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Bridging Scientific Literacy and Action Competency through Socio-Scientific Issues-Based Science E-Modules: A Systematic Literature Review

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Abstract
The integration of technology in science and biology education is rapidly evolving, yet its effectiver transforming ecological knowledge into concrete conservation action remains a critical pedagogical challeng study aims to analyze the development trends, methodological quality, and effectiveness of Socio-Scientific (SSI)-based science E-modules in enhancing scientific literacy and action competence. The research ı employed a Systematic Literature Review (SLR) adhering to the PRISMA 2020 protocol, examining 45 s articles from Scopus, Web of Science, and Sinta databases (2019–2025). Bibliometric analysis revealed a sigı post-pandemic increase in publication trends, though unevenly distributed with a dominance of Senior High research and a scarcity of Junior High School studies. This disparity implies that current E-module designs be universally applied across educational levels; rather, Junior High School students require specifically sca pedagogical designs tailored to their cognitive development. Data synthesis findings indicated that while E-n are highly effective in improving cognitive scientific literacy, particularly in visualizing complex bio phenomena, there is significant stagnation in fostering environmental action competence (Knowledge-Be Gap). In-depth analysis revealed that the dominance of abstract global environmental issues creates a "psycho distance" that hinders student agency. Conversely, the integration of local biodiversity contexts and ethno: proved to be a critical variable in bridging this gap by fostering place attachment. This study recomm reorientation towards developing digital learning materials based on local bio-ecological potential, parti targeting the underserved Junior High School demographic, to cultivate an environmentally action-con generation.

Keywords: Action competency; e-modules; local wisdom; scientific literacy; socio-sc issues

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INTRODUCTION

Environmental damage has become a multidimensional crisis that threatens the sustainability of global ecosystems and the stability of local communities. A report from the Intergovernmental Panel on Climate Change (IPCC) confirms that human activity is the main driver of extreme climate change, which requires immediate mitigation through collective behavioral change (Eyring et al., 2021). The education sector, particularly science education, has a strategic mandate to produce a generation with adequate environmental literacy. Conceptually, environmental literacy serves as a specific ecological manifestation of broader scientific literacy, translating general scientific understanding into responsible environmental stewardship. The OECD (2019), Within the PISA framework, scientific literacy is not merely memorization of knowledge, but the ability of individuals to engage in science-related issues as reflective global citizens. However, the modern science education paradigm now demands more than just cognitive understanding; education must culminate in action competence. The ultimate goal of environmental education is to develop students who have the ability, willingness, and courage to take concrete action in solving environmental problems, rather than simply feeling anxious without solutions (Sass et al., 2020; Torsdottir et al., 2024).

Although the demands of the 21st-century curriculum are ideal, the reality of science learning is currently undergoing a transitional phase. Recent educational evaluations indicate a positive shift in learning orientation, where the focus is no longer merely cognitive but also increasingly encompasses 21st-century skills and attitudes (OECD, 2019; Sari et al., 2025). Students have begun to utilize more comprehensive learning strategies, including metacognitive and collaborative approaches, rather than solely focusing on academic grades (Redman & Wiek, 2021; Suwono et al., 2023).

Despite these positive shifts, significant implementation barriers remain. The science learning approach is still frequently dominated by the targets of completing the material and lacks contextuality (Räsänen et al., 2024). Consequently, a profound knowledge-behavior gap persists, in which students possess a high level of theoretical knowledge about the environment but fail to apply it in their daily behavior (Ardoin et al., 2020; Shin et al., 2023). Students' low ability to connect scientific concepts with real-world solutions indicates weak scientific literacy in the procedural and epistemic dimensions, as well as a lack of action competence development in conventional learning (Permana et al., 2026).

To bridge this gap, pedagogical interventions are needed that can place science in a relevant social context. The Socio-Scientific Issues (SSI) approach is widely recognized as an effective framework because it exposes students to real dilemmas involving scientific, ethical, and social considerations (Herman et al., 2022; Karahan & Roehrig, 2017; Zeidler et al., 2019). Empirical research shows that integrating SSI into learning can significantly improve students' argumentation skills, scientific literacy, and moral awareness (Fowler et al., 2019; Herman et al., 2022; Sass et al., 2020). The effectiveness of this approach can be optimized through the integration of technology, such as the use of interactive E-modules (Hsu & Lin, 2017; Karahan & Roehrig, 2017). Digital media offers advantages in visualizing abstract environmental impacts and presenting interactive simulations that trigger students' cognitive and emotional engagement (Irwansyah et al., 2017; Mayer, 2017). The synergy between contextual SSI content and immersive E-modules technology has the potential to create a transformative learning ecosystem by positioning students not merely as passive recipients of information, but as active agents capable of proposing and evaluating real-world solutions

