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Development of an e-module for eco-enzyme production in biotechnology learning using the SETS approach oriented toward problem-solving skills

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Abstract

Theoretical and less contextual biotechnology learning often hinders students' problem-solving skills. This research aims to develop and test the feasibility and practicality of an eco-enzyme production e-module with a SETS (Science, Environment, Technology, and Society) approach oriented toward problem-solving skills. Development followed the ADDIE model, but evaluation was limited to expert validation and practicality testing, without conducting a full experimental effectiveness test. The participants consisted of 3 science teachers and 64 ninth-grade students from a public junior high school in Baki District, Sukoharjo. Data were collected using a needs analysis questionnaire, expert validation sheets (for materials and media), user response questionnaires, and problem-solving skills instruments adapted from Polya and Santrock. Quantitative data were analyzed descriptively to determine the feasibility and practicality percentages. Validity testing was conducted using item-total correlation, and reliability was assessed using Cronbach's alpha. Qualitative input from experts and users was analyzed descriptively for product improvement. The results show that the e-module is highly feasible, with scores of 91.1% from content experts and 86.9% from media experts. The practicality test was also very high, with 94.5% from teachers and 86.9% from students. These findings suggest that the e-module is both valid and practical, and is designed to enhance problem-solving skills in biotechnology learning.

Abstrak. *Pembelajaran bioteknologi yang bersifat teoretis dan kurang kontekstual seringkali membatasi keterampilan pemecahan masalah siswa. Penelitian ini bertujuan untuk mengembangkan serta mengevaluasi kelayakan dan kepraktisan e-modul produksi eco-enzyme dengan menggunakan pendekatan SETS (Science, Environment, Technology, and Society) yang berorientasi pada keterampilan pemecahan masalah. Pengembangan mengikuti model ADDIE dengan evaluasi yang difokuskan pada validasi ahli dan uji kepraktisan, tanpa melakukan uji efektivitas eksperimen secara penuh. Partisipan penelitian terdiri atas 3 guru IPA dan 64 siswa kelas IX dari salah satu SMP negeri di Kecamatan Baki, Sukoharjo. Pengumpulan data menggunakan angket analisis kebutuhan, lembar validasi ahli materi dan media, angket respons pengguna, serta instrumen keterampilan pemecahan masalah yang diadaptasi dari Polya dan Santrock. Data kuantitatif dianalisis secara deskriptif untuk menentukan skor kelayakan dan kepraktisan, dengan validitas diuji menggunakan korelasi item–total dan reliabilitas menggunakan Cronbach's alpha. Umpan balik kualitatif dari ahli dan pengguna dianalisis secara deskriptif untuk perbaikan produk. Hasil penelitian menunjukkan bahwa e-modul sangat layak, dengan skor 91,1% dari ahli materi dan 86,9% dari ahli media. Uji kepraktisan juga menunjukkan hasil sangat tinggi, yaitu 94,5% dari guru dan 86,9% dari siswa. Temuan ini menegaskan bahwa e-modul valid dan praktis, serta berpotensi meningkatkan keterampilan pemecahan masalah siswa dalam pembelajaran bioteknologi.*

A. Introduction

Biotechnology is a scientific discipline that continually advances, playing a crucial role in various areas of human existence, including healthcare, agriculture, industry, and environmental stewardship (Javed et al., 2022). The subject of biotechnology in education is sometimes perceived as intricate and challenging for pupils to comprehend, primarily due to the disconnect between theoretical concepts and practical applications (Chavre, 2020). Concepts such as fermentation, genetic modification, and microbes are frequently examined textually without being supplemented by contextual activities (Purnomo et al., 2023). A contextual learning method is essential for students to understand the significance of biotechnology in their daily lives (Yadav et al., 2022).

An essential and pertinent environmental concern for biotechnology education is the management of organic waste (Khan et al., 2022). Data indicate that the majority of household garbage in underdeveloped nations, such as Indonesia, comprises organic waste that has not been effectively used (Voukkali et al., 2024). Muliarta and Darmawan (2021) report that over 60% of Indonesia's total trash comprises organic materials, such as food remnants, vegetables, and fruits. If inadequately handled, this organic waste can pollute soil and water, and generate methane, a greenhouse gas that exacerbates climate change (Koul et al., 2022). Consequently, sustainable, science-based solutions are required to tackle this issue systematically.

