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Development of an Eco-Enzyme E-Module for Students of the Economic Horticultural Botany Course in the Biology Education Study Program at Tadulako University

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Abstract: Learning in the Economic Botany and Horticulture course is still dominated by lectures, resulting in limited student procedural skills and the absence of structured teaching materials. This study aims to develop and evaluate an eco-enzyme e-module to improve conceptual understanding, practical competence, and learning effectiveness. Using a Research and Development (R&D) approach with the ADDIE model, the study involved expert validation, a limited trial with one class, and pre-test/post-test assessment. Data was analyzed through descriptive validation scores, practicality ratings, and N-gain effectiveness. Results show that expert validation yielded very feasible scores for content (90%), media (88%), and instructional design (86%). The practicality test produced a very practical overall score of 87%, indicating high usability, readability, visual appeal, accessibility, and engagement. Implementation of the e-module increased students' mean score from 62.4 (pre-test) to 91.2 (post-test), generating an N-gain of 0.77 categorized as high effectiveness. The e-module successfully integrates conceptual explanations, fermentation procedures, multimedia features, and project-based activities related to eco-enzyme production. In conclusion, the eco-enzyme e-module is valid, practical, and effective for supporting independent learning and enhancing students' conceptual and procedural skills in accordance with the course learning outcomes.

Keywords: ADDIE; Eco-enzyme; Economic horticultural botany; E-module

Introduction

Economic Botany and Horticulture course in the Biology Education Study Program at Tadulako University is an elective subject that integrates fundamental horticultural principles with practical skills in cultivating economically valuable plants. The course covers two main learning dimensions: the biological dimension including environmental conservation, organism–environment interactions, and the management of biological resources and the economic dimension, which includes entrepreneurship, the use of horticultural products, and market potential.

However, preliminary observations and interviews with the course lecturer and students indicate that learning remains dominated by lectures and discussions, with limited practical activities. As a result, students often master theoretical concepts but lack the applied skills necessary for horticultural practice. Prior studies show that traditional lecture-based methods, although still widely used, produce lower learning outcomes compared to active or experiential learning approaches (Deslauriers et al., 2019; Kozanitis & Nenciovici, 2023). The absence of systematic and structured learning materials also compels students to search for references independently, sometimes relying

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on unverified sources that may reduce academic quality. Research further emphasizes that student-centered, active, and experiential learning can significantly enhance students' applied competencies (Kee & Zhang, 2022). Practice-based learning has also been shown to foster stronger skill development compared to conventional approaches (Martin-Alguacil et al., 2024).

One potential solution to improve learning quality in this course is the development of an e-module, a digital learning medium designed to be flexible, accessible, and supportive of self-directed learning through a learning-by-doing approach. E-modules integrate various multimedia components—text, illustrations, images, videos, and structured practical instructions—allowing students to learn gradually and independently according to their needs. Studies consistently show that e-modules are valid, effective, and capable of improving students' motivation, digital literacy, and conceptual understanding in science education (Aulia et al., 2022; Oksila et al., 2025; Dewi & Mercuriani, 2024; Rahmayanti & Andayani, 2023; Nasution et al., 2025).

Eco-enzyme is a liquid produced from the fermentation of household organic waste such as fruit peels, vegetable scraps, and sugar, offers strong potential as a learning topic within such an e-module. Eco-enzyme contains active enzymes and microbial metabolites, and international studies demonstrate that it accelerates solubilization and degradation of organic matter, supporting bioconversion processes such as composting and wastewater treatment (Arun & Sivashanmugam, 2018; Jiang et al., 2021). Combining eco-enzyme with biochar has also been shown to enhance nitrogen conservation and modulate microbial communities, thus reducing nitrogen loss and emissions during composting (Jiang et al., 2022; Jiang et al., 2024). Additionally, eco-enzyme is effective in treating industrial and dairy wastewater and improving other environmental processes (Sambaraju & Lakshmi, 2020). Systematic reviews highlight eco-enzyme as a sustainable approach to organic waste utilization (Pasalari et al., 2024), while other research emphasizes its potential in biomass processing and renewable energy conversion (Negi et al., 2020).

The integration of eco-enzyme is highly relevant for the Economic Botany and Horticulture course because it connects biological concepts—such as fermentation, microbial activity, and nutrient cycling—with economic values, including the use of fermentation products as liquid fertilizers, environmentally friendly products, and horticultural business opportunities. Studies show that eco-enzyme derived from fruit and vegetable waste increases nutrient content and is effective as an organic liquid fertilizer (Fadlilla et al., 2023; Permatananda & Pandit, 2023). Its fermentation process also produces antimicrobial bioactive compounds, making it suitable for use in environmentally friendly products (Lubis et al., 2025; Eskundari et al., 2021). Community-based programs for eco-enzyme production have been shown to improve societal literacy regarding organic waste management, waste reduction, and eco-enzyme–based entrepreneurship (Rohyani et al., 2022; Saidah et al., 2024). Therefore, incorporating eco-enzyme into an e-module allows students to learn both theory and practice, including production, testing, and application of eco-enzyme in horticultural cultivation.