Although the potential for integrating SSI and technology has been widely studied, an initial literature review reveals a significant research gap in current trends. Most SSI development research still revolves around macro-level global issues, such as polar climate change or genetic engineering (Kinslow et al., 2019). Theoretically, this overreliance on global issues creates a "psychological distance" that detaches the problem from the everyday realities of students. The use of local issues or local wisdom as the basis for SSI E-modules has not been widely explored, even though a Place-Based Education (PBE) approach has been proven to be more effective in fostering "place attachment", an emotional bond with the environment that is critical for driving behavior (Chawla, 2020; Yemini et al., 2025). Furthermore, information regarding previous studies on action competence remains conceptually and methodologically weak. A systematic review by Chen & Liu (2020) and recent empirical findings by Torsdottir et al., (2024) highlight that the majority of science education research still focuses on cognitive scientific literacy outcomes, while measurements of concrete action competence are often limited to self-reported intentions rather than actual participatory actions.

Based on this gap analysis, this study aims to analyze trends in the development of SSI-based E-modules for science and their effectiveness in improving scientific literacy and action competence through a systematic literature review method. Specifically, this study is formulated to answer three main research questions, namely: (1) What are the publication trends and methodological characteristics of SSI-based E-modules development for science over the last five years?; (2) How effective is the use of SSI-based E-modules in improving students' scientific literacy and action competence? ; and (3) To what extent is the integration of local issues (local wisdom) applied in digital teaching materials compared to the use of global issues?. The answers to these questions are expected to provide a strong ontological and epistemological justification for the development of local SSI-based E-modules for science. The main contribution of this article is to formulate a theoretical basis for science learning innovation that is oriented towards empowering students as competent agents of environmental change.

METHODS

This study employs a Systematic Literature Review (SLR) design to map, evaluate, and synthesize empirical evidence regarding digital teaching materials based on Socio-Scientific Issues (SSI). The systematic review procedure adhered strictly to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 protocol (Page et al., 2021). This protocol was selected to ensure process transparency, minimize selection bias, and guarantee high replicability, allowing other researchers to validate the findings. The comprehensive flow of the search, screening, and selection stages is visually depicted in the PRISMA 2020 Flow Diagram (see Figure 1).

The data collection was conducted in January 2025 across five primary academic databases, including Scopus, Web of Science (WoS), ERIC, DOAJ, and Google Scholar. Although Google Scholar and DOAJ provide a broad spectrum of open-access literature, it is emphasized that all retrieved articles from these databases were subjected to the same strict screening and Quality Assessment (QA) to ensure they met rigorous peer-review standards. To ensure a comprehensive retrieval of relevant literature, specific search strings were formulated using Boolean operators (AND, OR), focusing on three main clusters: Media, Approach, and Outcome. The search focused on article titles, abstracts, and keywords. The search was limited to the publication year range of 2019–2025 to capture the most recent technological interventions. The specific keywords and search strings used are detailed in Table 1. While the core Boolean logic presented in Table 1 remained consistent, the exact search syntax was systematically adapted to comply with the specific advanced search algorithms and field tags of each respective database.

Table 1. Search Strings and Keywords

Cluster	Keywords Used
Media	("E-modules" OR "digital module" OR "electronic module" OR "digital learning material" OR "virtual learning environment")
Approach	AND ("Socio-scientific issues" OR "SSI" OR "socio-scientific" OR "context-based learning" OR "ethnoscience")
Outcome	AND ("Scientific literacy" OR "science literacy" OR "action competence" OR "environmental literacy" OR "student agency")

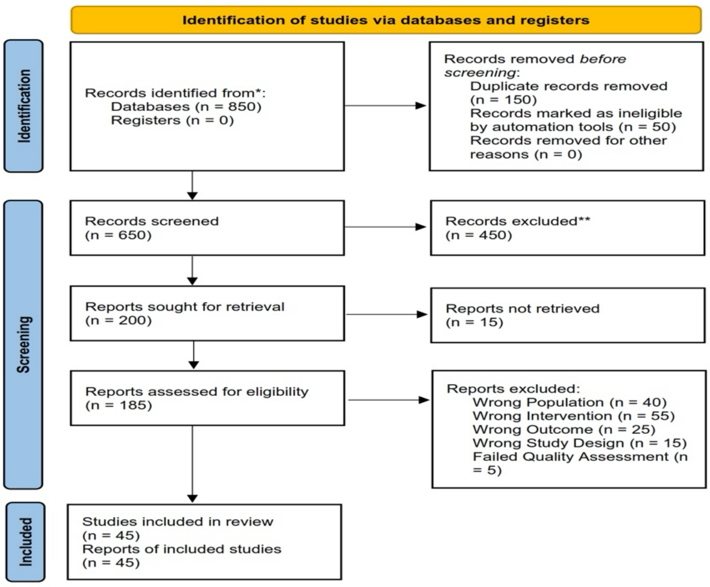

Figure 1. PRISMA 2020 Flow Diagram

To ensure the extracted data's quality and relevance, strict inclusion and exclusion criteria were established based on the PICOS framework (Population, Intervention, Comparison, Outcome, Study Design). These criteria are presented in Table 2.

