issues (Yusnaldi, 2023).

Within the framework of the Sustainable Development Goals (SDGs) adopted by the United Nations, education has a central role, particularly SDG 4 on Quality Education and SDG 13 on Climate Action (Manikutty et al., 2023). SDG 4 emphasizes the importance of inclusive and quality education for all, focusing on cognitive aspects and developing critical and creative thinking skills (Manikutty et al., 2023). Meanwhile, SDG 13 encourages immediate action to address climate change and its impacts (Rajan et al., 2022). Integrating these two goals in Indonesia's education system is essential to create synergy between improving the quality of education and environmental conservation efforts (Kristanti & Sujana, 2022).

At the national level, implementing the STEAM-based education approach (Science, Technology, Engineering, Arts, Mathematics) still faces various obstacles (Utaminingsih, Ellianawati, et al., 2023). The existing curriculum often does not fully accommodate interactive and contextual learning methods needed to develop students' critical reasoning dimension (Suminar, 2022). In this research area, especially in elementary schools, it was found that grade V students' critical reasoning skills are still limited in understanding and applying environmental concepts. This is exacerbated by the limitations of innovative educational resources, such as STEAM-based e-modules, which can be an effective medium for improving critical thinking skills (Lu et al., 2022).

In addition, one of the main triggering factors for this research is teachers' low use of technology in developing teaching materials (Sari & Sutihat, 2022). Many teachers in primary schools still rely on traditional learning methods and do not utilize information and communication technology (ICT) in the learning process (Sari & Sutihat, 2022). Teachers' inability or lack of skills in developing and integrating technology in teaching materials results in limitations in delivering engaging and interactive materials (Utaminingsih, Ellianawati, et al., 2024). This is a significant obstacle in developing students' critical reasoning skills (Nursalam & Suardi, 2022), especially in environmental conservation, which requires a dynamic and problem-based learning approach.

As an early-level educational institution, elementary school has a strategic role in shaping the foundation of students' thinking (Parinduri et al., 2022). However, in many elementary schools in Indonesia, there is a significant gap between the implemented curriculum and the absolute need to develop critical reasoning skills through the STEAM approach (Triwahyuningtyas et al., 2020). This gap is evident in the low participation of students in activities that encourage analytical thinking and creative solutions to environmental problems (Salsabila & Syaban, 2022). In addition, limited access to modern educational technology, such as e-modules integrated with STEAM principles, further exacerbates this situation (Utaminingsih & Ellianawati, 2025).

State-of-the-art and prior research. Recent scholarship shows a clear shift toward STEAM for sustainability in primary education, with reviews noting momentum but also uneven depth in sustainability-infused STEAM designs for young learners (Rantanen et al., 2025). Empirical and design studies report that digital modules/ICT and project-based STEAM can support higher-order thinking (critical/creative) and environmental literacy in elementary settings, including Indonesian contexts (Utaminingsih & Ellianawati, 2025). However, results hinge on curriculum fit and teacher readiness (Syahrir et al., 2024). A recent Indonesian review and field studies also underscore persistent challenges in ICT integration and teacher capacity at the primary level, which shape the quality of enactment in real classrooms (Salama et al., 2025). At the same time, critical thinking/critical reasoning assessment at the primary level is being advanced. However, it remains variably specified and not consistently embedded in sustainability-oriented STEAM packages, as mapped in a 2025 evidence synthesis and a new instrument-development study on elementary Earth-science topics. Consequently, few works delivers a single, classroom-ready e-module that explicitly aligns STEAM with SDG targets for upper-elementary learners and comes with clear critical-reasoning tasks/rubrics and validation. This study addresses that gap by developing and validating the BERSAKSI e-module with SDG-4/13 alignment and explicit critical-reasoning scaffolds to inform curriculum and teacher (Purwanti et al., 2024).