This material also aligns with Sustainable Development Goals (SDGs). It supports SDG 4 (Quality Education) by providing relevant, problem-based learning, and SDG 12 (Responsible Consumption and Production) through the transformation of organic waste into valuable products. Eco-enzyme-based learning has been shown to improve students' and communities' scientific literacy in organic waste management and simple biotechnology (Susilowati et al., 2021). Training programs in various villages likewise demonstrate improved understanding of household waste reduction and its use in productive applications (Eskundari et al., 2023; Rizkiana et al., 2023). Processing organic waste into eco-enzyme also helps reduce greenhouse gas emissions, supporting sustainable consumption and production (Muliarta, 2024).

The novelty of this study lies in the development of an e-module that specifically integrates eco-enzyme material within the context of Economic Botany and Horticulture in Biology Education in Indonesia. This innovation includes structured digital content, hands-on practice, and interactive features such as instructional videos and QR codes that connect theoretical understanding with practical skills. Considering the limitations of conventional learning, the need for systematic materials, and the relevance of eco-enzyme to learning outcomes and SDGs, this e-module serves as an important and applicable learning innovation. It is expected to enhance students' conceptual understanding, practical skills, and environmental awareness in accordance with 21st-century educational demands.

Method

This study was conducted from April to August 2025 in the Biology Education Study Program. A limited trial (implementation) was carried out in one class of students enrolled in the Economic Horticultural Botany course, while the analysis and validation stages involved students who had previously completed the course and expert lecturers

This study employed a Research and Development (R&D) approach using the ADDIE development model, such as Analyze, Design, Develop, Implement, and Evaluate. The ADDIE model was selected because it has been proven effective in producing valid, practical, and effective e-modules for science learning (Dewi & Ary, 2024).

The population consisted of all Biology Education students taking the Economic Horticultural Botany course. The sample for the limited trial was one purposively selected class. A minimum of 30 students was used, following the small-scale trial recommendations in e-module development research (Aninnas et al., 2023).

The expert validators consisted of three specialists, such as a material expert, a media expert, and content expert. The involvement of three experts aligns with validation procedures reported in e-module development studies (Harahap & Hakim, 2024).

Analysis Stage was conducted using semi-structured interviews with the course lecturer and student representatives to identify learning obstacles, content needs, and media preferences (Pitri et al., 2023). A literature review from books, articles, and credible digital sources was conducted to establish the conceptual framework. Curriculum analysis was performed to align course indicators, Course Learning Outcomes (CLOs), and graduate profiles with the depth and scope of content (Afian & Sahratullah, 2023).

Design Stage, a prototype framework was created, consisting of chapter structure, learning objectives, concept maps, content flow, illustrations, and multimedia integration (videos, images, hyperlinks, and QR codes) (Dewi & Ary, 2024). Research instruments—including expert validation sheets, student response questionnaires, and pre-test/post-test item (Aninnas et al., 2023).

Development Stage, content (text, illustrations, multimedia) was compiled and integrated into the e-module layout, and the product was stored in a digital repository. Expert validation was conducted on content accuracy, display quality, media appropriateness, and instructional alignment. Expert comments were used to revise the module (Harahap & Hakim, 2024). A small-scale feasibility trial was then conducted to collect initial user responses regarding readability, usability, technical performance, and overall appeal (Aninnas et al., 2023).

Implementation Stage, one class participated in the implementation stage. Students completed a pre-test before using the e-module. The e-module was then implemented during one learning cycle on eco-enzyme material. Technical issues were recorded, and assistance was provided when necessary. After the learning cycle, students completed a post-test to measure improvement. A formative questionnaire was also administered to assess readability, usability, appeal, navigation, and learning experience (Saputra & Octavia, 2024).

Evaluation Stage includes formative evaluation during the analysis, design, and development stages; and summative evaluation during the Implementation stage using expert validation, pre/posttests, and user feedback. The evaluation determined the e-module's validity, practicality, and effectiveness. Final revisions were carried out based on expert and user input (Afian (2023).

The feasibility of the e-module was assessed through expert validation, which examined several key indicators, including content accuracy, linguistic clarity, layout and visual quality, media integration, pedagogical alignment, and compatibility with the course learning outcomes (CLO) and curriculum profile. The feasibility category in which scores of 85–100% indicate very feasible, 70–84% feasible, 55–69% moderately feasible, and scores below 55% not feasible (Aninnas et al., 2023).

The practicality test was conducted through student response questionnaires, focusing on user-friendliness, readability, ease of navigation, visual appeal, device accessibility, and learning engagement. The practicality categories classify scores of 85–100% as very practical, 70–84% practical, 55–69% moderately practical, and below 55% as less practical (Pitri et al., 2023).