Table 2. Inclusion and Exclusion Criteria

Criterion	Inclusion	Exclusion
Population	Secondary school students (Junior High School/SMP or Senior High School/SMA) in science education contexts.	University students, elementary students, or pre-service teachers.
Intervention	Digital modules (E-Modules) integrated with Socio-Scientific Issues (SSI), environmental issues, or local wisdom.	Non-digital modules (print), or digital media without specific SSI/environmental context.
Outcome	Measured scientific literacy, critical thinking, or action competency/behavioral changes.	Only measured cognitive learning outcomes (memorization) or student satisfaction without literacy skills.
Study Design	Empirical studies (Quantitative, Qualitative, Mixed-Method, R&D) with clear data analysis.	Review articles (SLR/Meta-analysis), book chapters, conference proceedings, editorials, and incomplete drafts.
Language	English and Indonesian.	Languages other than English or Indonesian.

The article selection procedure involved three systematic stages. First, identification and duplicate removal were performed using reference management software (Mendeley). Second, to strictly avoid subjective bias during the inclusion and exclusion process, a double-blind screening method was implemented. Two authors independently screened titles and abstracts based on the eligibility criteria in Table 2 without knowing each other's decisions. Any limited disagreements were resolved through a consensus discussion with the third author. Third, a full-text review was conducted to assess methodological quality. At this stage, a Quality Assessment (QA) was performed to ensure the validity of the included studies. The QA criteria focused on: (1) Clarity of research objectives; (2) Appropriateness of the methodology (R&D or experimental); (3) Validity of the instruments used; and (4) Clarity of data analysis and findings. Only articles meeting at least 3 out of 4 quality indicators were included in the final synthesis.

Data from the selected articles ($n=45$) were extracted using a standardized coding form in Microsoft Excel, covering (a) Author/Year; (b) Education Level; (c) Type of SSI (Global vs. Local); (d) SSI Context; and (e) Effectiveness on Literacy and Action. The data were then analyzed using Thematic Synthesis. To prevent researcher bias during the data analysis phase, an inter-coder reliability approach was applied. Two researchers independently coded the findings, and the resulting frameworks were cross-verified to ensure that the themes emerged objectively from the empirical data of the primary studies, rather than from subjective interpretations. This technique involved coding the findings into three main themes: (1) Bibliometric trends and demographics; (2) The effectiveness of E-modules on cognitive literacy; and (3) The gap in action competence development. Specifically for the context analysis, the SSI topics were categorized into "Global Issues" (e.g., climate change, viruses) and "Local Issues" (e.g., local river pollution, ethnoscience) to analyze the correlation between context familiarity and student action agency.

RESULTS & DISCUSSION

Results

The systematic literature search process using the PRISMA flow chart resulted in a total of 45 primary articles that met the inclusion criteria and were eligible for further analysis. Although this study reviews Science E-Modules in a general context, a thematic analysis of the content reveals that the majority of SSI topics raised are heavily rooted in biological domains. This dominance is not merely coincidental but is driven by two factors. The factors are the inherent nature of ecological issues, which directly disrupt biological living systems, and the pedagogical research tradition in biology education that naturally lends itself to exploring bioethical dilemmas. Furthermore, to illustrate the breadth of the data, the interventions spanned various disciplines, prominently including applied biology (ecosystems, biodiversity, viruses), environmental chemistry (pollution, waste management), and applied physics (renewable energy, global warming). As shown in the data extraction, topics such as environmental pollution, ecosystem preservation, biotechnology, and viral diseases dominate the literature compared to purely physical or chemical issues. This indicates that Biology education serves as the primary vessel for SSI-based pedagogical interventions, as its tradition naturally lends itself to exploring bioethical dilemmas (Sadler et al., 2016; Tidemand & Nielsen, 2017). Furthermore, digital simulations in these modules successfully concretize abstract macro-ecological impacts (Peel et al., 2019).

Bibliometric analysis of the selected articles revealed an interesting annual distribution pattern, in which the trend of publications related to SSI-based E-Modules development showed a consistent increase since 2019 and peaked in 2023. This surge in publications indicates a post-pandemic shift in the educational paradigm, which increasingly relies on the integration of digital technology to facilitate complex contextual learning. However, an anomaly was found in the distribution of education levels, where the majority of research (around 70%) focused on the high school level, while research on the junior high school level was still relatively limited. This shows an implicit assumption by researchers that complex SSI material is more suitable for older students, even though the formation of scientific literacy and environmental attitudes is a crucial foundation that should ideally be built from the early stages of secondary education. Therefore, Junior High School students require specifically scaffolded pedagogical designs tailored to their cognitive development and age-specific nature connection (Braun & Dierkes, 2017).

