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Development of Biology Modules with Integrated STEM Approaches Socio-Scientific Issues to Train Critical Thinking Skills

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Abstract: The 21st century requires students to develop various competencies to face the challenges of globalization, including critical thinking skills. Initial assessments showed that students' critical thinking skills still needed to be improved. Appropriate learning methods can support the development of these skills. One suitable method is an integrated STEM approach to Socio-scientific Issues (SSI), which can be packaged into a learning module. This research employed a research and development method using the ADDIE development model. The study was conducted at MA Fathul Hidayah Maduran Lamongan, involving 48 tenth-grade MIPA students selected through purposive sampling. This study aimed to determine the feasibility of the developed module. The results showed that the module was highly feasible as teaching material. The feasibility scores were 93.75% from material experts, 100% from critical thinking experts, 92.9% from SSI-integrated STEM experts, and 95% from teaching material experts. Biology teacher and student responses were 95.4% and 94.2%, respectively.

Keywords: Critical Thinking; Modules; Socio-Scientific Issues; STEM.

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Introduction

According to Cahyadi (2019), critical thinking skills are a crucial 21st-century competency. The rapid advancement of science and technology requires learners to think reflectively, evaluatively, and adaptively when solving various problems (Anisa et al., 2021; Ennis, 2013; Dominguez & Barajas, 2021). Therefore, teachers need to design instruction that systematically fosters students' critical thinking skills (Schafersman, 1991).

Critical thinking is a way of thinking that is reflective and rational or based on reason that is focused on determining what to believe and do (Ennis, 1993). Critical thinking is defined as a process of thinking deeply to obtain logical and relevant information (Agnafia, 2018; Zakiah & Lestari, 2019). In addition, critical thinking is an intellectual process in conceptualizing, applying, synthesizing (Komarudin, 2022; Agustina et al., 2021) analyzing, and evaluating (Fadilah et al., 2022; Sukma et al., 2023; Yusmar et al., 2022) various information obtained from observation, experience and reflection (Butterworth & Thwaites, 2013).

Because individuals possess varying levels of critical thinking, standardized indicators are necessary for accurate assessment (Satriani, 2017). This study adopts the framework by Ennis (1993), comprising five indicators: 1) providing simple explanations, 2) building basic skills, 3) making inferences, 4) providing further explanations, and 5) arranging strategies and tactics. This framework was selected because its measurable stages align perfectly with the scientific problem-solving process required in the STEM integrated with Socio-scientific Issues (SSI) approach. Furthermore, these indicators directly guided the design of the module's activities and assessments, ensuring that tasks—such as analyzing SSI phenomena and designing STEM solutions—specifically measure and develop these five cognitive steps.

Critical thinking is important for every individual to have because critical thinking skills make someone think and work more carefully, are able to understand information from different perspectives and can carry out in-depth analysis of problems and situations (Afandi et al., 2021; Muslich, 2009). Critical thinking skills in the learning process are important for students, because by thinking critically, students will use their minds optimally in solving problems that exist in everyday life (Shafique et al., 2006; Deviananda & Mawardi, 2022; Alsaleh, 2020). In addition, critical thinking can encourage and increase student creativity (Bradley & Lang, 2007).

The results of research by Adah et al. (2022) and Agustina et al. (2021) show that STEM-based teaching materials are effective in improving students' critical thinking skills, because there is a thinking process through discussion and can train creativity through project activities. The STEM approach is oriented towards problem solving, so it requires problem topics as bait in learning. Qamariyah et al. (2021) stated that in order for students to participate in discussions, topics are needed that can connect the material with events that occur around them. According to Khasanah & Prayitno (2019), Critical thinking arises as a result of disagreements in perspectives, ideas, and feedback throughout the discussion process. Therefore, one model that can be integrated into the STEM approach is the socio-scientific problem model or Socio-Scientific Issue (SSI).