This problem gap indicates an urgent need to develop and implement a STEAM-based e-module focusing on "Save the Earth's Beauty." This e-module is expected to be an interactive and contextual learning tool that can train the critical reasoning dimension of grade V elementary school students in understanding environmental issues. Thus, students gain theoretical knowledge and practical critical and creative thinking skills to solve real problems their environment faces (Kristanti & Sujana, 2022).

The urgency of this research lies in the need to provide relevant and innovative educational solutions in the context of environmental conservation. The development of STEAM-based e-modules directed at training the critical reasoning dimension is expected to improve the quality of educators (Utaminingsih, Anwar, et al., 2024). This research aims to develop a STEAM-based e-module that can train the critical reasoning dimension of grade V elementary school students through the topic "Save the Earth's Naturalness" and evaluate the module's effectiveness in improving students' critical thinking skills. This research also aims to identify the constraints and potentials of integrating the STEAM approach into the elementary school curriculum and to provide strategic recommendations for developing educational policies that support environmental conservation through quality education. Thus, this research is expected to contribute to improving the quality of education at the elementary school level and to collective efforts in maintaining and preserving the beauty of the Earth. This research aligns with global and national agendas in addressing the challenges of climate change and environmental degradation through innovative and sustainable education.

METHODS

The Research and Development (R&D) method, using the 4D model (Define, Design, Develop, Disseminate) (Thiagarajan et al., 1974), served as a robust framework in this study for the development of a STEAM-based e-module titled "Bersama Selamatkan Keasrian Bumi" (BERSAKSI). The module aims to improve critical reasoning skills among elementary school students, meeting curriculum needs and

broader educational objectives. Each stage in the 4D model was carefully implemented to ensure that the e-module meets high standards of relevance, quality, and usability.

This research demonstrates the efficacy of the 4D model in addressing educational challenges by developing digital learning resources. STEAM-based e-modules successfully bridge the gap between traditional teaching methods and modern digital approaches. By integrating multimedia and interactive elements, the module enhances student engagement and fosters critical reasoning skills essential for facing complex global challenges. The interdisciplinary design ensures that students experience a holistic learning process that incorporates scientific inquiry, technological innovation, and creative problem-solving (Alim et al., 2025). Tools such as Canva and Quizizz exemplify how technology can create dynamic and effective educational materials. A detailed flowchart of the 4D model process is presented in Figure 1.