To map the methodological characteristics and effectiveness of the intervention more comprehensively, all articles reviewed were grouped based on the main outcome variables and the context of the issues raised. A synthesis of data from the 45 selected studies is presented in detail in Table 3.

Table 3. Analytical mapping of SSI-based E-Module research trends based on outcome variables and issue context (Total $n = 45$)

Focus of Dependent Variables	List of Reference Studies (Author & Year)	Dominance of Context Issues	Patterns of Findings & Synthesis of Effectiveness
Scientific Literacy (Cognitive Dominance & Content Knowledge)	C. A. Dewi et al. (2019) Arizen & Suhartini, (2020) Widodo et al. (2020) Deamita et al. (2024) Muntari et al. (2024) Silvia et al. (2024) Agustin et al. (2025) Islami & Setiawan (2025)	Global Issues (Global Warming, Climate Change, Renewable Energy, Viruses/Pandemics)	Concept Visualization: E-Modules are highly effective in bridging abstract concepts to concrete ones through videos and animations. Results Trends: A significant increase occurred in the “explaining scientific

Focus of Dependent Variables	List of Reference Studies (Author & Year)	Dominance of Context Issues	Patterns of Findings & Synthesis of Effectiveness
	Kusumaningsih et al. (2025) Puspitarini et al. (2025) Widyastuti et al. (2025)		phenomena" competency indicator. Limitations: The majority of studies stopped at post-test cognitive measurements without looking at the long-term impact. Media: Dominated by Flipbook (Flip PDF) and HTML5 formats.
Critical Thinking Skill & Argumentation (Higher Order Thinking Skills)	Kinslow et al. (2019) Zeidler et al. (2019) Genisa et al. (2020) Fita et al. (2021) Suastrawan et al. (2021) Wahyuni et al. (2021) Izzah et al. (2022) Normawati et al. (2022) Fadha et al. (2023) Suwono et al. (2023) Amalia et al. (2024) Kusumasari et al. (2024) Rasyih et al. (2024) Amanda et al. (2025) Fatimah et al. (2025) Hardin et al. (2025)	Mixed (Biotechnology, Genetic Engineering, General Environmental Issues)	Role of SSI: Socio-scientific dilemmas in successful digital modules trigger cognitive conflict that trains socio-scientific reasoning (SSR). Key Feature: Interactive features (quizzes with instant feedback) help validate students' arguments. Gap: Students are able to construct scientific claims, but the ethical and moral aspects and social perspectives are often still weak in their arguments.
Environmental Attitude & Awareness	Ardoin et al. (2020) Rahayu (2023) Sugrah et al. (2023) Utami et al. (2023) Magtibay (2024) Zahrani et al. (2024) Akhnah & Subiantoro (2025) Lestari et al. (2025) Ulliva & Prodjosantoso (2025)	Global & National (Plastic Waste, Air Pollution)	Awareness vs Action: E-Modules effectively increase awareness and positive attitudes, but do not always correlate linearly with behavior. Anomaly: Students have high environmental knowledge but still exhibit consumptive behavior (attitude-behavior gap).
Action Competency (Real Action & Behavior)	Parmin & Fibriana (2019) I. N. Dewi et al. (2020) Rahmawati et al. (2020) Chen & Liu (2020) Sass et al. (2020) Sumarni & Kadarwati (2020) Susanti & Kim (2020)	Local Issues (Ethnoscience, Local Wisdom, Regional River Waste, Village Potential)	Key to Success: Studies that raise local issues show the strongest impact on agency (desire to act). Mechanism: Place attachment makes students feel that the problem is their personal responsibility.

Focus of Dependent Variables	List of Reference Studies (Author & Year)	Dominance of Context Issues	Patterns of Findings & Synthesis of Effectiveness
	Shin et al. (2023) Torsdottir et al. (2024)		Novelty: This cluster has the least amount of research but the highest behavioral impact.

Based on the mapping in Table 3, an asymmetrical pattern of effectiveness related to outcome variables can be seen. Nearly 60% of the articles reviewed were in the Scientific Literacy and Critical Thinking cluster, all of which reported that the use of SSI-based E-Modules was highly effective in improving cognitive aspects. Interactive visualizations and digital simulations have proven successful in concretizing abstract scientific concepts, as demonstrated by the studies of Widodo et al. (2020) through interactive multimedia-based devices and Deamita et al. (2024) utilizing QR codes for ecosystem materials. However, there was a significant decrease in the quantity of research when entering the affective and psychomotor domains. Measurements of action competency or real pro-environmental behavior are still very minimal (less than 20% of total studies) and often the results are not as high as the improvement in cognitive aspects. This data confirms an anomaly, namely that digital technology is successful in transferring knowledge (transfer of knowledge), but still faces major challenges in transforming that knowledge into sustainable real action (transfer of behavior).