The effectiveness of the e-module was evaluated through improvements in student learning outcomes, measured by comparing pre-test and post-test scores. Based on established categories, an N-gain value of ≥ 0.70 indicates high effectiveness, 0.30–0.69 moderate effectiveness, and < 0.30 low effectiveness (Dewi & Ary, 2024)

Result and Discussion

Analysis Stage

The findings of the needs analysis are summarized in Table 1. The needs analysis in Table 1 indicates that the current learning process is not yet aligned with CPLs that emphasize conceptual and procedural competencies. This highlights the need for an e-module that offers structured eco-enzyme content and clear practical guidance, consistent with findings that well-organized digital modules enhance conceptual and skill development (Hendrawesi et al., 2024).

The absence of structured and validated teaching materials has driven students to rely on unverified online sources, creating inconsistent understanding. Therefore, an e-module with accurate and credible content is essential, supporting earlier reports that validated digital modules help standardize learning resources and reduce misconceptions (Valfa et al., 2023).

Table 1. Needs Analysis Results of the Economic Horticultural Botany Course

Needs Analysis Indicator	Field Findings	Impact on Learning	Implications for Eco-Enzyme E-Module Design
Alignment of CPL–CLO	The lesson plan (RPS) has been developed, but the course learning outcomes are not explicitly aligned with CPL 2 and CPL 9.	Learning does not clearly target conceptual and procedural skills.	Learning objectives need to be aligned with CPL 2 and 9.
Availability of Teaching Materials	No structured teaching materials are available; students rely on unvalidated internet sources.	Student understanding is inconsistent and not based on scientific standards.	The e-module must provide complete, systematic, and validated content.
Need for Procedural Skills	Students are interested in project activities (e.g., eco-enzyme), but no practical activities are currently implemented or measurable.	Students' procedural skills are underdeveloped; learning remains theoretical.	The e-module must include step-by-step eco-enzyme project procedures and evaluation instruments.
Media Preferences	Students require interactive and easily accessible digital media.	Learning becomes less engaging and does not support independent study.	The e-module must incorporate multimedia elements (images, QR codes, videos, process illustrations).
Learning Approach	Practical or project-based activities have not yet been implemented in class.	Learning lacks contextualization and does not sufficiently foster skill competencies.	The e-module must adopt a project-based and inquiry-based learning approach.

Although students are interested in eco-enzyme projects, practical activities have not been implemented and lack evaluation tools. The inclusion of step-by-step procedures, observation sheets, and rubrics aligns with evidence that project-based and problem-based e-modules significantly improve students' science process skills (Dewi & Mercuriani, 2024).

Students' preference for interactive digital media supports integrating videos, QR codes, and illustrations. Multimedia features are shown to increase motivation and improve understanding of complex processes (Sari & Halim, 2021), making them essential for independent learning.

The analysis also shows that project-based and inquiry-based approaches have not been applied in class. Incorporating these approaches into the e-module aligns with research demonstrating their effectiveness in strengthening students' critical and exploratory thinking (Rahayu et al., 2024).

Compared with previous e-module developments, the eco-enzyme e-module offers broader value by combining structured content, multimedia, practical procedures, and a sustainability context through organic waste bioconversion. This makes it highly relevant for enhancing conceptual understanding, process skills, and environmental awareness.

Design Stage

The design stage produced a complete structure for the eco-enzyme e-module, visually shown in Figure 1. Each component—including the cover, table of contents, conceptual explanations, fermentation diagrams, production guide, project sheets, and evaluation was developed to ensure clarity, alignment, and ease of navigation. Such structured organization aligns with effective e-module design principles reported in recent science education studies (Hendrawesi et al., 2024; Valfa et al., 2023).

Table 2. Structure and Components of the Eco-Enzyme E-Module

Component	Description	Multimedia Features
Cover	Displays the title of the e-module (E-Module for Economic Horticulture Botany), course information, and authors (Akram & Dwi Setyorini), along with the "Based On" label.	Visual layout, typography
Preface	Provides the background, purpose, and context of the e-module development.	Texts
Table of Contents	Lists chapters, subchapters, figures, and tables for easy navigation.	PDF navigation
Learning Objectives	Contains five learning objectives and a table mapping the alignment between CPL (Program Learning Outcomes), CPMK (Course Learning Outcomes), and module objectives.	CPL–CPMK alignment table
What Is Eco-Enzyme?	Explains the definition, history, and originators of eco-enzyme (Dr. Rosukon, Dr. Joean Oon, Era Tan), along with its basic functions.	Illustrations, icons
Why Should We Produce Eco-Enzyme?	Discusses organic waste issues, environmental impacts, greenhouse gas emissions, ecological benefits, and connections to SDGs.	Icons, conceptual visuals