STEM and SSI share a complementary relationship, where SSI provides complex, real-world problems and STEM offers multidisciplinary solutions (Siribunnam et al., 2019). Extensive research demonstrates that integrating STEM and SSI significantly enhances students' critical thinking skills—such as analyzing facts, evaluating issues, and reasoning through alternative solutions (Adah et al., 2022; Agustina et al., 2021; Sukma et al., 2023; Nava & Prasetyo, 2018; Septiningrum et al., 2021). However, while the theoretical effectiveness of the STEM-SSI approach is well-documented, there remains a lack of practical, systematically developed biology modules that teachers can readily implement. Most previous studies have focused primarily on classroom learning interventions rather than the rigorous development of the learning materials themselves. Therefore, this study focuses on the development of a validated biology module specifically covering the topics of ecosystems and environmental change. Furthermore, this module distinguishes itself from existing instructional materials by incorporating localized issues relevant to students, providing specialized project rubrics, and utilizing interactive visual designs.

According to Sadler (2011), there are five steps that can be taken in SSI contextual learning, namely (1) problem analysis, (2) clarification of the science, (3) refocus on the socio-scientific, (4) role-playing tasks, and (5) meta-reflective activity. This learning model will train students to think critically. This can be seen in the syntax of problem analysis which presents socio-scientific issues. These stages make students actively participate in discussions in finding the right solution to a problem. Meanwhile, in the syntax clarification of the science, teachers help students understand issues from a scientific perspective according to the theories that have been learned. This can help students to exchange ideas and analyze together the problems given by the teacher (Khasanah & Setiawan, 2022). The syntax refocus on the socio-scientific, students focus their attention on the issues presented, where students are required to make decisions and take actions. The syntax role-playing task students play a role in discussions and roles, realized in the form of debates, presentations and demonstrations (making projects). Through these activities, students' cognitive abilities and creativity will be facilitated, so that they are able to think systematically in formulating concepts and arguments (Sutoyo et al., 2023). The syntax meta-reflective activity students are encouraged to reflect on their overall experiences during learning. Reflection at the end can increase self-confidence, especially in expressing and exchanging opinions during discussions and responding to questions. Subiantoro & Treagust (2021) stated that there is a significant influence of self-confidence on critical thinking skills.

The successful implementation of the integrated STEM-SSI approach in schools requires adequate supporting facilities, particularly appropriate teaching materials (Stohlmann et al., 2012). Teaching materials are essential to facilitate the delivery of content and guide independent learning, especially given the limited biology class hours of only 3 x

40 minutes per week (Angraini et al., 2022; Al-Azri & Al-Rashdi, 2014). However, most currently available biology teaching materials are insufficient because they are predominantly theoretical and lack authentic, problem-based contexts. They rarely provide interdisciplinary project tasks or integrate real-world socio-scientific issues, which are crucial for stimulating critical thinking. To address these limitations, an alternative instructional material in the form of a specialized learning module is urgently needed. The STEM-SSI biology module proposed in this study is specifically designed to bridge this gap. It features localized socio-scientific issues relevant to students, interactive visual designs, and specialized STEM project rubrics that systematically guide students to analyze environmental problems and engineer practical solutions. By synthesizing the unresolved problems from previous studies, this research emphasizes the development of learning materials rather than mere classroom intervention. Therefore, the objective of this study is to develop a valid and practical biology learning module based on the integrated STEM-SSI approach, specifically covering the topics of ecosystems and environmental change, to effectively train students' critical thinking skills.

Methods

This study employed a Research and Development (R&D) design using the ADDIE model to produce a valid and practical biology learning module based on the integrated STEM-SSI approach (Dick & Carey, 1996; Sugiyono, 2019). The systematic development process in this study was implemented through the following five stages:

Analysis A preliminary needs analysis was conducted using multiple data collection techniques: direct classroom observation, structured interviews with the biology teacher, and documentation analysis of lesson plans (RPP) and existing textbooks. Additionally, an initial essay test based on critical thinking indicators was administered to evaluate students' baseline skills. The collected data revealed a performance gap: students struggled with critical thinking because existing materials lacked real-world socio-scientific contexts and hands-on activities. Consequently, the Phase E biology curriculum, specifically covering ecosystems and environmental change, was selected for module development. ‘

Design The module blueprint was formulated by comprehensively aligning learning objectives with critical thinking indicators and the STEM-SSI syntax. This stage included designing specific, high-school-appropriate project-based tasks to serve as practical assessment tools. The selected projects were a planting movement (gerakan ayo menanam) and phytoremediation using water hyacinth (eceng gondok), ensuring the activities were both feasible and relevant for the students.