Eco-enzyme is an ecologically sustainable biotechnological invention with prospective uses in educational contexts (Prihanto et al., 2024). This product is produced through the fermentation of organic waste, combined with sugar and water, resulting in a liquid that contains active enzymes suitable for use as a natural cleanser, fertilizer, or waste decomposer (Öztürk, 2024). The manufacturing procedure is straightforward and may be conducted by students as part of project-based learning, offering direct experience with fermentation and the function of microbes (Viareco et al., 2025). Furthermore, the creation of eco-enzymes fosters ecological awareness and encourages appropriate waste management practices.

The SETS approach integrates science, environment, technology, and society, then combined with problem-based learning (PBL), it enhances biotechnology education, especially in eco-enzyme production. In PBL, SETS is operationalized through steps like problem orientation, investigation, and solution evaluation. This enables students to develop critical thinking and gain a better understanding of how scientific findings relate to daily life (Zidny et al., 2020; Sihombing et al., 2024). Students also consider the broader impacts of technology on society and the environment (Sharifi, 2023). Supporting this, Benvenuti et al. (2023) found that incorporating social context into science learning enhances awareness of environmental issues and fosters responsible action.

The initial observation results in one of the public junior high school classes in Sukoharjo show that students' problem-solving skills are still low, with an average score of 52 out of 100. About 68% of students have difficulty identifying problems, formulating solutions, and evaluating results. Students need to cultivate problem-solving abilities as one of the essential competencies for learning in the 21st century (Szabo et al., 2020). The capacity to recognize issues, examine data, and create and assess remedies is all part of these abilities, as noted by Shanta and Wells (2022). According to Benny et al. (2023), students may encounter a range of real-world challenges when creating eco-enzymes, including selecting fermentation ingredients, managing contamination, and evaluating the outcomes. Students can cultivate critical thinking, reasoning, and problem-solving abilities that are essential for navigating life's challenges (Wen et al., 2023).

Junior high school students' problem-solving skills are still considered low, particularly in science learning, which causes many students to struggle with identifying problems, analyzing data, formulating alternative solutions, and evaluating problem-solving outcomes. This condition is influenced by several factors, including learning processes that still focus on memorizing concepts, limited use of contextual learning media, and a lack of opportunities for students to practice facing real-life problems. If not addressed immediately, this weakness will hinder students from developing the critical, creative, and adaptive thinking skills that are highly needed in the 21st century (Dilekçi & Karatay, 2023). Therefore, there is a need for learning innovations that not only convey concepts but also train students to apply their knowledge in real-world situations.

According to Wally (2024), e-modules, which are interactive digital media, are a versatile and efficient way to provide biotechnology problem-based content to students. By integrating text, images, videos, and interactive simulations, e-modules can enhance student involvement in the learning process (Milidar, 2024), as stated by the author. Students can study at their own pace and focus on topics that interest them with the help of e-modules (Wahyuningsih, 2022). The use of e-modules in eco-enzyme learning allows for the participatory, exploratory, and informative transmission of information (Akour & Alenezi, 2022). Students can gain a comprehensive understanding of environmental challenges and develop problem-solving skills through projects integrated into e-modules (Saputra & Oktarina, 2023).

Considering these challenges, an innovative learning medium is required that not only delivers

concepts but also trains students to apply them in real-life contexts. Among various alternatives, the development of e-modules was chosen because this medium was considered more suitable than other learning products used in biotechnology education. Teachers tend to rely on textbooks, student worksheets , and one-way printed teaching materials. These materials are limited to theoretical presentations. This preference was identified through needs analysis, observations, and interviews. Stanciulescu et al. (2024) found that printed teaching materials hinder active student engagement, fail to integrate multimedia effectively, and are less effective in developing higher-order thinking skills. Other learning media, such as posters, leaflets, and learning videos, have also been used. However, these are partial and do not present a comprehensive learning flow. Digital e-modules are considered more relevant. They can integrate text, images, videos, simulations, and interactive evaluations into a systematic whole (Angela et al., 2023). With these advantages, e-modules address the shortcomings of existing products and introduce new innovations that make biotechnology learning more contextual, flexible, and student-centered.

The selection of the SETS approach in this e-module has a strong basis. It directly relates to the problems students face. Low problem-solving skills are not only about understanding science concepts, but also the ability to connect those concepts to real-world issues. The SETS approach enhances learning relevance, bridges theory with everyday life, and cultivates critical and problem-solving skills. Although the SETS approach is well-established in science education, its application in eco-enzyme topics remains limited, particularly in teaching materials and interactive media such as e-modules (Lisdiana et al., 2025). To date, no study has explicitly integrated biotechnology modules with eco-enzyme production using the SETS approach, highlighting the originality of this research. Therefore, this study aims to develop a SETS-based e-module that incorporates eco-enzyme production into biotechnology instruction, oriented toward fostering students' problem-solving skills.

