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EDUCATION FOR SUSTAINABLE DEVELOPMENT–BASED LEARNING OF CHEMICAL REACTIONS THROUGH E-MODULES TO ENHANCE JUNIOR HIGH SCHOOL STUDENTS' CRITICAL THINKING SKILLS

Dian Norma Aprillia [*1)], Suriswo [2)], Tity Kusrina [3)]
[1,2,3)] Master's Program in Pedagogy, Graduate School, Pancasakti Tegal University, Central Java, Indonesia
[*]*Corresponding author*
e-mail: dian.norma@gmail.com [*1)], suriswo44@gmail.com [2)], titykusrina@upstegal.ac.id [3)]

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ABSTRACT

This research investigates the effectiveness of Education for Sustainable Development (ESD) oriented learning implemented through e-modules on chemical reaction topics in improving junior high school students' critical thinking skills. The study employed a quantitative method using a quasi-experimental design and involved 139 junior high school students from Tegal Regency, Indonesia. The developed e-module integrates chemical reaction concepts with real-life sustainability issues at the local level, including waste management and water pollution. Students' critical thinking skills were measured using pre-test and post-test instruments, and the data were analyzed through gain score analysis and inferential statistical testing. The findings reveal a significant improvement in students' critical thinking abilities after the implementation of ESD-based e-modules. These results indicate that e-modules integrating ESD principles are effective learning media for enhancing students' analytical, evaluative, and inferential thinking in science education. Consequently, ESD-based e-modules can be considered a viable instructional alternative to improve the quality of science learning at the junior high school level.

Keywords: sustainable development; e-module; chemical reactions; critical thinking; science

INTRODUCTION

The mastery of critical thinking skills has become a fundamental demand in 21st-century science education. Such competencies refer to an individual's proficiency in systematically interpreting information, critically scrutinizing claims, and constructing well-reasoned judgments that are firmly supported by empirical research findings. However, science learning practices at the junior high school level often remain focused on theoretical concept delivery, which has not fully supported the development of students' higher-order thinking skills (Putri, 2022; Firmansyah, 2024).

The utilization of digital learning media, particularly e-modules, has emerged as a strategic alternative to enhance the quality of science learning. E-modules facilitate the systematic and interactive presentation of learning materials while supporting students' independent learning. Within the framework of Education for Sustainable Development (ESD), such learning environments are designed to engage students in analyzing real-world sustainability issues, thereby fostering critical reflection, problem-solving, and decision-making processes that underpin the development of critical thinking skills**.** Through the integration of ESD principles

into e-modules, students are encouraged to connect scientific concepts with environmental, social, and economic contexts, strengthening their analytical, evaluative, and inferential thinking abilities. Previous studies have reported that the use of e-modules can increase student engagement and improve critical thinking skills by providing analytical, evaluative, and reflective learning activities throughout the learning process (Wulandari *et al*., 2021; Kumalasani & Eilmelda, 2022; Sulistyaningrum *et al*., 2023). In addition, science education is required to respond to global challenges through the implementation of Education for Sustainable Development (ESD). the learning approach emphasizes the integration of scientific concepts with environmental, social, and economic sustainability issues, enabling students not only to understand scientific knowledge but also to apply it responsibly in real-life contexts. Previous research has indicated that ESD-based learning has the potential to enhance students' sustainability awareness as well as their critical thinking skills (Fatiyah *et al*., 2021). However, many existing studies have primarily focused on conceptual discussions or general classroom implementations, with limited empirical evidence examining the effectiveness of ESD-oriented digital learning media, particularly e-modules, in improving students' critical thinking skills at the junior high school level.

Addressing this gap, the present study empirically investigates the effectiveness of e-modules integrating ESD principles in teaching chemical reaction topics, providing quantitative evidence on their impact on students' critical thinking skills.

Chemical reaction topics represent one of the abstract areas of science learning that often pose difficulties for junior high school students in achieving deep conceptual understanding. Therefore, integrating ESD principles into e-modules for chemical reaction materials is considered relevant to help students connect chemical concepts with local sustainability issues, such as waste management and water pollution. Prior studies have demonstrated that the development of ESD-based chemistry learning media can improve students' conceptual understanding and scientific literacy (Fibonacci *et al*., 2020).

Although numerous studies have examined the use of e-modules and the implementation of ESD independently, empirical research specifically investigating the effectiveness of ESD-based e-modules on chemical reaction topics in improving junior high school students' critical thinking skills remains limited, particularly within the Indonesian local context. Therefore, this study aims to analyze the effectiveness of ESD-oriented learning through e-modules on chemical reaction materials in enhancing junior high school students' critical thinking skills.