Development The initial prototype of the module was constructed and subsequently evaluated through survey techniques by a panel of four experts from UIN Walisongo. These validators specialized in subject matter, instructional media, integrated STEM-SSI, and critical thinking assessment. Validation data were collected using Likert-scale questionnaires to obtain factual primary data regarding the module's feasibility.

Implementation Following expert revisions, a field test was conducted at MA Fathul Hidayah Lamongan involving one biology teacher as a practitioner and a sample of 48 tenth-grade science students (X MIPA). The sample size was mathematically determined using Slovin's formula with a 5% margin of error from a total population of 55 students. To ensure a comprehensive evaluation of the module across different cognitive levels, the participants were selected using a purposive sampling technique based on their preliminary test results, consisting of 10 high-achieving, 18 average-achieving, and 20 low-achieving students.

Evaluation Data obtained from the expert validation sheets and user response surveys (from both the teacher and students) were analyzed using quantitative descriptive techniques. The raw scores were converted into percentages and interpreted using standard feasibility criteria to determine the product's final practicality.

Results & Discussion

The STEM-integrated Socio-Scientific Issues (SSI) biology module was successfully developed to cover the topics of Ecosystems and Environmental Change. The novelty of this module lies in its integration of specific, highly relevant socio-scientific cases, namely the impact of the fast fashion trend on ecosystems and the issue of global warming and motorcycles.

The initial product underwent a rigorous validation process involving four experts from UIN Walisongo and one biology teacher as an education practitioner. Validation results demonstrated exceptionally high feasibility ratings across all assessment aspects. Content experts scored the module at 83.9%, leading to minor but crucial improvements such as image size adjustments and scientific terminology corrections (e.g., implementing proper binomial nomenclature). Instructional design experts gave a highly suitable rating of 95.0%, particularly praising the systematic layout, typography, and clear visual components that support self-instructional learning.

The STEM-SSI methodology validation yielded 92.9%. The methodology expert confirmed that the module successfully integrated the five core SSI syntaxes: problem analysis, clarification of the science, refocus on the socio-scientific, role-playing tasks, and meta-reflective activities. Furthermore, the critical thinking assessment expert awarded a perfect score (100%), confirming that the evaluation instruments perfectly align with the targeted cognitive skills. A summary of the validation results is presented in Table 1.

Table 1.
Module Validation Summary.

Validator	Assessment Aspect	Score (%)	Category
Content Expert	Material completeness, conceptual accuracy	83.9	Highly Suitable
Design Expert	Design, layout, systematicity	95.0	Highly Suitable
STEM-SSI Expert	STEM and SSI integration syntaxes	92.9	Highly Suitable
Critical Thinking Expert	Alignment of tasks with Ennis' indicators	100	Highly Suitable
Biology Teacher	Curriculum alignment and practicality	95.4	Highly Suitable

To illustrate the design and structure of the developed module, examples of the module display are presented in Figure 1.

Figure 1.
Display of the STEM–SSI Biology Module.

Cover Module | **STEM-based activities** | **SSI discussion sections**

MODUL BIOLOGI

TEKNIK

Gerakan Ayo Menanam Lidah Mertua (*Sansevieria sp.*)

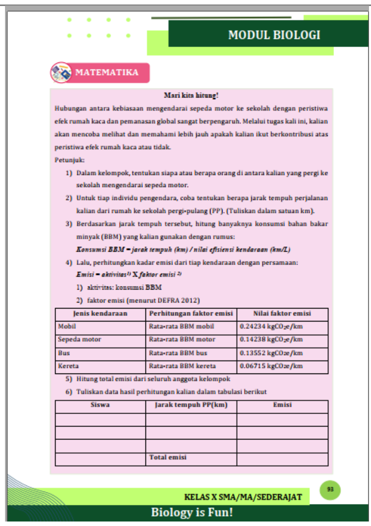
Polusi udara memberikan dampak yang sangat signifikan terhadap kesehatan. Itulah sebabnya, mereka yang tinggal di perkotaan atau memiliki rumah di dekat jalan raya, sebaiknya memelihara tanaman yang mampu menghirup polusi udara. Tumbuhan tertentu terbukti dapat menyerap racun sehingga dapat meningkatkan kualitas udara dalam ruangan dan sekitar rumah. Pertumbuhan tanaman membantu pertukaran dengan sebagian gas atmosfer melalui fotosintesis, proses respirasi, dan tahap akhir dekomposisi yaitu mineralisasi. Tumbuhan memainkan peran penting dalam mengurangi kandungan CO2 di atmosfer melalui fotosintesis. Pengurangan kandungan CO2 atmosfer ini memiliki peran penting dalam pengurangan efek rumah kaca dan perubahan iklim. Karbon yang tersimpan dalam tumbuhan adalah hasil keseimbangan antara karbon yang difiksasi oleh fotosintesis dan karbon yang dilepaskan di atmosfer melalui respirasi.