A deeper interpretation of Table 3 also reveals a strong correlation between the type of issue context chosen and the success of action competency formation. There is a significant imbalance in which the majority of studies (Scientific Literacy and Attitude Cluster) adopt global issues, such as melting polar ice caps or the theoretical greenhouse effect. These issues, although important, are often considered abstract and psychologically distant by students, so they are only effective in increasing knowledge without motivating students to take action. In contrast, studies in the Action Competency Cluster, such as recent research by Permana et al. (2026) and Parmin & Fibriana (2019), show a different pattern. These studies consistently raise local issues or local wisdom, such as local river ecosystems or the indigenous knowledge of local communities. The findings of I. N. Dewi et al. (2020) emphasize that integrating local potential (local genius) into learning offers crucial emotional closeness (place attachment), which becomes a bridge between scientific knowledge and students' desire to take real action.

Researchers also mapped the orientation of SSI-based E-Modules research in the 2019–2025 period, focusing on the outcome variables of 45 selected articles. This mapping aims to strengthen the imbalance in the distribution of outcome variables in the studies reviewed. To ensure the validity of the proportion claims and prevent double-counting, a mutually exclusive clustering criterion was applied. Each article was assigned to one of four main clusters: Scientific Literacy, Critical Thinking Skills, Environmental Attitudes, and Action Competency. If a study measured multiple outcomes (e.g., cognitive literacy and attitudes), it was categorized based on the highest behavioral or pedagogical tier it empirically evaluated as its primary objective. The frequency distribution of articles in each variable cluster is visualized in Figure 2.

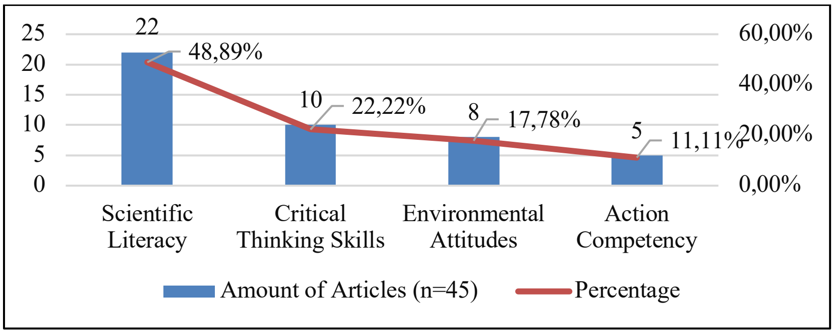

Figure 2. Frequency distribution of articles in each variable cluster

Based on Figure 2, there is a clear trend of a sharp decline (drop-off) in the quantity of research as the complexity of expected outcomes increases. Research is significantly dominated by cognitive aspects, where scientific literacy and critical thinking skills are the main focus in the majority of studies, as reported by Amalia et al. (2024) and Agustin et al. (2025). In contrast, research targeting real behavioral change or action competency accounts for the lowest proportion. This imbalance confirms the existence of a knowing-doing gap in SSI implementation, where digital technology has proven effective in facilitating the transfer of scientific knowledge but has not been optimally explored to transform that knowledge into real conservation action, as indicated in the study by Permana et al. (2026).

A deeper interpretation of the extracted data reveals a strong correlation between the selected SSI context and the success of action competence formation. There is a significant imbalance where the majority of studies (particularly in the Literacy and Attitude clusters) adopt global issues, such as the melting of polar ice caps or theoretical greenhouse effects. Conversely, studies within the Action Competence cluster consistently raise local issues or local wisdom, such as local river ecosystems or indigenous knowledge.

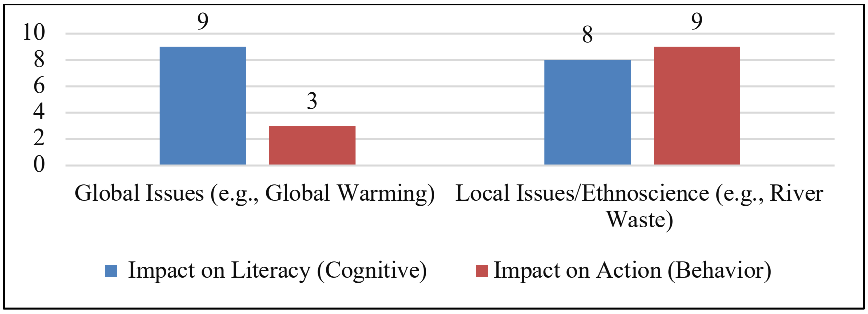

Figure 3. Comparison matrix of SSI effectiveness in global and local contexts

The comparative matrix in Figure 3 illustrates the effectiveness contrast between global and local contexts. Methodologically, the effectiveness of "actions" across these contexts was synthesized qualitatively by comparing the reported effect sizes and the significance of behavioral constructs (e.g., intention to act versus actual participation) detailed in the primary studies. The mapping indicates that integrating local potential significantly enhances the transition toward action compared to global scenarios.