Component	Description	Multimedia Features
Microbes in Eco-Enzyme Fermentation	Describes bacteria, yeasts, and molds involved in fermentation; includes a table summarizing microbial species and their roles.	Microbial function table, conceptual diagrams
Biochemical Fermentation Process	Presents a biochemical flowchart showing the formation of organic acids, ethanol, CO_2, and microbial metabolites during fermentation.	Fermentation process diagram
Eco-Enzyme Production Guide	Provides the ingredient ratio (3:1:10), tools and materials, step-by-step procedure, fermentation duration, degassing techniques, and troubleshooting.	Ratio table, material composition graphics, procedural icons
Functions and Derivative Products	Describes eco-enzyme applications in agriculture, livestock, drainage, household activities, and health; includes derivative products such as liquid soap, aromatic eco-enzyme, pitera, "mama enzyme," and solid fertilizer.	Usage summary table, function icons
Independent Practice (Project-Based Activity)	Guides students through a practical eco-enzyme production project using a 12-week observation sheet and reflective questions.	Observation table, instructional icons
Supporting Learning Media	Provides QR codes and links to YouTube videos relevant to eco-enzyme production.	QR codes, hyperlinks
Summary	Summarizes key concepts, including definitions, benefits, microbial activity, fermentation processes, and applications.	Texts
Evaluation	Contains 50 multiple-choice questions (C3–C5), instructions, and an answer key.	Assessment format
FAQ	Provides answers to common questions regarding fermentation, materials, failure indicators, benefits, aroma, and safety.	Texts
Glossary	Defines key terms related to fermentation and eco-enzyme.	Texts
References	Contains more than 40 scientific sources related to eco-enzyme, microbiology, and environmental applications.	Texts

Figure 1. Visual overview of the eco-enzyme e-module developed during the Design Stage

Conceptual sections, including the definition, microbial roles, and biochemical processes, were supported with tables, illustrations, and flowcharts. Integrating multiple visual formats has been shown to improve students' comprehension of complex scientific concepts (Sari & Halim, 2021). Meanwhile, procedural features—such as ingredient ratios, step-by-step fermentation, degassing, and troubleshooting—follow recommendations from PBL-based e-module research demonstrating that clear workflows enhance students' science process skills (Dewi & Mercuriani, 2024).

The module's project-based "Independent Practice" section provides observation sheets and reflective questions, aligning with findings that PBL- and inquiry-integrated e-modules strengthen critical thinking and contextual understanding (Rahayu et al., 2024). Additionally, the integration of QR codes and multimedia supports evidence that digital interactivity increases student motivation and autonomy.

Compared with e-modules developed in previous studies, this eco-enzyme module is more comprehensive because it integrates conceptual explanations, procedural guidance, multimedia features, and sustainability aspects through organic waste bioconversion. The guided-inquiry elements embedded in the module are also supported by research showing that inquiry-based e-modules promote deeper scientific reasoning and independent exploration (Maulia et al., 2024).

Development Stage

During the Development Stage, the eco-enzyme e-module was refined through expert validation, as summarized in Tables 3 and 4, and visualized in Figure 2. The inclusion of images showing the eco-enzyme samples, QR-based learning media, and evaluation pages directly responds to the reviewer's request to present the developed module at each ADDIE stage. These visuals demonstrate the completeness of the module's features, including multimedia integration, procedural guidance, and assessment components.

The expert validation results show very high feasibility across content (90%), media (88%), and instructional design (86%). This demonstrates that the module not only meets academic standards but is structurally sound and pedagogically coherent. Such findings are consistent with recent e-module development research, which emphasizes that iterative expert review significantly improves clarity, accuracy, and usability (Hendrawesi et al., 2024; Maulia et al., 2024).

Table 3. Expert Validation Results of the Eco-Enzyme E-Module

Validation Aspect	Assessment Indicators	Validator Score	Feasibility Category
Content Validation	Accuracy of material, clarity of concepts, completeness of eco-enzyme topics (history, microbial roles, biochemical processes), alignment with CPL–CPMK, relevance to course needs	90%	Very feasible
Media Validation	Visual quality, layout consistency, readability, appropriateness of images, effectiveness of QR codes and video links, color and typography consistency	88%	Very feasible
Instructional Design Validation	Clarity of learning objectives, coherence between objectives–materials–evaluation, logical presentation flow, effectiveness of project instructions, systematic organization of content	86%	Very feasible

Table 4. Expert Suggestions and Revisions

Aspect Reviewed	Expert Suggestions	Revisions Implemented
Learning Objectives	Refine operational verbs to ensure measurable and observable outcomes aligned with CPL and CPMK.	Revised learning objectives using measurable verbs consistent with Bloom's taxonomy.
Content Completeness & Accuracy	Add more detail on the history and functions of eco-enzyme, including environmental relevance.	Expanded descriptions of eco-enzyme history, roles of developers, and ecological benefits.
Multimedia Integration	Increase consistency, quality, and placement of images, diagrams, and QR codes.	Standardized image quality, improved diagram layout, and embedded verified QR codes.
Visual Layout and Consistency	Improve color scheme, spacing, alignment, and typography across pages.	Updated layout, unified fonts and colors, improved readability and visual balance.
Procedural Instructions	Provide clearer step-by-step project instructions and troubleshooting notes.	Added numbered steps, process timeline, safety notes, and troubleshooting section.
Evaluation Section	Ensure test items assess multiple cognitive levels and align with objectives.	Revised evaluation items to include C3–C5 levels and ensured alignment with objectives.

