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From Environmental Context to Digital Learning: Developing and Evaluating an Environment-Based Practicum E-Module for Green Chemistry

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Abstract: This study aims to develop an Environment-Based Practicum E-Module for green chemistry and to evaluate its validity, practicality, and effectiveness. The study employed a Research and Development (R&D) method using the three-dimensional (3-D) development model, which consists of the Define, Design, and Develop stages. The participants were 28 tenth-grade students from Class X-A at SMAS Mujahidin Pontianak. Data were collected through interviews, classroom observations, expert validation sheets, student response questionnaires, and pretest–posttest assessments. The effectiveness evaluation in the Develop stage employed a one-group pretest–posttest design, with students completing a pretest before using the e-module and a posttest after the learning intervention. The data were analyzed using percentage analysis to determine the validity and practicality of the e-module, while its effectiveness was evaluated using the Normalized Gain (N-Gain) index. The results indicated that the developed e-module achieved average validity scores of 96% from material experts, 98% from media experts, and 98% from language experts, all of which were classified as highly valid. The practicality evaluation yielded an average score of 84%, indicating that the E-Module was highly practical. In addition, the effectiveness test produced an average N-Gain score of 0.86, which falls within the high category, as reflected by the increase in students' mean scores from 85 on the pretest to 98 on the posttest. These findings demonstrate that the Environment-Based Practicum E-Module is valid, practical, and effective, making it a suitable digital instructional resource for supporting green chemistry learning, particularly in schools with limited laboratory facilities.

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Introduction

Education for Sustainable Development (ESD) is an educational framework that promotes the integration of knowledge across multiple disciplines by employing interdisciplinary and transdisciplinary approaches. Its primary objective is to prepare learners with the knowledge, skills, values, and competencies required to act as responsible agents of change while encouraging ongoing critical reflection on educational practices and the cultural values that support sustainable development (Perasso & Reiss, 2019). Education for Sustainable Development (ESD) has become an essential approach for advancing the Sustainable Development Goals (SDGs) by enabling learners to acquire the knowledge, skills, and competencies needed to respond effectively to sustainability-related issues (Foley, 2021). Within the Indonesian educational context, ESD represents a promising framework that can support sustainable development while enhancing the overall quality of education.

The objectives of green chemistry education strongly reflect the principles of Education for Sustainable Development (ESD), as it encourages students to recognize the

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environmental consequences of chemical practices, cultivate responsible attitudes toward environmental stewardship, and develop the competencies needed to solve sustainability-related problems, such as reducing waste and promoting the use of renewable resources (Wahid et al., 2025). In the Indonesian education system, green chemistry has become an integral component of the Merdeka Curriculum and is formally included as a mandatory subject area in senior high school chemistry courses (Pertiwi & Wahyuningrum, 2024). The concept of green chemistry refers to the design of chemical products and processes that reduce or eliminate the use and production of hazardous substances by prioritizing waste minimization, safer solvents, catalytic methods, renewable raw materials, and greater energy efficiency (Maulidiningsih et al., 2023).

Various pedagogical strategies and learning resources have been introduced to support the implementation of green chemistry education in schools. Among these are project-based learning activities that incorporate green chemistry principles into the creation of environmentally sustainable products (Saptorini et al., 2014). Problem-based learning approaches that engage students in examining environmental problems related to chemical practices (Rosita et al., 2014) and simple experimental activities that utilize natural materials easily obtained from the local environment (Sofia et al., 2022; Yuniar et al., 2019). Although these initiatives have contributed to the advancement of green chemistry instruction, much of the existing research has concentrated on printed teaching modules and traditional student worksheets (LKPDs). As a result, interactive and context-oriented digital learning materials that include environmentally based practicum guides and can be broadly accessed are still relatively scarce (Aliah et al., 2024).

Environment-based practicum learning involves experimental activities that utilize materials readily available in the surrounding environment, including river water, soil, sand, plant-derived materials, organic waste, and other naturally occurring resources (Liswijaya et al., 2025). Through these activities, students are able to strengthen their laboratory competencies while gaining experience in conducting experiments that prioritize environmentally friendly practices by using safer chemical substances and methods designed to reduce hazardous waste generation (Paristiowati et al., 2019). The growing urgency of environmental issues, such as pollution, climate change, and the accumulation of toxic waste, highlights the importance of incorporating environment-based practicum learning into chemistry education (Djangi et al., 2024). By connecting theoretical concepts with authentic environmental situations, these practicum activities encourage students to recognize the relevance of chemistry in environmental protection and support the development of sustainable attitudes and practices.