Discussion

Synergy of Technology and Pedagogy in Building Scientific Literacy

The empirical consistency of E-Modules integrated with the Socio-Scientific Issues (SSI) approach in improving scientific literacy can be fundamentally explained through the Technological Pedagogical Content Knowledge (TPACK) framework. The analysis reveals that effective E-Modules do not merely digitize textbooks (Technology), but successfully intertwine controversial biological issues (Content) with inquiry-based scaffolding (Pedagogy). This triad integration creates a learning ecosystem that significantly enhances content and procedural knowledge across various educational levels (Agustin et al., 2025; Arizen & Suhartini, 2020; Islami & Setiawan, 2025; Khery et al., 2019; Kusumaningsih et al., 2025; Puspitarini et al., 2025).

From a cognitive perspective, the success of this synergy is best elucidated by the Dual Coding Theory. Environmental issues raised in the modules, such as climate change, microplastic pollution, or biotechnology, often possess a high level of abstraction and invisibility that burdens students' working memory. The E-Modules act as crucial visual scaffolding as dynamic animation, video, and virtual simulation features help deconstruct these complex processes into concrete representations processed simultaneously through visual and verbal channels. This mechanism effectively reduces extraneous cognitive load, allowing students to allocate their mental capacity to processing core scientific concepts rather than struggling to imagine the phenomena (Deamita et al., 2024; Rahayu, 2023; Widodo et al., 2020).

Furthermore, an in-depth analysis reveals that this success is not solely due to technological sophistication, but rather the "cognitive conflict" designed through the SSI narrative. Zeidler et al. (2019) and Kinslow et al. (2019) argue that scientific literacy grows through the friction of thought when students face moral-scientific dilemmas. This mechanism is reinforced by findings indicating that interactive socio-scientific inquiry triggers *Socio-Scientific Reasoning* (SSR) and decision-making regarding bioethical issues (Akhnah & Subiantoro, 2025; Fadha et al., 2023; Suwono et al., 2023). Consequently, this pedagogical friction acts as a catalyst for *Higher Order Thinking Skills* (HOTS), training students to analyze arguments critically (Amalia et al., 2024; Fatimah et al., 2025; Fita et al., 2021; Izzah et al., 2022). For instance, Sobach et al. (2023) demonstrated that interactive digital modules significantly enhance literacy in biotechnology topics, while N. H. Utami et al. (2023) confirmed similar validity in environmental pollution topics, proving technology's role in bridging abstract concepts with concrete learning experiences (Amanda et al., 2025; Hardin et al., 2025; Kusumasari et al., 2024; Normawati et al., 2022; Suastrawan et al., 2021; Sugrah et al., 2023; Wahyuni et al., 2021). Similar to findings by Mulbar et al. (2025) Digital narratives effectively engage Junior High School students in environmental topics, although the transition to concrete action remains a challenge. Addressing the demographic disparity found in this review, it is evident that Junior High School students require specifically scaffolded pedagogical designs tailored to their cognitive development and age-specific nature connection (Braun & Dierkes, 2017).

Technically, features such as hypercontent and digital flipbooks facilitate a self-regulated learning journey, allowing students to explore multiperspective evidence beyond linear textbook constraints (Magtibay, 2024; Rasyih et al., 2024; Widyastuti et al., 2025). This aligns with constructivist principles, where immediate adaptive feedback aids memory retention (Lestari et al., 2025; Muntari et al., 2024; Silvia et al., 2024). However, a critical analysis of the assessment instruments reveals a limitation: the majority of literacy gains are measured through lower-order cognitive items (C1-C3). While students demonstrate a surge in understanding scientific phenomena (Genisa et al., 2020). Their ability to navigate ethical and social dimensions often remains underdeveloped. This suggests that while current E-Modules technology is mature as a tool for knowledge transfer, the pedagogical design of assessment in many studies still lags, focusing more on cognitive validation than on measuring complex ethical transformation.