METHOD

An empirical investigation was conducted to assess the effectiveness of e-modules integrating Education for Sustainable Development principles in teaching chemical reactions and promoting students' critical thinking skills.

1. Research Design

This research utilized a quantitative, quasi-experimental approach in which a single group of students underwent assessments before and after receiving the instructional treatment. This design

enabled the evaluation of changes in students' performance while accommodating practical constraints in school settings (Huang & Pagano, 2024).

The *pre-test* was administered to measure students' baseline critical thinking skills prior to the implementation of the ESD-based e-module. After completing the learning intervention, a post-test was conducted to assess changes in students' analytical, evaluative, and inferential thinking abilities. This design is appropriate for identifying learning gains resulting from instructional innovation in authentic classroom contexts (Solihah *et al*., 2024). The developed e-module is structured into several main components, including an introduction section, learning objectives aligned with curriculum standards, conceptual explanations of chemical reactions, ESD-integrated contextual cases, interactive learning activities, and evaluation tasks.

Interactive tasks within the e-module include guided questions, short problem-based exercises related to local sustainability issues such as waste management and water pollution, and reflection prompts that encourage students to analyze, evaluate, and draw conclusions based on scientific concepts. Each learning session using the e-module was designed to be completed within approximately 2 × 40 minutes, allowing sufficient time for exploration, discussion, and individual reflection.

The validation results indicated that the e-module was categorized as "very valid" and suitable for implementation after minor revisions.

2. Participants

The study involved 139 junior high school students from Tegal Regency**,** **Indonesia**, selected using **purposive sampling**. Participants were chosen based on: Prior exposure to science learning. Willingness to engage with e-module–based learning.

Table 1. Participant Distribution by Grade and Gender

Grade	Male	Female	Total
VII	22	27	49
VIII	21	25	46
IX	23	21	44
Total	66	73	139

3. E-Module Development

The ESD-based e-module was designed following a systematic instructional design to integrate chemical reaction concepts with local sustainability issues such as waste management and water pollution.

Development steps included: Needs analysis: Identified learning gaps in students' critical thinking skills (Sakinah *et al*., 2023) and (Kolong & Wowe, 2025). Content integration: Embedded chemical reactions concepts within real-life sustainability contexts. Interactive design: Included reflective questions, problem-solving exercises, and visual simulations to encourage higher-order thinking (Indri Dwiyanti1 *et al*., 2021). Expert validation: The e-module underwent expert judgment involving two chemistry education lecturers and one ESD practitioner. The validation assessed four aspects: (1) content accuracy, (2) relevance to ESD principles, (3) instructional design, and (4) pedagogical suitability. The validation results indicated that the e-module was categorized as "very valid" and suitable for implementation after minor revisions.

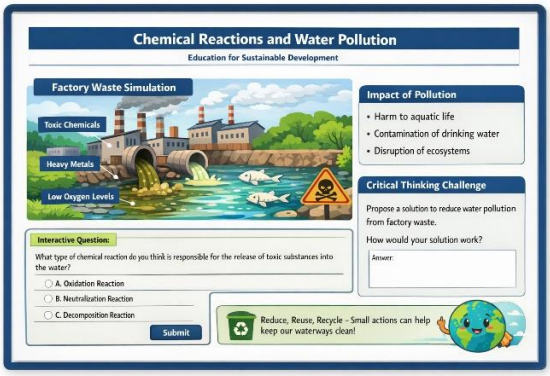


Figure 1. Sample Page of the ESD-Based E-Module.

4. Research Instruments

Students' critical thinking skills were measured using pre-test and post-test instruments. Indicators measured: Analytical thinking ability to distinguish relevant vs. irrelevant information. Evaluative thinking ability to assess arguments and evidence. Inferential reasoning ability to draw conclusions from scientific data. Instrument validation was conducted through expert judgment and item-total correlation analysis following established procedures for validity and reliability testing (Lawson, 2004; Taherdoost, 2016).

Table 2. Critical Thinking Skill Indicators and Sample Questions

Indicator	Sample Question
Analytical	Identify which chemical reaction in the scenario produces hazardous waste.
Evaluative	Assess whether the suggested solution for reducing water pollution is effective.
Inferential	Predict the outcome of mixing substances A and B in the context of sustainability.