Solusi untuk mengurangi gas karbondioksida (CO2) adalah dengan menanam tanaman yang mampu menyerap gas karbondioksida (CO2) dengan baik, salah satunya adalah lidah mertua (*Sansevieria sp.*). Tanaman ini mudah di dapat dan dipelihara. Jenis tanamannya juga bervariasi dari umur, tinggi, ketebalan, serta kerapatan yang berbeda. *Sansevieria sp* memiliki banyak kelebihan yaitu dapat hidup pada rentang waktu suhu dan cahaya yang sangat luas,resisten terhadap polutan. Menurut penelitian NASA tanaman ini dapat menyerap 107 jenis polutan di daerah yang memiliki lalu lintas yang padat dan ruangan yang penuh dengan asap rokok, serta dapat menyerap radiasi barang elektronik. Sansevieria juga memiliki daya adaptasi yang tinggi terhadap lingkungan (Megia, dkk, 2015).

Pada tahap perkembangannya, semakin tua umur *Sansevieria sp.* maka ukuran daun semakin lebar, sehingga luas penampang semakin besar dan kemampuan untuk menyerap polusi semakin besar. *Sansevieria sp.* merupakan tanaman yang mengandung bahan aktif pregnane likosid yang berfungsi untuk mereduksi polutan menjadi asam organic, gula dan asam amino yang tidak berbahaya bagi manusia.

KELAS X SMA/MA/SEDERAJAT 91

Biology is Fun!



MODUL BIOLOGI

MATEMATIKA

Mari kita hitung!

Hubungan antara kebiasaan mengendarai sepeda motor ke sekolah dengan peristiwa efek rumah kaca dan pemanasan global sangat berpengaruh. Melalui tugas kali ini, kalian akan mencoba melihat dan memahami lebih jauh apakah kalian ikut berkontribusi atas peristiwa efek rumah kaca atau tidak.

Petunjuk:

1) Dalam kelompok, tentukan siapa atau berapa orang di antara kalian yang pergi ke sekolah mengendarai sepeda motor.
2) Untuk tiap individu pengendara, coba tentukan berapa jarak tempuh perjalanan kalian dari rumah ke sekolah pergi-pulang (PP). (Tuliskan dalam satuan km).
3) Berdasarkan jarak tempuh tersebut, hitung banyaknya konsumsi bahan bakar minyak (BBM) yang kalian gunakan dengan rumus:
   Konsumsi BBM = jarak tempuh (km) / nilai efisiensi kendaraan (km/L)
4) Lalu, perhitungkan kadar emisi dari tiap kendaraan dengan persamaan:
   Emisi = aktivitas[1] X faktor emisi [2]
   1) aktivitas: konsumsi BBM
   2) faktor emisi (menurut DEFRA 2012)

Jenis kendaraan	Perhitungan faktor emisi	Nilai faktor emisi
Mobil	Rata-rata BBM mobil	0.24234 kgCO_2e/km
Sepeda motor	Rata-rata BBM motor	0.14238 kgCO_2e/km
Bus	Rata-rata BBM bus	0.13552 kgCO2e/km
Kereta	Rata-rata BBM kereta	0.06715 kgCO2e/km

5) Hitung total emisi dari seluruh anggota kelompok
6) Tuliskan data hasil perhitungan kalian dalam tabulasi berikut

Siswa	Jarak tempuh PP(km)	Emisi
	Total emisi	

KELAS X SMA/MA/SEDERAJAT 93

Biology is Fun!

In the limited field trial involving 48 students of varied academic abilities (selected via purposive sampling), the module received positive feedback with an average overall practicality score of 94.2%. Based on the student response questionnaire, the STEM implementation aspect scored the highest (96%), indicating that hands-on projects effectively engaged students.