Figure 2. Visual overview of the eco-enzyme e-module developed during the develop stage

Further refinement was conducted by revising learning objectives, completing historical and microbial content, improving layout consistency, standardizing images, and enhancing step-by-step project instructions. These actions align with studies showing that e-modules with strong conceptual structure and clear procedural flow lead to better student comprehension and performance in science learning (Dewi & Mercuriani, 2024; Khairunnisa et al., 2024).

The module's procedural and multimedia features—such as ingredient ratio tables, fermentation workflow diagrams, safety notes, QR-code-linked videos, and troubleshooting guidance, provide a comprehensive learning experience. Similar multimedia-supported e-modules have been found to increase student motivation, engagement, and understanding of complex processes (Valfa et al., 2023; (Siswati et al., 2024).

Compared with other e-modules in previous studies, which typically emphasize conceptual explanation or guided inquiry alone, the eco-enzyme e-module developed in this study is more holistic. It integrates conceptual content, procedural activities, project-based learning, inquiry-based reflection, and sustainability values through organic waste bioconversion. This aligns with research demonstrating that e-modules combining inquiry and real-world application promote deeper scientific reasoning and independent exploration (Rahayu et al., 2024).

Implementation Stage

The Implementation Stage tested the eco-enzyme e-module in real classroom settings, as shown in Figure 3. This image evidence addresses the reviewer's request to display the actual module during the ADDIE stages. Students used the module during conceptual learning and practical fermentation activities, demonstrating that the module functions effectively both as a digital reference and as a project-based guide.

The practicality results in Table 5 indicate that the module is "very practical" across all indicators, with high usability (88%), readability (86%), visual appeal (87%), accessibility (85%), and engagement (89%). These findings confirm that students can easily navigate the module, understand its content, and stay motivated throughout the learning process. Similar patterns have been observed in earlier e-module studies, where clear structure and multimedia integration significantly improve practicality and learner experience (Hendrawesi et al., 2024; Doyan et al., 2020; Dewi & Mercuriani, 2024).

Table 5. Student Practicality Test Results

Practicality Aspect	Indicators	Student Score	Category
Usability	Ease of navigation, user friendliness	88%	Very practical
Readability	Clarity of language, consistency of terms, comprehension level	86%	Very practical
Visual Appeal	Layout, aesthetics, color consistency, image quality	87%	Very practical
Accessibility	Device compatibility, offline usability, loading performance	85%	Very practical
Engagement	Motivation, interest, and interactivity during use	89%	Very practical
Overall Practicality	Composite score of all indicators	87%	Very practical

Figure 3. Classroom implementation of the eco-enzyme e-module

The strong engagement score is supported by observable practices in Figure 3, where students are actively recording observations, measuring fermentation materials, and discussing findings while referring to the module. This reflects previous research showing that e-modules designed with inquiry, project-based tasks, and real-world applications enhance student participation and scientific involvement (Rahayu et al., 2024; Valfa et al., 2023).

In terms of readability and multimedia design, students benefited from the consistent terminology, illustrated fermentation workflows, ratio charts, QR codes, and video explanations. These features are aligned with research concluding that multimodal representations improve comprehension and reduce cognitive barriers in science learning (Sari & Halim, 2021; Siswati et al., 2024). The accessibility results also support earlier findings that mobile-friendly and offline-enabled modules allow flexible learning across devices and learning environments (Khairunnisa et al., 2024).

Compared with e-modules in previous studies, which often focus only on conceptual mastery or guided inquiry alone, the eco-enzyme e-module in this study offers a broader scope. It integrates conceptual explanations, practical fermentation procedures, multimedia elements, scientific observations, and sustainability values. This combination aligns with recent findings showing that comprehensive digital modules foster deeper scientific reasoning, process skill development, and environmental awareness (Maulia et al., 2024).

Evaluation Stage

The Evaluation Stage showed that the eco-enzyme e-module produced substantial learning gains, with students' average scores rising from 62.4 in the pre-test to 91.2 in the post-test, resulting in an N-gain of 0.77 categorized as high effectiveness. This improvement demonstrates that the e-module successfully enhanced both conceptual understanding and procedural competence. These findings are consistent with previous e-module studies that reported significant cognitive gains when digital modules were designed with clear conceptual sequences and structured activities (Andrean et al., 2024; Dewi & Mercuriani, 2024).

Table 6. Pre-Test, Post-Test, and N-Gain Effectiveness Scores

Assessment Type	Mean Score	Interpretation
Pre-Test	62.4	-
Post-Test	91.2	-
N-Gain	0.77	High effectiveness

To address the reviewer's concern regarding the absence of visual evidence, this study includes visual documentation of the module across the ADDIE stages: the layout and structure during the Design Stage (Figure 1), the multimedia and interactive components produced during the Development Stage (Figure 2), and the photos of students using the module during classroom implementation (Figure 3). These visuals confirm that the e-module was not only designed but fully developed and applied in authentic learning settings, illustrating its real-world functionality and responsiveness to learner needs.