Developing an environment-based practicum e-module for green chemistry offers a promising strategy to overcome existing educational constraints while maintaining the effectiveness of the learning process. The e-module functions as an interactive digital learning resource that combines conceptual explanations with practicum activity instructions based on the use of simple tools and locally available materials, including household kitchen ingredients, domestic waste, and natural resources from the surrounding environment (Umar et al., 2023). By incorporating these accessible materials into practicum activities, students can actively explore green chemistry concepts through direct experimentation, even in schools with limited laboratory facilities (Listyarini et al., 2019). Consequently, this environment-based practicum e-module has the potential to address current challenges in chemistry education by providing an accessible and effective alternative for practicum learning.

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Previous studies have demonstrated the successful development of chemistry practicum e-modules that are both valid and appropriate for instructional use. Wahida *et al.* (2020) developed a green chemistry-based environmental chemistry practicum module that was rated as highly feasible, achieving an average validation score above 3.4 and receiving positive responses from students, with an average response score exceeding 0.49. More recently, Sayyidatuzzahrah *et al.* (2025) developed a green chemistry-based practicum e-module on reaction rate topics, which achieved an Aiken's V validity index of 0.9, indicating a very high level of validity, while also demonstrating excellent practicality based on highly positive student responses. However, previous studies have not specifically developed an environment-based green chemistry practicum e-module that integrates contextual problems, simple practical activities, observation sheets, and discussion questions for schools with limited laboratory facilities. Unlike a conventional digital module, the developed e-module guides students from identifying environmental problems to conducting practical activities and drawing conclusions. This integration represents the main novelty of the present study and provides an accessible and contextual resource for Grade 10 green chemistry at SMAS Mujahidin Pontianak.

In light of these conditions, there is a need for an innovative and contextually relevant learning solution to support the implementation of Education for Sustainable Development (ESD) in chemistry education, particularly in green chemistry instruction. The present study proposes the development of an environment-based practicum e-module as a digital learning resource that integrates green chemistry concepts with simple practicum activities using materials and equipment readily available in the surrounding environment. The e-module is expected to assist teachers in delivering more meaningful learning experiences, enhance students' motivation and conceptual understanding, and foster greater awareness of the importance of applying sustainability principles. Consequently, the development of this environment-based practicum e-module is anticipated to provide a relevant and practical instructional resource for schools with limited laboratory facilities, particularly SMAS Mujahidin Pontianak.

Research Method

This study employed a Research and Development (R&D) method using the Four-D (4-D) development model, which was adapted into a three-stage (3-D) model consisting of the Define, Design, and Develop phases, while excluding the Disseminate phase (Thiagarajan et al., 1974; Rahayu, 2025). The Define phase was conducted to identify and determine instructional needs through five activities: front-end analysis, learner analysis, task analysis, concept analysis, and the formulation of learning objectives. The Design phase involved developing assessment criteria, selecting appropriate instructional media, determining the e-module format, and preparing the initial prototype of the e-module. The Develop phase included expert validation, a limited field trial, product revision, a large-scale field trial, and the production of the final version of the e-module. The target population of this study included all tenth-grade students at SMAS Mujahidin Pontianak. A sample of 28 students from Class X-A was selected using purposive sampling based on the suitability of the class with the research objectives and implementation conditions, whereby all members of the class participated in the field testing of the developed e-module.