5. Research Procedure

This study progressed through three primary phases. In the first phase, students completed a pre-test to assess their baseline critical thinking skills. Learning phase: Students engaged with the ESD-based e-module, completing interactive tasks, problem-solving exercises, and reflection prompts (Oe & Yamaoka, 2022). Post-learning phase: Students completed the post-test to measure improvements in critical thinking skills.

The intervention was conducted over four instructional meetings (2 × 40 minutes each). The e-module was implemented during regular chemistry classes under the supervision of the classroom teacher, with the researcher monitoring the learning process.

6. Data Analysis

Data were analyzed using quantitative statistical techniques: Gain score analysis: Calculated as the difference between post-test and pre-test scores for each participant. Paired-sample t-test: Tested the statistical significance of improvements in critical thinking skills (Winanda *et al*., 2024).

Table 3. Example of Gain Score Analysis

Student	Pre-Test Score	Post-Test Score	Gain Score
1	65	80	15
2	70	85	15
3	60	78	18

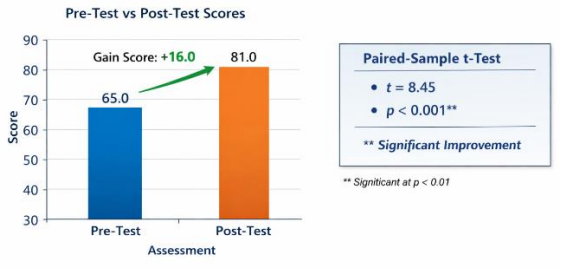


Figure 2. Pre-Test vs Post-Test Score Comparison.

RESULTS AND DISCUSSION

A. Research Findings

This section presents the results of data analysis concerning the improvement of students' critical thinking skills after participating in chemistry learning based on Education for Sustainable Development (ESD) through an e-module.

1. Description of Pre-test and Post-test Results

The measurement results of students' critical thinking skills before and after the implementation of the ESD-based e-module are presented in Table 4.

Table 4. Descriptive Statistics of *Pre-test* and *Post-test* Scores

Test Type	N	Mean	Standard Deviation
Pre-test	139	66.42	8.15
Post-test	139	81.37	7.92

As shown in Table 4, there was a noticeable increase in the average score of students' critical thinking skills following the implementation of the ESD-based e-module. The mean post-test score exceeded the pre-test score, indicating an enhancement in students' critical thinking performance after the instructional intervention. Similar gains have been reported in previous studies, where interactive e-modules significantly improved students' critical thinking in science and educational contexts (Meryastiti *et al*., 2023).

2. Gain Score Analysis

To determine the magnitude of improvement in students' critical thinking skills, a gain score analysis was conducted. The results are displayed in Table 5.

Table 5. Gain Score Analysis of Critical Thinking Skills

Aspect	Mean Gain	Category
Overall Critical Thinking	14.95	Moderate–High

The gain score analysis reveals that learning through the ESD-based e-module contributed to a moderate-to-high improvement in students' critical thinking skills.

3. Significance Testing of Improvement

To examine whether the observed improvement was statistically significant, a paired-sample t-test was performed comparing pre-test and post-test scores. The results are presented in Table 6.

Table 6. Paired-Sample t-Test Results

Variable	t-value	Sig. (p)
Pre-test – Post-test	18.72	0.000

The statistical analysis yielded a significance value of $p < 0.05$, indicating a statistically significant difference between pre-test and post-test scores. These findings confirm that the implementation of the ESD-based e-module significantly improved students' critical thinking skills.

In addition, the effect size was calculated using Cohen's d and obtained a value of 1.12, which is categorized as a large effect size. This result indicates that the intervention produced not only statistical significance but also a strong practical impact on students' critical thinking development.

The comparison between pre-test and post-test scores is visually illustrated in Figure 2, which demonstrates a clear increase in students' performance after the use of the ESD-based e-module.

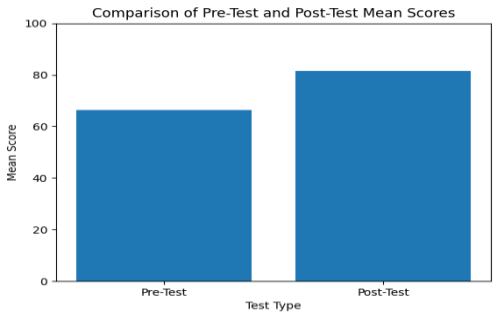


Figure 2. *Pre-Test* and Post-Test Mean Score Comparison

B. Discussion

The findings demonstrate that chemistry instruction grounded in Education for Sustainable Development (ESD) and implemented through an e-module significantly improved junior high school students' critical thinking skills. This enhancement is reflected in the higher post-test mean scores compared to the pre-test results, the moderate-to-high gain score category, and the statistically significant outcome of the paired-sample t-test analysis.