Furthermore, students gave a score of 88.4% for the module's critical-thinking design aspect. It is crucial to clarify that this score (88.4%) represents the students' self-reported perception and response to how well the module's exercises facilitated their analytical thinking; it is not an empirical measurement of their actual critical-thinking cognitive performance.

Qualitative feedback from validators and the field test was explicitly utilized to refine the module. Substantively, the expert recommendation to ensure localized relevance and increase the complexity of inference-building exercises was addressed by revising the student worksheets. The final product incorporates specific, localized projects, notably the *gerakan ayo menanam* (planting movement) and water hyacinth phytoremediation, to provide a more authentic learning context.

The finalized module features several superior qualities that distinguish it from conventional materials. The consistent implementation of Ennis' (1985) critical thinking indicators in the developed module is presented in Table 2.

Table 2.
Critical Thinking Indicator Implementation in the Module.

Indicator (Ennis, 1985)	Sample Task / Activity in the Module
Providing simple explanations	Focusing questions on local river pollution cases
Building basic skills	Evaluating the credibility of environmental news sources
Making inferences	Interpreting water quality data from lab observations
Providing further explanations	Debating various environmental solutions (Role-playing)
Arranging strategies and tactics	Designing phytoremediation / eco-enzyme projects

The high validation and practicality scores demonstrate that this module meets the strict standards of innovative learning media. Pedagogically, the success of the STEM-SSI integration lies in its mechanism to trigger cognitive dissonance and contextual problem-solving. The SSI component provides the "why" by presenting complex, real-world environmental problems (e.g., fast fashion waste) that challenge students' existing perspectives and moral reasoning. Simultaneously, the STEM component provides the "how" by offering a structured engineering design framework to actively resolve these issues. This synergistic mechanism explains the highly positive student response (96%) toward the module's hands-on activities, effectively bridging the gap between theoretical biological concepts and real-world application (Zeidler, 2014; Hunaepi et al., 2020).

Furthermore, the module explicitly utilizes essay-based questions rather than multiple-choice for its critical thinking assessment. As Susongko (2010) argues, essay questions demand integrative knowledge to organize answers, forcing students to apply the five Ennis indicators systematically rather than merely guessing predefined options. The integration of meta-reflective activities at the end of the module also plays a crucial role in building students' self-regulation, which is a key driver of advanced critical thinking.

However, while the feasibility data and positive student responses strongly indicate that the module provides a highly conducive environment for developing critical thinking, these results must be carefully interpreted within the boundaries of this Research and Development (R&D) study. Because this research focused strictly on product development, validity, and user practicality due to time constraints, the claims are limited to the module's suitability and readiness as an instructional tool. Further experimental research, employing extensive pre-test and post-test designs, is required to empirically measure the module's true effectiveness in improving students' actual critical-thinking test scores.

Conclusion & Recommendation

This research successfully developed a biology module integrating STEM and Socio-Scientific Issues (SSI) to facilitate students' critical thinking skills on the topics of Ecosystems and Environmental Change. The module systematically incorporates learning objectives, concept maps, SSI-based content, STEM activities, and assessments strictly aligned with critical-thinking indicators. Based on rigorous evaluations by subject matter, instructional design, methodology, and critical thinking experts, as well as highly positive responses from a practicing biology teacher and students, the module is declared highly feasible, valid, and practical for classroom instruction. The primary contribution of this study is the provision of a systematically designed, ready-to-use instructional tool that bridges theoretical science with real-world problem-solving to promote students' analytical and evaluative skills. However, as this Research and Development (R&D) study focused exclusively on product feasibility and was limited to a small-scale field trial, it does not provide empirical evidence of the module's effectiveness in enhancing actual cognitive performance.

Based on these findings, several recommendations are proposed. First, biology educators are encouraged to utilize this validated STEM-SSI module as an alternative learning resource to support student-centered, contextual learning. Second, it is highly recommended that future researchers conduct broader experimental studies, utilizing pre-test and post-test designs, to empirically measure and validate the module's actual effectiveness in improving students' higher-order thinking skills. Finally, the integration of STEM and SSI approaches should be expanded into other biological topics to enrich innovative learning materials relevant to contemporary real-world issues.

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