Data collection involved observations, interviews, and a set of questionnaires. Observations were undertaken to identify the current learning environment and classroom practices in chemistry, whereas interviews were conducted during the preliminary stage to support the needs assessment. Three research instruments were utilized in this study. The first

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instrument was an e-module validation form completed by subject matter specialists, media specialists, and language specialists using a four-point Likert scale consisting of Strongly Agree, Agree, Disagree, and Strongly Disagree. The second instrument was a student questionnaire designed to examine the practicality of the developed e-module, focusing on aspects such as visual presentation, ease of navigation, content quality, the incorporation of an environment-based learning approach, and overall user experience. The third instrument comprised pretest and posttest assessments used to evaluate the effectiveness of the e-module in enhancing students' understanding of green chemistry. The pretest was administered before students used the e-module to determine their baseline knowledge, while the posttest was conducted after the instructional intervention to measure improvements in students' learning achievement. The validity of the developed e-module was evaluated by subject matter experts, media experts, and language experts. The validity score was calculated by comparing the total score obtained with the maximum possible score using the following formula:

$$Percentage = \frac{Total\ Score\ Obtained}{Maximum\ Possible\ Score} \times 100\%$$

Table 1. Validation Assessment Criteria

Percentage	Category
81% – 100%	Highly Valid
61% – 80%	Valid
41% – 60%	Moderately Valid
20% - 40%	Less Valid
0% - 20%	Invalid

(Azkiya et al., 2022)

The practicality of the developed e-module was assessed based on students' responses collected through a questionnaire. The practicality score was calculated using the following formula:

$$Percentage = \frac{Total\ Score\ Obtained}{Maximum\ Possible\ Score} \times 100\%$$

Table 2. Practicality Assessment Criteria

Percentage	Category
0% - 20%	Not Practical
21% - 40%	Less Practical
41% – 60%	Moderately Practical
61% – 80%	Practical
81% – 100%	Highly Practical

(Azkiya et al., 2022)

The effectiveness of the developed e-module was evaluated using the Normalized Gain (N-Gain) proposed by Hake (1998). The N-Gain score was calculated using the following formula:

$$N - Gain = \frac{Posttest\ Score - Pretest\ Score}{Maximum\ Score - Pretest\ Score}$$

Table 3. N-Gain Classification Criteria

N-Gain	Category
g > 0,7	High
0,3 ≤ g ≤ 0,7	Moderate
0 < g < 0,3	Low
g ≤ 0	No Gain

(Kamal et al., 2018)

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Results and Discussion

The findings indicate that the developed Environment-Based Practicum E-Module for Green Chemistry satisfies the criteria for use as a digital instructional resource. Its feasibility is supported by the results of the needs analysis that informed the development process, the quality of the e-module design, expert validation outcomes, students' responses following its implementation, and the improvement in students' learning outcomes. The results of the study, including the needs analysis, product design, validity, practicality, and effectiveness of the developed e-module, are presented and discussed in the following sections.

1) Define Phase

The needs analysis was conducted to identify instructional challenges, existing learning conditions, and students' learning needs as the basis for developing the Environment-Based Practicum E-Module for Green Chemistry. This stage corresponded to the define phase of the adapted 3-D development model, which comprised front-end analysis, learner analysis, task analysis, concept analysis, and the formulation of learning objectives. The analysis was carried out through interviews with chemistry teachers and classroom observations at SMAS Mujahidin Pontianak to obtain information relevant to the development of the e-module.

The results of the needs assessment indicated that green chemistry lessons were mainly conducted through teacher-centered instruction, with textbooks and online resources serving as the principal sources of learning. Environment-based practicum activities had not yet been incorporated into classroom instruction because of inadequate laboratory facilities, limited equipment, and insufficient experimental materials, causing the learning process to focus primarily on theoretical content. As a result, many students found it difficult to relate green chemistry concepts to environmental issues encountered in their daily lives. Despite these limitations, most students had access to smartphones and regularly used digital technology to support their learning. These findings provided the basis for developing an Environment-Based Practicum E-Module that enables independent learning while guiding students through practicum activities using simple equipment and materials available in their local surroundings. This finding is consistent with previous studies showing that e-modules can improve learning flexibility and encourage self-directed learning (Najuah et al., 2020), while contextual digital learning resources have been found to enhance students' active participation and engagement during the learning process (Delima et al., 2021).