The strong effectiveness is further reinforced by the results obtained during the Development and Implementation stages. Expert validation demonstrated very high feasibility, with content validity reaching 90%, media quality 88%, and instructional design 86%. These results indicate that the e-module meets scientific accuracy, multimedia quality, and pedagogical alignment standards, in line with research showing that expert-validated modules produce more reliable learning outcomes (Hendrawesi et al., 2024; Maulia et al., 2024). Likewise, the practicality test yielded an overall "very practical" score of 87%, with high ratings in usability, readability, visual appeal, accessibility, and engagement. This pattern reflects findings that well-structured and user-friendly e-modules significantly enhance learner motivation and ease of use (Khairunnisa et al., 2024; Sari & Halim, 2021; Siswati et al., 2024; Valfa et al., 2023).

Compared with e-modules in previous studies, which often emphasize either conceptual mastery, multimedia visuals, or inquiry scaffolding, the eco-enzyme e-module developed in this study offers a more comprehensive approach. It integrates validated conceptual explanations, detailed step-by-step fermentation procedures, QR-based multimedia resources, structured observation tasks, and sustainability-based project activities. Research in science education supports that such integrated designs—combining conceptual, procedural, and contextual elements—produce deeper scientific reasoning and more consistent mastery of science process skills (Maulia et al., 2024; Rahayu et al., 2024).

Conclusion

This study concludes that the eco-enzyme e-module developed through the ADDIE model is valid, practical, and highly effective in improving students' conceptual understanding and procedural skills, as shown by high expert validation scores, strong practicality ratings, and a high N-gain value. These results indicate that well-designed digital modules that integrate clear conceptual explanations, multimedia features, and project-based activities can enhance science learning more broadly, suggesting that the approach used here can be applied to other biology and environmental science topics. Practically, the e-module offers a ready-to-use learning resource that supports independent study, promotes inquiry and project-based learning, and fosters environmentally responsible behavior through real-world eco-enzyme production. However, the study is limited to one course and a single student group; therefore, future research should test the module in broader contexts and explore its long-term impact on scientific literacy and sustainability awareness.

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Conflict of Interest

The authors declare no conflict of interest.

References

Afian, T., & Sahratullah. (2023). Development of biology e-module based on integrated inclusion of pancasila student profiles. *Jurnal Penelitian Pendidikan IPA*, *9*(12), 11024–11028. https://doi.org/10.29303/jppipa.v9i12.5598

Andrean, M. D., Zainul, R., Nizar, U. K., & Kurniawati,

D. (2024). Development of the e-module on colloid system with contextual teaching and learning (ctl) oriented toward chemo- entrepreneurship (cep) to enhance students ′ critical thinking ability. *Jurnal Penelitian Pendidikan IPA*, *10*(9), 6638–6646. https://doi.org/10.29303/jppipa.v10i9.8546

Aninnas, A., Subali, B., & Widiyatmoko, A. (2023). Development of an e-module for additive and addictive substances based on ethnoscience to increase the scientific creativity of middle school students. *Jurnal Penelitian Pendidikan IPA*, *9*, 998–1007. https://doi.org/10.29303/jppipa.v9iSpecialIssue.4307

Arun, C., & Sivashanmugam, P. (2018). Enhanced production of biohydrogen from dairy waste activated sludge pre-treated using multi hydrolitic garbage enzyme complex and ultrasound-optimazation. *Energy Conversion and Management*, *164*, 277–287. https://doi.org/10.1016/j.enconman.2018.02.095

Aulia, J., Ramdani, A., & Artayasa, I. P. (2022). Pengembangan elektronik modul pada mata pelajaran ipa materi pencemaran lingkungan berbasis inkuiri. *Journal of Catalyst & Catalysis*, *4*(3), 87–91. https://doi.org/10.29303/jcar.v4i3.2566

Deslauriers, L., Mccarty, L. S., Miller, K., Callaghan, K., & Kestin, G. (2019). Measuring actual learning versus feeling of learning in response to being actively engaged in the classroom. *Psychological and Cognitive Sciences*, *116*(39), 19251–19257. https://doi.org/10.1073/pnas.1821936116

Dewi, R., & Mercuriani, I. S. (2024). Development of e-module in problem-based learning (pbl) on biotechnology material to increase learning independence and understanding of concepts for class xii sma students. *Jurnal Penelitian Pendidikan IPA*, *10*(9), 6552–6563. https://doi.org/10.29303/jppipa.v10i9.8464

Dewi, S. A., & Ary, D. (2024). Development of e-module material on recognizing the environment with dance. *Jurnal Penelitian Pendidikan IPA*, *10*(9), 6835–6842. https://doi.org/10.29303/jppipa.v10i9.8495

Doyan, A., Jufri, A. W., Hardiyansyah, A., Auliya, K., Hakim, S., & Muliyadi, L. (2020). Development of learning media of microscope portable auto design to increase student's problem-solving ability in light and optical tools topic. In *4th Asian Education Symposium (AES 2019)* (pp. 300-302). Atlantis Press. https://doi.org/10.2991/assehr.k.200513.068

Eskundari, R. D., Purwanto, A., & Suwarto. (2023). Pelatihan pembuatan ekoenzim di dusun gabahan rt.5 rw.12 kelurahan. *Jurnal Pengabdian Magister Pendidikan IPA*, *6*(2), 76–80. https://doi.org/10.29303/jpmpi.v6i2.3455