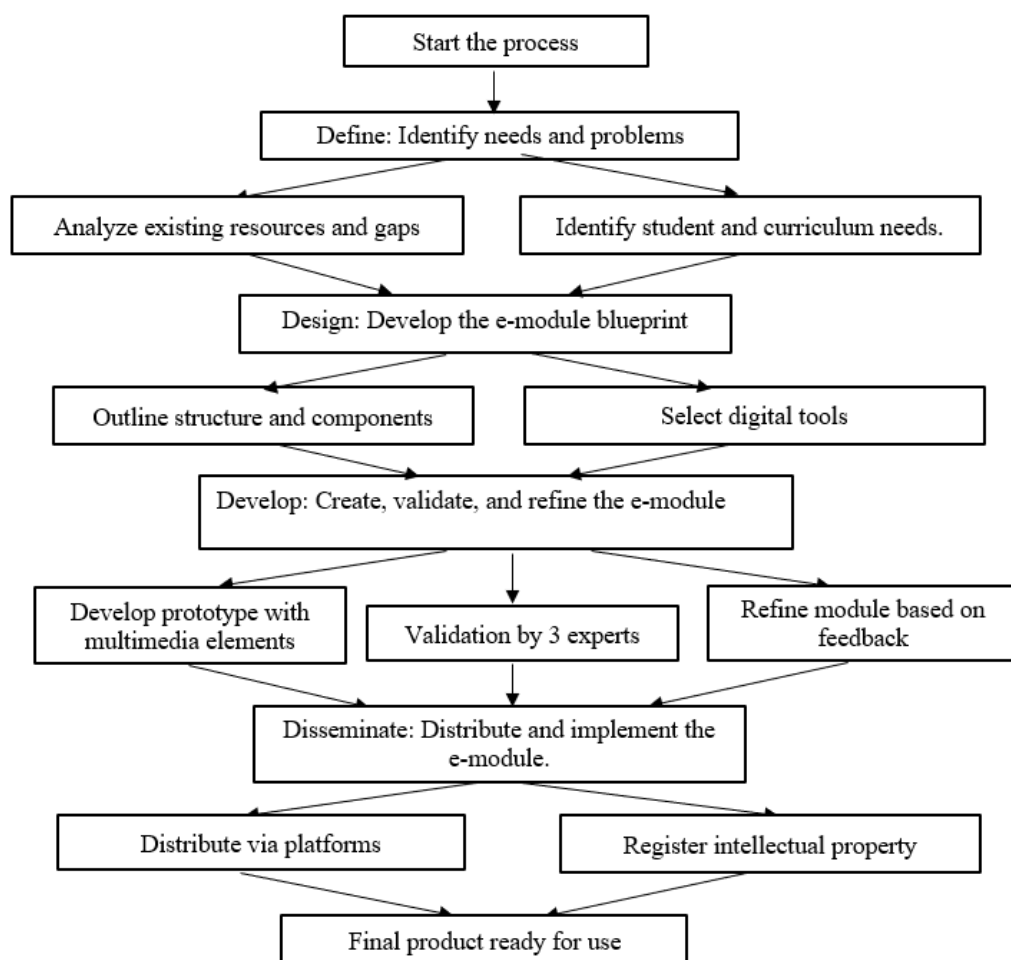


Figure 1.
 Flowchart of the 4D Model

Define Phase: Identifying Needs and Problems

The Define phase established the foundation for the development process by identifying problems and analyzing needs within the educational setting. This study began with field research at Sekolah Dasar Negeri 1 Ngawen, where interviews and observations revealed critical gaps in teaching materials. Teachers relied predominantly

on government-issued textbooks and had limited exposure to digital tools or innovative resources. This issue was particularly significant in the context of the new “Kurikulum Merdeka,” where topics such as “saving the earth from environmental damage” required updated and engaging materials.

Moreover, the analysis highlighted that students' critical reasoning skills were underdeveloped. These skills are essential to the Pancasila Student Profile, preparing students to analyze, evaluate, and respond effectively to real-world challenges such as environmental sustainability. These findings highlighted the need for a digital instructional module to integrate STEAM principles while fostering critical reasoning.

Design Phase: Structuring the Module

The Design phase focused on creating a comprehensive blueprint for the e-module, ensuring it was pedagogically sound and engaging for students. The module's structure was developed to include several key components: (1) introduction is a visually appealing cover and an engaging foreword to introduce the topic and objectives; (2) learning objectives is an articulated outcomes aligned with critical reasoning dimensions; (3) content sections is lessons enriched with multimedia elements, including animations, images, and videos, to provide an immersive learning experience; (4) interactive exercises is an activity and quizzes integrated through platforms like Quizizz to reinforce learning outcomes, and (5) navigation tools is an intuitive interactive menu to enhance accessibility and user experience. The design emphasized alignment with the STEAM approach, combining science, technology, engineering, arts, and mathematics to provide a holistic and interdisciplinary learning experience. Tools such as Canva and Heyzine Flipbook created a visually dynamic and user-friendly module.

Develop Phase: Creating, Validating, and Refining the Module

The development phase involved the creation, validation, and iterative refinement of the e-module. The initial prototype was structured around three key sessions: (1) earth's changes: Addressing natural disasters such as tectonic and volcanic earthquakes and tsunamis, focusing on their causes and impacts; (2) human activity and environmental damage: Encouraging students to evaluate the effects of human behavior on environmental sustainability; and (3) interactive evaluations: Including quizzes and exercises designed to assess and enhance students' critical reasoning abilities.