2) Design Phase

The design phase focused on developing the structure of the e-module, which comprised a cover page, preface, table of contents, concept map, introduction, learning materials, five environment-based practicum activities, observation sheets, discussion questions, a glossary, and a closing section. The learning content was developed in accordance with the Learning Outcomes (CP) and Learning Objectives Flow (ATP) specified in the Merdeka Curriculum, while integrating green chemistry principles throughout each practicum activity. In addition to promoting conceptual understanding, the instructional materials were designed to enable students to relate green chemistry concepts to environmental issues encountered in everyday life. This approach is consistent with the perspective of Anastas & Warner (2000), who emphasized that green chemistry education should promote the use of safer materials, waste prevention, and the adoption of sustainable chemical processes. A key feature of the developed e-module is the inclusion of five environment-based practicum activities. Each activity was designed using simple tools and locally available materials, allowing practical work to be carried out even in schools with limited laboratory facilities. By presenting contextual practicum activities, the e-module is

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expected to provide students with authentic learning experiences that encourage them to apply green chemistry concepts beyond theoretical understanding and into real-life situations. Previous research by Delima et al. (2021) demonstrated that systematically designed e-modules incorporating contextual learning activities can enhance student engagement and create more meaningful learning experiences. Likewise, Siagian et al. (2024) reported that integrating green chemistry-based practicum activities into e-modules provides students with opportunities to develop science process skills while strengthening their environmental awareness. The overall design of the developed e-module is presented below.

Figure 1. Cover of the Environment-Based Practicum E-Module

Figure 2. Concept Map of the Environment-Based Practicum E-Module

Figure 3. Practicum Activity Section of the Environment-Based Practicum E-Module

3) Develop Phase

The development phase involved an expert validation process to ensure that the developed Environment-Based Practicum E-Module met the required standards of validity. The validity of the e-module was assessed by subject matter, media, and language experts, while its practicality was evaluated through a student response questionnaire. The findings obtained during the development phase are presented in the following sections.

a) Validity of the Environment-Based Practicum E-Module for Green Chemistry

The validity of the e-module was examined through a systematic expert review. A total of nine validators participated in the evaluation, including three subject matter experts (two university lecturers and one chemistry teacher), three media experts (two university lecturers and one teacher), and three language experts (two university lecturers and one teacher). Each validator was appointed according to their professional expertise in the relevant area of assessment. The e-module underwent revisions based on the comments and suggestions provided during the validation process before being finalized for implementation.

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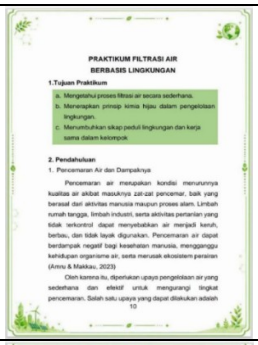
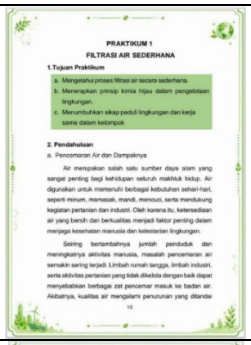
Table 4. Suggestions and Revisions from the Validators

Comments and Suggestions	Revision	
	Before	After
"The introduction to each practicum activity should begin with a real-world problem encountered in everyday life and gradually lead students toward an appropriate solution"		
"The image resolution should be improved"		
"The e-module contains several typographical errors. **"**		

Product revision is an integral component of research and development because it provides an opportunity to improve the quality of the product before it is introduced to the target users. In the present study, the developed e-module was refined according to the comments and recommendations provided by the expert validators, resulting in improvements to its instructional content and overall design. These findings are in agreement with Rahma et al. (2024), who found that revisions based on expert evaluation contributed substantially to improving the quality of an e-module and resulted in very high validity across all assessment criteria. Comparable findings were reported by Siagian et al. (2024), who highlighted that the validation and revision stages play a fundamental role in ensuring the relevance of the learning content, the effectiveness of the media design, and the clarity of the language, thereby producing instructional materials that are better aligned with educational requirements. After incorporating the recommendations provided by the expert validators, the e-module was re-evaluated to confirm its overall quality. The final validation results indicated that the content aspect achieved a score of 96%, whereas both the media and language aspects reached 98%, placing all assessment components within the highly valid category (Azkiya et al., 2022). The validation outcomes for each assessment aspect are illustrated in the following figure.