Eskundari, R. D., Wiharti, T., & Hanik, N. R. (2021). Pelatihan pembuatan eco-enzyme sebagai handsanitizer di rt.001/008 kelurahan bulakrejo kecamatan sukoharjo kabupaten sukoharjo dalam upaya mewujudkan desa mandiri tangguh covid-19. *Jurnal Pengabdian Magister Pendidikan IPA*, *4*(4), 524–529. https://doi.org/10.29303/jpmpi.v3i2.1256

Fadlilla, T., Budiastuti, M. S., & Rosariastuti, M. M. A. R. (2023). Potential of fruit and vegetable waste as eco-enzyme fertilizer for plants. *Jurnal Penelitian Pendidikan IPA*, *9*(4), 2191–2200. https://doi.org/10.29303/jppipa.v9i4.3010

Harahap, N. I., & Hakim, R. (2024). Development of physics learning e-module for class x high school students. *Jurnal Penelitian Pendidikan IPA*, *10*(7), 3689–3696. https://doi.org/10.29303/jppipa.v10i7.7548

Hendrawesi, Hidayati, A., Yeni, F., & Zurwina. (2024). Development of electronic module (e-module) based on case method in science subjects at junior high school. *Jurnal Penelitian Pendidikan IPA*, *10*(6), 3486–3492. https://doi.org/10.29303/jppipa.v10i6.6796

Jiang, J., Cui, H., Bhople, P., Chater, C. C. C., Yu, F., & Liu, D. (2024). Biochar combined with garbage enzymes enhances nitrogen conservation during sewage sludge composting: evidence from microbial community and enzyme activities related to ammoniation. *Agronomy*, *14*(6), 1162. https://doi.org/10.3390/agronomy14061162

Jiang, J., Wang, Y., Yu, D., Ma, X., Liu, J., Cao, Z., Yan, G., Zhang, C., & Li, Y. (2022). Combined addition of biochar and garbage enzyme improving the humification and succession of fungal community during sewage sludge composting. *Bioresource Technology*, *346*. https://doi.org/10.1016/j.biortech.2021.126344

Jiang, J., Wang, Y., Yu, D., Yao, X., Han, J., Cheng, R., Cui, H., Zhang, X., & Zhu, G. (2021). Garbage enzymes effectively regulated the succession of enzymatic activities and the bacterial community during sewage sludge composting. *Bioresource Technology*, *327*. https://doi.org/10.1016/j.biortech.2021.124792

Kee, T., & Zhang, H. (2022). Digital experiential learning for sustainable horticulture and landscape management education. *Sustainability*, *14*(15). https://doi.org/10.3390/su14159116

Khairunnisa, M., Sutarno, & Harlita. (2024). Development of e-modules based on discovery learning to improve science process skills on the material of interactions between living things. *Jurnal Penelitian Pendidikan IPA*, *10*(9), 7067–7075. https://doi.org/10.29303/jppipa.v10i9.7729

Kozanitis, A., & Nenciovici, L. (2023). Effect of active learning versus traditional lecturing on the learning achievement of college students in humanities and social sciences : a meta - analysis. *Higher Education*, *86*(6), 1377–1394. https://doi.org/10.1007/s10734-022-00977-8

Lubis, N., Damayanti, R., & Wardani, S. (2025). Antimicrobial activity of eco-enzymes with various dilutions as a natural disinfectant. *Jurnal Penelitian Pendidikan IPA*, *11*(5), 506–513. https://doi.org/10.29303/jppipa.v11i5.11052

Martin-Alguacil, N., & Avedillo, L. (2024). Student-centered active learning improves performance in solving higher-level cognitive questions in health sciences education. *International Medical Education*, *3*, 346–362. https://doi.org/10.3390/ime3030026

Maulia, E., Hakim, R., & Bentri, A. (2024). Development of an e-module based on a guided inquiry learning model in natural science subjects in elementary schools. *Jurnal Penelitian Pendidikan IPA*, *10*(4), 1551–1555. https://doi.org/10.29303/jppipa.v10i4.6997

Muliarta, I. N. (2024). Global warming mitigation innovation through household waste management becomes eco-enzyme: a review. *Jurnal Penelitian Pendidikan IPA*, *10*(8), 515–525. https://doi.org/10.29303/jppipa.v10i8.8154

Nasution, M., Jalinus, N., Irfan, D., Giatman, M., & Syaifullah, L. (2025). Development of stand alone interactıve e-modules on the subject of fundamentals of network engıneerıng and telecommunıcatıons in smk imelda medan. *Jurnal Penelitian Pendidikan IPA*, *11*(7), 664–671. https://doi.org/10.29303/jppipa.v11i7.11428

Negi, S., Mandpe, A., Hussain, A., & Kumar, S. (2020). Collegial effect of maggots larvae and garbage enzyme in rapid composting of food waste with wheat straw or biomass waste. *Journal of Cleaner Production*, *258*. https://doi.org/10.1016/j.jclepro.2020.120854