The e-module underwent a rigorous validation process involving three experts for each domain content, media, and language. Content Experts assessed the material's scientific accuracy and curriculum alignment, ensuring the module addressed educational standards. Media Experts evaluated the design, interactivity, and accessibility, focusing on the user experience and the effectiveness of multimedia elements. Language Experts reviewed the linguistic clarity, grammar, and appropriateness for the target audience, ensuring that the text was comprehensible and engaging. The assessment results are used as a reference for product validity using Equation 1 (Utaminingsih, Raharjo, et al., 2023).

$$P = \frac{F}{n} \times 100\% \quad (1)$$

Description:

P = Final score

F = Score obtained

n = Highest score

The validation results were then interpreted in four criteria presented in Table 1.

Table 1.
 Product Feasibility Category (Rofiyadi & Handayani, 2021)


Achievement Level	Criterion
85,01%-100%	Very good
70,01%-85%	Good
50,01%-70%	Fair
0-50%	Not Good

RESULTS & DISCUSSION

Results

This research and development resulted in the e-module "Bersama Selamatkan Keasrian Bumi" (BERSAKSI), which can be accessed in <https://heyzine.com/flip-book/4a1b4082d1.html> and its evaluation in: <https://quizizz.com/join/quiz/65bb20992db4ea22d033289b/start>. A brief overview of the e-module is presented in Table 2.

Table 2.
 Brief Overview of E-Module

Part	Development Results
Cover	

Title and Preface



Menu



Learning Objectives and Outcomes



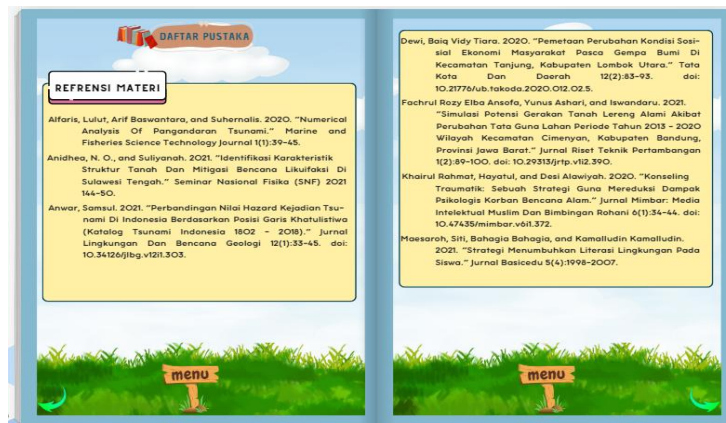
Material



Evaluation



Info



Quiz on
 Quizizz at the
 link



The e-module was delivered in three meetings. The list of activities of each meeting is presented in Table 3.

Table 3.
 Activity List of Each Meeting

Meeting	Topic	Critical Reasoning Dimension
I	1. Causes and Impacts of Earth Change 2. Earthquake Tectonic	Element: a. Acquire and process information and ideas

II	1. Volcanic Earthquakes 2. Tsunami	a. Reflecting and evaluating reasoning b. Analyze and evaluate reasoning
III	1. Human Activities against Environmental Damage 2. Practice Questions Connected with <i>Quizizz</i>	a. Acquire and process information and ideas b. Reflecting and evaluating reasoning c. Analyze and evaluate reasoning

"BERSAKSI" e-module It is interactive, allowing for easy learning content transition because it can accommodate audiovisual media and is equipped with practice and evaluation questions. This makes it easier for students to obtain information, analyze, reflect, and reason. This means that in each of their meetings, e-modules train critical reasoning elements. The findings are in line with the results of the study (Utaminingsih, Raharjo, et al., 2023), e-module-based STEAM can improve the critical reasoning dimension. It is also supported by (Rahmawati et al., 2022) Learning media that display images, sounds, and audiovisuals can increase the dimension of critical reasoning.

The results of the e-module validation of the validation of material, media, and language experts are presented in Table 4 to Table 4.