Improvement in students' critical thinking abilities is closely associated with the distinctive features of the developed e-module, which integrates chemical reaction concepts with sustainability issues closely related to students' everyday experiences, including waste management and water pollution. The contextualization of scientific concepts within authentic environmental challenges encourages learners to examine real-world problems, assess the environmental consequences of chemical reactions, and formulate evidence-based conclusions. These findings are consistent with (Sobari & Ramalis, 2022) and (Sastradewi & Agung, 2022), who assert that ESD-oriented learning promotes higher-order thinking skills by actively involving students in sustainability-centered problem-solving activities.

Enhancement in the evaluative and inferential dimensions of critical thinking is also influenced by the interactive components incorporated into the e-module, such as reflective prompts, structured problem-solving tasks, and visual simulations. This instructional approach transforms learning from passive content absorption into an active process of knowledge construction, requiring students to evaluate alternative solutions and develop predictions grounded in chemical principles. Similar conclusions were reported by (Saputra *et al*., 2025) and (Arni *et al*., 2024) who found that interactive digital learning media effectively facilitate the development of students' critical thinking skills.

The moderate-to-high gain score classification indicates that the ESD-based e-module serves not only as a digital instructional resource but also as an instrument for fostering essential 21st-century competencies, particularly critical thinking. This interpretation aligns with (Sulistyaningrum *et al*., 2023) and (Andriani & Izzati, 2020), who concluded that contextualized e-modules contribute to strengthening students' analytical reasoning and decision-making abilities in science education.

The overall findings are consistent with prior studies highlighting the importance of integrating Education for Sustainable Development (ESD) into science education to improve learning quality and sustainability awareness (Fredriksson *et al*., 2020), (Riess *et al*., 2022) and (Vilmala *et al*., 2022). Previous research has predominantly focused on curriculum analysis, policy alignment, teacher competence, or general pedagogical approaches for ESD implementation (Weng *et al*., 2020), (Ershad, 2022) and (Nugroho *et al*., 2025). Although several studies have reported the effectiveness of ESD-based digital learning media, such as mobile learning or digital comics, in enhancing students' sustainability awareness and engagement (Fibonacci *et al*., 2020) and (Ramadhany *et al*., 2024), empirical evidence specifically examining systematically designed ESD-based e-modules in junior

high school chemistry learning remains limited.

This study extends existing literature by providing empirical evidence that an ESD-based e-module on chemical reactions and their dynamics not only enhances students' sustainability awareness but also significantly improves their critical thinking skills. By explicitly linking chemical concepts with real-world sustainability issues, the e-module offers a more contextualized and reflective learning experience, thereby reinforcing the pedagogical potential of ESD-oriented digital learning materials in science education.

However, this study employed a one-group *pretest–posttest* design without a control group, which may limit causal generalization. Future research involving experimental and control groups is recommended to strengthen internal validity.

CONCLUSION

This study demonstrates that the implementation of an Education for Sustainable Development (ESD) based e-module on chemical reaction topics effectively enhances junior high school students' critical thinking skills. The significant difference between pre-test and post-test scores, supported by a moderate-to-high gain score classification, indicates that contextualizing chemical concepts within sustainability issues such as waste management and water pollution contributes meaningfully to students' cognitive development. The integration of real-world environmental problems encourages analytical reasoning, evaluation of alternative solutions, and evidence-based conclusion drawing, while the interactive features embedded in the e-module promote active knowledge construction and higher-order thinking processes. These findings confirm that ESD-oriented digital learning materials not only strengthen students' conceptual understanding but also support the development of 21st-century competencies, particularly critical thinking. However, this study has several limitations that should be considered when interpreting the results. The intervention was conducted within a relatively short duration and involved a limited sample from a single junior high school, which may restrict the generalizability of the findings to broader educational contexts. In addition, the study employed a quasi-experimental design without a fully randomized control group, potentially influencing the internal validity of the results.

Despite these limitations, the findings provide meaningful evidence of the pedagogical value of integrating ESD principles into science instruction through systematically designed e-modules. The results highlight the potential of ESD-based digital learning materials as an effective approach to improving the quality of junior high school chemistry learning, while also indicating the need for future studies with larger samples, longer implementation periods, and more rigorous experimental designs to strengthen the generalization of the findings.

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