Epistemological Gap: From Knowledge to Conservation Action Competency

Although quantitative data show that scientific literacy has increased significantly after the intervention, qualitative analysis highlights a worrying stagnation in the domain of action competency. There is a striking gap between "knowing" and "doing," a phenomenon known in environmental psychology literature as the Knowledge-Behavior Gap. Theoretically, this stagnation can be dissected using Stern's Value-Belief-Norm (VBN) Theory. The synthesized data indicate that current E-Modules successfully build *Awareness of Consequences* (AC) regarding environmental damage, producing students who can explain catastrophic impacts scientifically (Permana et al., 2026; Zahrani et al., 2024). However, these modules often fail to trigger *Ascription of Responsibility* (AR), the internal belief that the individual is personally responsible for the solution. Consequently, E-Modules tend to produce "intelligent spectators", students who possess high sustainability awareness but lack the volition to act, as their scientific understanding remains detached from their personal value systems (Kurniasih et al., 2023; Sinakou et al., 2019; Ulliva & Prodjosantoso, 2025).

From a methodological standpoint, this review identifies a systemic weakness in how "action" is measured in the analyzed literature. A significant portion of the studies relies on self-reported *Likert scales* (e.g., "I intend to recycle") (Lange & Dewitte, 2019), which are highly susceptible to Social Desirability Bias (Bencze et al., 2020). Students tend to select "ideal" answers to please educators, masking their actual behavior. This explains the dissonance found by Permana et al. (2026), where high intent scores did not correlate linearly with actual participation in river cleaning projects. Thus, the reported "effectiveness" in many studies might be an overestimation of intention rather than a reflection of genuine, tangible competence. To address this, future research must prioritize authentic alternative instruments or validated evaluation frameworks (Hadjichambis & Paraskeva-Hadjichambi, 2020).

The root cause of this stagnation can also be analyzed using the fundamental framework of Action Competence, which distinguishes between "activity" and "action." As criticized in systematic reviews by Ardoin et al. (2020) and Sass et al. (2020)The majority of E-Modules get caught up in providing pseudo-activities. Students may be busy performing virtual recycling simulations or answering interactive pollution quizzes, but these activities do not qualify as "action" because they do not involve risk-taking, value commitment, or real impact on the community (Torsdottir et al., 2024). In this context, the digitization of learning acts as a double-edged sword; overly comfortable virtual simulations create a "bubble of isolation" that distances students from the complexity of real environmental issues. When solutions are just a mouse click away, students are not trained to deal with the social resistance or technical difficulties integral to real-world conservation.

Furthermore, Ardoin et al. (2020) Note that excessive exposure to global environmental damage data without concrete solutions can trigger *eco-anxiety* or despair. Students perceive the problem as a "hyper-object" (too big to solve), leading to apathy rather than activism. This is exacerbated by a lack of "procedural knowledge" regarding how to act locally (Shin et al., 2023). E-Modules often stop at the level of *why* (why the environment is damaged) but are absent at the level of *how* (how to fix it specifically here and now). Therefore, this review implies the urgency of a radical reorientation in pedagogy. Digital teaching materials must transform from repositories of information into catalysts for action by integrating real-world projects, not just simulations, to bridge the gap between cognitive knowledge and behavioral agency (Chen & Liu, 2020; Dewi et al., 2020).

However, given that this conclusion is based on a qualitative synthesis, it must be clarified that the integration of VBN Theory and action competency findings represents strong indicative and associative trends, rather than definitive direct causal relationships. The stagnation in action competency is also exacerbated by methodological weaknesses in previous studies (Bencze et al., 2020), which heavily rely on self-reported questionnaires to measure student intentions (Lange & Dewitte, 2019). To address this, future research must prioritize authentic alternative instruments, such as longitudinal observations, community-based project evaluations, or performance-based assessments. Furthermore, the call for a radical reorientation in E-Modules design requires concrete integration of participatory pedagogical strategies. Future digital modules should embed real-world applications, such as citizen science data collection, service-learning tasks, or local conservation projects, directly into the platform's workflow to prevent these recommendations from appearing merely normative.

The Urgency of Local Contextualization as a Bridge to Concrete Conservation Action

A comparative analysis of the material characteristics in the reviewed literature reveals an epistemological imbalance that appears to be the root cause of students' low action competence. The dominance of global issues in previous research, such as polar ice melt, ozone depletion, or general renewable energy concepts, creates a phenomenon best explained by Construal Level Theory (CLT) (Jones et al., 2017). According to this theory, students perceive these global environmental problems as "high-level construals", which are abstract, distant, and decontextualized events that occur "there" and "later." Consequently, although E-Modules successfully instill cognitive knowledge, they fail to touch the deeper affective dimension necessary for behavioral change because the psychological distance is too great (Arizen & Suhartini, 2020; Kurniasih et al., 2023).