Table 4.
Material Expert Validation Results

Point	Score
1	4
2	4
3	4
4	3
5	3
6	3
7	4
8	4
9	4
10	3
11	4
12	4
Total Score	44
Percentage	91,6%
Criterion	Excellent

Table 5.
Media Expert Validation Results

Point	Score
1	4
2	4
3	3
4	4
5	4
6	4
7	3
8	3
9	4
10	4

11	4
12	4
Total Score	45
Percentage	93,7%
Criterion	Excellent

Table 6.
Linguist Validation Results

Point	Score
1	3
2	4
3	4
4	4
5	3
6	4
7	4
8	3
9	4
10	3
11	4
12	4
Total Score	45
Percentage	93,7%
Criterion	Excellent

The results of the validity of all aspects are presented in Table 7.


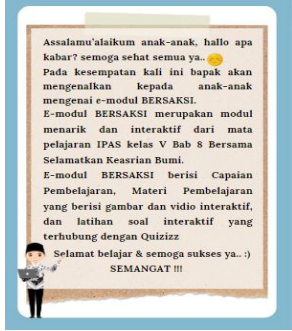
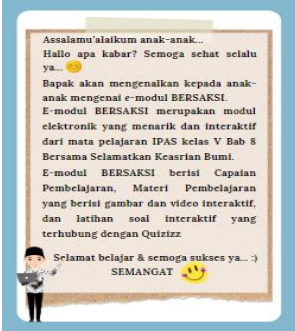




Table 7.

Results of Validation of All Aspects

Aspects	Value
Material	91,6%
Media	93,7%
Language	93,7%
Total Score	93%
Criterion	Excellent

Table 7 shows that viewed from all aspects, e-The "Testify" module meets the criteria of "excellent". E-modules with similar topics have also been developed by (Salsabila & Syaban, 2022), obtained the "excellent" criterion with a percentage of 84.43%. E-modules must be declared "valid" and "excellent" by experts to be suitable for use in learning (Noroozi & Mulder, 2017). Violadini & Mustika (2021) added, before e-modules used, should be declared "valid" according to improvements from experts, so that students will be interested in using e-modules. Decent and interesting e-module will motivate students to continue to seek out about the continuation of the knowledge being studied (Seruni et al., 2020) that leads students to the achievement of learning objectives (Asri & Dwiningsih, 2022). This shows that e-The "Witness" module is worth disseminating. Validation experts in addition to giving assessments also provide suggestions for improvement e-modules presented in Table 8.

Table 8.
Improvements and Suggestions

Expert Validation	Before the Revision	After the Revision	Information
Material			Materials are separated for easy reading
Media			The exclamation mark was replaced with an emoticon to make it more friendly
			Fix the letters to make them legible and attractive
Language			New full name acronym

E-modules that have been repaired and declared "feasible" are then registered with copyright to the Ministry of Law and Human Rights and disseminated to the www.staimuhblora.ac.id website and to the Blora Elementary School Teacher Working Group.

Discussion

The Effectiveness of STEAM-Based E-Modules in Enhancing Critical Thinking Skills

The study demonstrated that developing STEAM-based e-modules significantly improved elementary students' critical thinking skills. Validation results from experts indicated that the e-modules achieved excellent ratings in terms of content (91.6%), media (93.7%), and language (93.7%). These high scores reflected the well-designed nature of the e-modules, which were aligned with the curriculum and accessible and engaging for students. The e-modules provided a multidisciplinary, holistic, and contextually relevant learning experience by integrating science, technology, engineering, arts, and mathematics.

These findings were consistent with previous studies, such as Khasanah et al. (2022), which highlighted the effectiveness of STEAM approaches in enhancing students' analytical and creative skills. Similarly, Syahroni et al. (2016) found that interactive technology in education positively impacted students' engagement, conceptual understanding, and collaborative skills. However, challenges in implementation were also evident. Dhillon & Murray (2021) emphasized that the effectiveness of technology in education heavily depended on teachers' preparedness and the availability of infrastructure. In this context, adequate training and support for teachers were crucial to ensure the successful integration of STEAM-based e-modules in classrooms (Ilmi et al., 2021). Additionally, access to digital devices and stable internet connectivity emerged as essential prerequisites, especially in rural and remote areas (Hosman et al., 2020).