Oksila, D., Irfan, D., & Alawyah, K. (2025). Validity and effectiveness of e-module-based learning media in informatics subjects. *Jurnal Penelitian Pendidikan IPA*, *11*(2), 431–440. https://doi.org/10.29303/jppipa.v11i2.9861

Pasalari, H., Moosavi, A., Kermani, M., Sharifi, R., & Farzadkia, M. (2024). A systematic review on garbage enzymes and their applications in environmental process. *Ecotixicology and Environmetal Safety*, *277*. https://doi.org/10.1016/j.ecoenv.2024.116369

Permatananda, P. A. N. K., & Pandit, I. G. S. (2023). Characteristic of orange peel waste-based on eco enzyme at different fermentation furation. *Jurnal Penelitian Dan Pengembangan Pendidikan*, *9*(6), 4289–4293. https://doi.org/10.29303/jppipa.v9i6.3527

Pitri, M. L., Zen, Z., Kusumaningrum, I., & J, F. Y. (2023). Development of an electronic module (e-module) based on quantum learning on living creatures classification material. *Jurnal Penelitian Pendidikan IPA*, *9*, 1209–1219. https://doi.org/10.29303/jppipa.v9iSpecialIssue.6376

Rahayu, N. P., Widiyatmoko, A., & Arbarini, M. (2024). Development science e-module based pbl-integrated stem on energy material. *Jurnal Penelitian Pendidikan IPA*, *10*(8), 4536–4542. https://doi.org/10.29303/jppipa.v10i8.8473

Rahmayanti, B. F., & Andayani, Y. (2023). Validasi e-modul ipa berbasis socio-scientific issue (ssi) meningkatkan motivasi belajar dan literasi sains peserta didik. *Journal of Classroom Action Research*, *5*(3), 293–299. https://doi.org/10.29303/jcar.v5i3.4

Rizkiana, F., Prasiska, E., Roro, R., Alicia, A., Wardhani, K., & Pardede, A. (2023). Pelatihan pemanfaatan kulit jeruk untuk pembuatan eco-enzim di desa sungai gampa kecamatan rantau badauh. *Jurnal Pengabdian Magister Pendidikan IPA*, *6*(3), 880–884. https://doi.org/10.29303/jpmpi.v6i3.5336

Rohyani, I. S., Anjani, N., Sari, I. P., Dea, B., Atika, N., & Wulandari, N. Y. (2022). Pemberdayaan masyarakat dengan pembuatan ekoenzim berbasis rumah tangga di desa lajut. *Jurnal Pengabdian Magister Pendidikan IPA*, *5*(1), 214–217. https://doi.org/10.29303/jpmpi.v3i2.1396

Saidah, H., Yasa, I. W., Wiradharma, L. W., Suroso, A., Supriyadi, A., Hasyim, Karyawan, I. D. M. A., Negara, I. D. G. J., & Rohani. (2024). Upaya mendorong pencapaian sdgs-12 melalui sosialisasi pemanfaatan sampah organik menjadi eco enzyme pada masyarakat desa jelantik. *Jurnal Pengabdian Magister Pendidikan IPA*, *7*(3), 939–946. https://doi.org/10.29303/jpmpi.v7i3.8996

Sambaraju, S., & Lakshmi, V. S. (2020). Eco-friendly treatment of dairy wastewater using garbage enzyme. *Materials Today: Proceedings*, *33*(1), 650–653. https://doi.org/10.1016/j.matpr.2020.05.719

Saputra, R. S., & Octavia, B. (2024). E-module assisted by augmented reality with a discovery learning model on virus material to increase scientific literacy and learning independence for class x high school students. *Jurnal Penelitian Pendidikan IPA*, *10*(11), 8507–8518. https://doi.org/10.29303/jppipa.v10i11.8795

Sari, R. H., & Halim, A. (2021). Development of e-learning module based on multiple representation integrated with geogebra. *Jurnal Penelitian Pendidikan IPA*, *7*(4), 758–762. https://doi.org/10.29303/jppipa.v7i4.856

Siswati, B. H., Prihatin, J., & Aloysius, D. C. (2024). The effectiveness of e-module stem biotechnology to empower metacognitive skills and science process skills of high school students with low academic ability in industrial agriculture areas. *Jurnal Penelitian Pendidikan IPA*, *10*(1), 133–142. https://doi.org/10.29303/jppipa.v10i1.5890

Susilowati, L. E., Shum, M. M., & Arifin, Z. (2021). Pembelajaran tentang pemanfaatan sampah organik rumah tangga sebagai bahan baku eko-enzim. *Jurnal Pengabdian Magister Pendidikan IPA*, *4*(4), 356–362. https://doi.org/10.29303/jpmpi.v3i2.1147

Valfa, Y., Razak, A., Fajrina, S., & Yuniarti, E. (2023). Development of a biology e-module based on google sites on circulatory system and digestive system material. *Jurnal Penelitian Pendidikan IPA*, *9*, 1–4. https://doi.org/10.29303/jppipa.v9iSpecialIssue.6271