This study proposes the fundamental proposition that the integration of SSI based on local biodiversity, local wisdom, or ethnoscience is "the missing link" to bridge this gap. This proposition is validated by empirical findings (see Table 1), where studies raising region-specific issues, such as the analysis of local river ecosystems or traditional agricultural practices, show significantly higher levels of student agency compared to general issues (Permana et al., 2026; Susanti & Kim, 2020). The mechanism behind this success aligns with the lens of Place-Based Education (PBE). When E-Modules adopt local narratives, learning is anchored in the physical realities familiar to students. The integration of local potential, as also highlighted in recent studies on indigenous science (Irawan et al., 2025), is crucial for contextualizing abstract scientific concepts. Research consistently shows that this contextual relevance triggers Place Attachment, an emotional bond to one's environment, which acts as the primary fuel for conservation action competency (Dewi et al., 2020; Khery et al., 2019; Rahmawati et al., 2020). For example, a digital simulation of conservation on the slopes of Mount Merapi (Parmin & Fibriana, 2019) or the analysis of the *Jatigede Reservoir* ecosystem (Siddiq et al., 2020) feels more "reasonable" and actionable for local students than simulating global carbon emissions. Thus, locality is not merely a backdrop, but a determining variable that changes students from "problem observers" to "solution owners."

Furthermore, the integration of local wisdom via an ethnoscience approach offers cultural validation often overlooked in modern science education. Reconstructing *indigenous science* into scientific knowledge serves as a form of Culturally Responsive Teaching, helping students break down barriers between school science and their daily lives. Parmin & Fibriana (2019) emphasize that when students realize their ancestors possessed indigenous conservation technologies, a sense of pride and cultural identity is formed. This aligns with findings that E-Modules infused with ethnoscience are effective in improving not just scientific literacy, but also conservation character and critical thinking, as they resonate with the belief systems already present within students (Sumarni & Kadarwati, 2020; Susanti & Kim, 2020).

While CLT and PBE provide compelling explanatory frameworks for this phenomenon, it is important to temper these claims by emphasizing that the findings demonstrate strong trends, not absolute causal relationships; local contextualization significantly increases the likelihood of pro-environmental behavior, but it must be supported by adequate pedagogical scaffolding. Figure 2 visualizes the contrasting effectiveness patterns between the two contexts. Methodologically, the effectiveness of "actions" across these contexts was synthesized qualitatively by comparing the reported effect sizes and the significance of behavioral constructs (e.g., intention to act versus actual participation) detailed in the primary studies. The use of global issues proved highly effective in building literacy and awareness but weak in triggering real action due to psychological distance

(Arizen & Suhartini, 2020). Conversely, the integration of local issues demonstrated a superior impact on the action dimension by creating a strong emotional attachment (Permana et al., 2026). In the context of Biology education, this finding implies that teaching materials need to evolve from merely explaining ecological concepts to facilitating real conservation actions.

Therefore, these findings lead to the conclusion that the future development of E-Modules for science and biology education should no longer be trapped in technological sophistication alone, but should be oriented towards “down-to-earth technology.” There is an urgent need to develop “glocal” (*Think Global, Act Local*) digital teaching materials using global technology standards to solve local environmental and biodiversity problems. This study recommends a paradigm shift: from E-Modules presenting universal biological concepts, to adaptive E-Modules responsive to specific bio-ecological Socio-Scientific Issues in the surrounding ecosystem. This innovation is predicted to produce a generation that is not only cognitively intelligent (*biologically literate*) but also morally and socially resilient to take real conservation action (*action competent*).

CONCLUSION

Based on the systematic synthesis of empirical evidence from 45 primary studies, this study highlights three core findings. First, the development of SSI-based science E-modules experienced a significant post-pandemic surge, though it remains predominantly concentrated at the Senior High School level, leaving a demographic gap in Junior High School research. Second, while the integration of E-modules technology and SSI pedagogy is highly effective in enhancing cognitive scientific literacy and visualizing abstract biological phenomena, the current evidence indicates a limitation in translating these cognitive gains into concrete conservation action competence. Third, given the qualitative nature of this synthesis, the observed stagnation in action competence shows a strong associative trend, rather than a definitive causal relationship, with the dominance of global environmental issues, which may create a "psychological distance" for students. Conversely, integrating local biodiversity contexts and ethnoscience emerges as a highly promising approach to bridge this knowledge-behavior gap by fostering emotional place attachment and student agency.

These indicative findings encourage a paradigm shift in science education design: moving away from E-modules that rely solely on technological sophistication toward those grounded in Place-Based Education principles. Practically, this review establishes a foundation for developing adaptive E-modules that respond to specific, local bio-ecological issues. This study acknowledges methodological limitations, primarily the reliance on qualitative synthesis and the literature search restriction to specific databases from 2019 to 2025, which may exclude relevant grey literature. Therefore, future research should focus on empirically testing the effectiveness of E-modules integrated with local ethno-biological wisdom, specifically at the junior high school level. Furthermore, future studies must prioritize the development of authentic assessment instruments, such as longitudinal observations or project-based evaluations, to measure actual conservation action competence, moving beyond mere self-reported environmental intentions.

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