This research underscored the importance of aligning technological innovations with the demands of contextual learning. The STEAM-based e-modules equipped students with tools to think critically, evaluate information, and propose creative solutions to real-world problems such as environmental preservation (Salsabila & Syaban, 2022). Thus, e-modules served as educational tools and mechanisms to effectively empower students to address global challenges (Sari & Sutihat, 2022).

Contributions to the SDGs through Sustainable Education

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Contributions to the SDGs through Sustainable Education

The findings of this research strongly aligned with the global Sustainable Development Goals (SDGs), particularly SDG 4 on Quality Education and SDG 13 on Climate Action. By providing innovative and contextually relevant e-modules, the study contributed to SDG 4.7, which aims to ensure that learners acquire the knowledge and skills needed to support sustainable development (Tarigan et al., 2023). The STEAM-based e-modules facilitated academic understanding and instilled environmental awareness through problem-based learning approaches (Diana & Zulherman, 2024).

The topics covered in the e-modules, such as climate change and environmental preservation, resonated with the objectives of SDG 13 (Wagner & Pramling Samuelsson, 2019). By engaging students in critical analyses of global issues like climate change, the e-modules encouraged them to propose actionable solutions (Runyowa & Fourie, 2021). This approach was particularly vital as the younger generation plays a pivotal role in addressing climate challenges (Membrillo-Hernández et al., 2023).

Furthermore, the STEAM approach developed 21st-century skills, including critical thinking, creativity, communication, and collaboration (Milara et al., 2020). These skills are essential for preparing individuals to navigate the complexities of modern global challenges, particularly those related to environmental issues (Field, 2022). The research demonstrated that STEAM-based education could strategically integrate quality education with climate action, fostering academic excellence and environmental stewardship (Kumar et al., 2023).

At the national level, the findings were highly relevant to Indonesia's efforts to improve education quality and cultivate environmental awareness among young learners (Hassan et al., 2023). As a country with immense biodiversity, Indonesia faces significant challenges in ensuring environmental sustainability (Subeno et al., 2022). By engaging students early on through interactive and contextualized learning, the STEAM-based e-modules prepared the younger generation with the intellectual and moral capacity to act as change agents in conserving the Earth's natural resources (Utaminingsih & Ellianawati, 2025).

This study also highlighted the importance of synergizing technological innovations with educational policies. Government and institutional support in providing teacher training and ensuring access to digital infrastructure were key to the widespread adoption of STEAM-based e-modules (Robiah et al., 2025). Consequently, the e-modules represented an educational innovation and a strategic effort to align quality education with sustainable development, as envisioned by the SDGs. Overall, this research contributed to educational literature and practice by offering concrete solutions to

improve elementary education through STEAM approaches. Moreover, it provided a foundation for future studies to explore broader applications of STEAM-based e-modules and assess their long-term impacts on student learning and environmental awareness.

CONCLUSION

The study developed and validated the STEAM-based e-module Together Save the Beauty of the Earth (BERSAKSI) and found preliminary evidence that it enhanced elementary students' critical reasoning, with excellent expert ratings for content (91.6%), media (93.7%), and language (93.7%). Purposeful alignment with SDG 4 (Quality Education) and SDG 13 (Climate Action) provides classroom-ready tasks and rubrics that connect sustainability themes to integrated learning in science, technology, engineering, arts, and mathematics. The findings indicated practical value for curriculum design and teacher professional development to embed STEAM–SDG competencies; however, the evidence is based mainly on expert appraisal and limited piloting, which necessitated broader, longitudinal classroom trials across diverse schools paired with teacher training and infrastructure support to establish effectiveness, equity, and scalability. Future work should examine learning gains using controlled or quasi-experimental designs, document implementation fidelity, and refine professional development models and digital access strategies. Overall, BERSAKSI offered a validated, SDG-aligned pathway to strengthen critical reasoning in sustainability education and a foundation for policy and school-level adoption.

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