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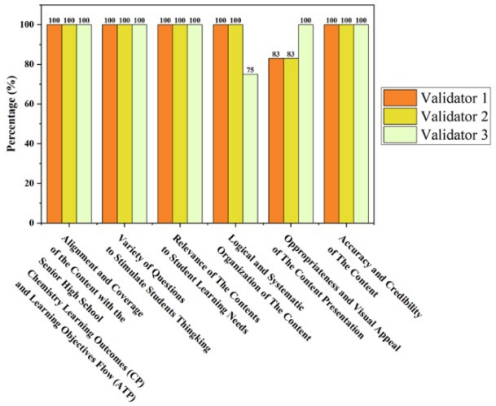

Figure 4. Results of the Subject Matter Expert Validation of the Environment-Based Practicum E-Module

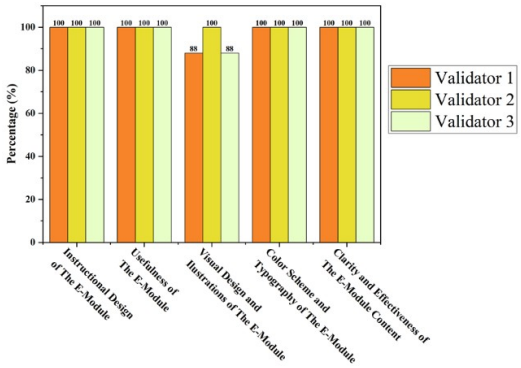

Figure 5. Results of the Media Expert Validation of the Environment-Based Practicum E-Module

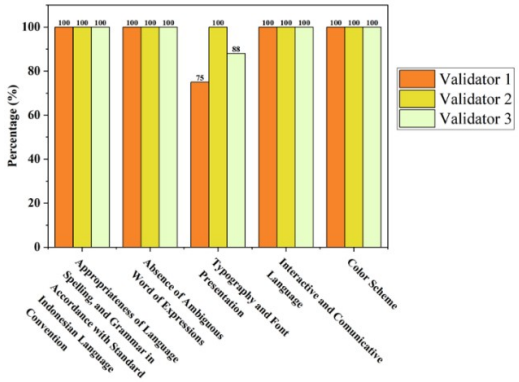

Figure 6. Results of the Language Expert Validation of the Environment-Based Practicum E-Module

These outcomes suggest that the developed e-module fulfills the essential criteria related to content accuracy, instructional organization, visual presentation, and language quality, supporting its use as a digital learning resource for green chemistry. The consistently high validation scores reflect the effectiveness of the development process, which included needs analysis, instructional planning, expert review, and iterative revision. Through these stages, the resulting e-module was successfully adapted to students' learning characteristics and classroom requirements. This finding is consistent with previous research demonstrating that the quality of instructional materials depends on meeting acceptable standards of content, media, and language validity. Similarly, Rahma et al.

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(2024) concluded that incorporating expert recommendations during the revision process significantly enhanced the quality of an e-module, allowing it to attain a highly valid rating.

b) Students' Responses to the Environment-Based Practicum E-Module for Green Chemistry

Students' responses were gathered during the field implementation to examine the practicality of the developed e-module. Feedback was obtained using an 11-item Likert-scale questionnaire designed to evaluate five dimensions: (1) the visual design of the e-module, (2) usability, (3) the quality of the learning content, (4) the integration of an environment-based learning approach, and (5) the overall benefits of the e-module. The field trial was conducted with 28 students from Class X-A, who used the e-module during the complete instructional session, including environment-based practicum activities and the completion of discussion worksheets. The findings revealed that all evaluation aspects were rated within the highly practical category, with an overall average percentage of 84%. Among the assessed dimensions, the environment-based learning approach received the highest score (87)**,** whereas usability obtained the lowest score (81%). Despite this difference, all aspects satisfied the criteria for a highly practical learning resource. The results for each practicality aspect are illustrated in the following figure:

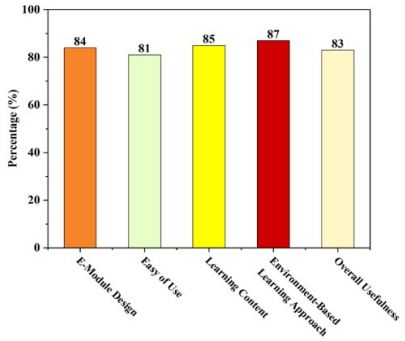

Figure 7. Results of the Practicality Analysis of the Environment-Based Practicum E-Module Based on Students' Responses

These results indicate that the e-module is easy to use, engaging for students, and supports their understanding of green chemistry through simple practical activities. The favorable practicality score may be attributed to the systematic organization of the learning materials, clear and informative illustrations, and practical procedures that are easy to follow. In addition, smartphone accessibility allows students to learn more flexibly both inside and outside the classroom. These findings are consistent with Najuah et al. (2020), who reported that e-modules support independent learning through flexible access to learning materials. Maharni et al. (2021) also found that digital e-modules are highly practical because they are easy to use and encourage student engagement. Similar results were reported by (Leny et al., 2024), whose chemistry e-module achieved a practicality score of 84.46%. More specifically, Sayyidatuzzahrah *et al.* (2025) reported 91% practicality for a green chemistry-based practicum e-module. These findings strengthen the evidence that well-structured and contextual e-modules can provide practical and accessible learning resources for chemistry education.

c) Effectiveness of the Environment-Based Practicum E-Module for Green Chemistry

The effectiveness of the e-module was determined by analyzing students' learning gains using the Normalized Gain (N-Gain) derived from the pretest and posttest results. Students' mean score increased from 85 on the pretest to 98 on the posttest, producing an N-

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Gain score of 0.86, which is classified as high according to the established criteria (Kamal et al., 2018). The results of the N-Gain analysis are presented in the following figure:

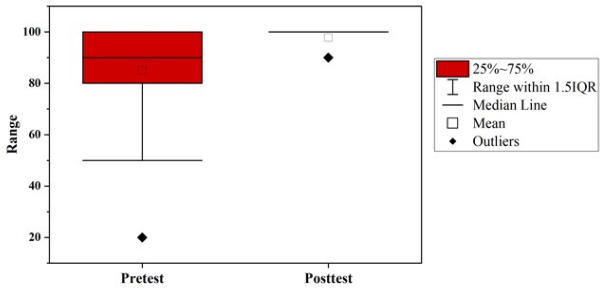

Figure 8. Results of the N-Gain Analysis of the Environment-Based Practicum E-Module

This outcome demonstrates that the Environment-Based Practicum E-Module contributed positively to improving students' achievement in green chemistry learning. The substantial increase in students' performance is likely associated with the integration of theoretical concepts and environment-based practicum activities throughout the learning process. This instructional approach enabled students to strengthen their conceptual understanding by observing real phenomena, performing simple experiments, interpreting experimental findings, and formulating conclusions based on their observations. The present findings are consistent with Hake's (1998) classification, in which N-Gain values above 0.70 indicate a high level of learning improvement. Similar findings were reported by Siagian et al. (2024) and Khoirunnisa et al. (2024), who found that green chemistry-based e-modules can improve students' conceptual understanding and learning outcomes through contextual materials and practical activities. Astuti et al. (2021) also found that a Green Chemistry-based e-module contributed to improving students' higher-order thinking, with an N-Gain of 0.647 in the moderate category. These findings support the present result, indicating that the integration of digital learning materials with contextual and Green Chemistry-oriented learning activities can contribute to improving students' learning outcomes.

Conclusion

The present study resulted in the development of an Environment-Based Practicum E-Module for green chemistry by applying the adapted 4-D development model up to the Develop phase. Findings from the expert assessment indicated that the e-module met the criteria for high validity, obtaining validation scores of 96% from subject matter experts, 98% from media experts, and 97% from language experts. In terms of practicality, students' evaluations produced an average score of 84%**,** reflecting that the e-module is easy to use, engaging, and appropriate for supporting the learning process. The effectiveness analysis showed an N-Gain value of 0.86, which is categorized as high, indicating a substantial improvement in students' learning outcomes after using the developed e-module. Taken together, these findings demonstrate that the Environment-Based Practicum E-Module fulfills the requirements of validity, practicality, and effectiveness. Therefore, it can be considered an appropriate digital learning resource for teaching green chemistry to tenth-grade senior high school students.

Recommendation

The next research should involve larger and more diverse samples and, where possible, comparison groups to provide stronger evidence of the e-module's effectiveness.

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Further studies may also examine its impact on students' scientific process skills, environmental awareness, and higher-order thinking.

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