B. Material and method

Research and development (R&D) is the process of gathering information to create a product (Sugiyono, 2018). The goal of this study is to develop an electronic teaching tool, namely an e-module for biotechnology, which focuses on eco-enzyme production using the SETS approach. This study employed the ADDIE model, consisting of five stages: analyze, design, develop, implement, and evaluate (Branch, 2009). Formative evaluation was carried out at each stage through continuous feedback and revisions during the analysis, design, development, and implementation phases. The evaluation stage was limited to summative evaluation through expert validation (content and media experts) and practicality testing by teachers and students. A full experimental effectiveness assessment was not conducted. The ADDIE model was chosen to support the needed descriptive and methodical procedures (Branch, 2009). This study specifically examines the feasibility and practicality of the e-module during its development phase. The overall research methodology is illustrated in Figure 1.

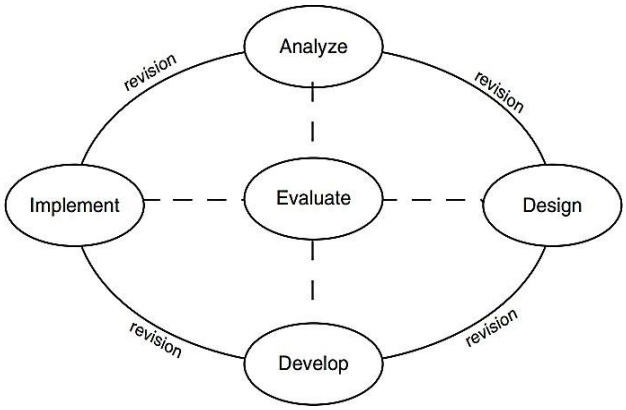

Figure 1 ADDIE model scheme (Branch, 2009)

Study included ninth-grade students from a public junior high school in Baki District, Sukoharjo Regency, with two classes: one designated as the experimental group (n=32) and the other as the control group (n=32). The class selection was purposively selected, considering the school's preparedness and the resemblance of student attributes. The research was conducted from February to June 2025, covering needs analysis, product development, validation, and practicality testing.

This study employed four primary data collection instruments: a needs questionnaire for teachers and students, an expert validation questionnaire for media and materials, and a response questionnaire for both teachers and students. In the e-module, the problem-solving skill instruments were adjusted according to the indicators from Santrock (2009), adapted from Polya (1973). The instruments were verified and evaluated using IBM SPSS Statistics 20, with validity testing conducted through item–total correlation and reliability testing using Cronbach's Alpha, confirming that the instruments were valid and reliable. An investigation was then conducted to assess the feasibility of the e-module in supporting problem-solving skills based on the validation results. The subsequent data analysis is as follows:

1. Feasibility analysis of the e-module

Qualitative data comprises inputs or recommendations on the instructional material assessment sheet from validators, as well as surveys from educators and students, which are examined

using descriptive qualitative methods. The analysis is beneficial for refining the instructional materials that have been created. Quantitative data is gathered to ascertain the attributes of the viable e-module. The feasibility or validity of the e-module is assessed by statements on the validation sheet completed by the validator. The validity questionnaire results are computed to ascertain the percentage. The acquired findings are subsequently transformed into a percentage utilizing Formula 1. Then, the data was analyzed and interpreted using the criteria in Table 1, and revisions were made based on the obtained interpretation results.

$$\% \text{ Feasibility} = \frac{\text{Score count}}{\text{Maximum score}} \times 100\% \ldots \text{Formula 1}$$

Table 1 Criteria for e-module feasibility

Percentage (%)	Criteria
81%-100%	Very feasible
61%-80%	Feasible
41%-60%	Quite feasible
21%-40%	Less feasible
0%-20%	Very not feasible

(Source: Damayanti & Budiawanti, 2024)

2. Practicality analysis of the e-module

The practicality level of the SETS-based e-module may be assessed using Formula 2, depending on the outcomes of the instructor and student response surveys. The computational findings are subsequently transformed into practical outcome criteria, as presented in Table 2.

$$\% \text{ Practicality} = \frac{\text{Score count}}{\text{Maximum score}} \times 100\% \ldots \text{Formula 2}$$

Table 2 Criteria for e-module practicality

Percentage (%)	Criteria
81% – 100%	Very practical
61% – 80%	Practical
41% – 60%	Quite practical
21%- 40%	Less practical
0% – 20%	Very impractical

(Source: Damayanti & Budiawanti, 2024)

C. Results and discussion

The findings from the needs analysis regarding the development of biotechnology e-modules utilizing the SETS approach reveal that 9th-grade science (biology) education at junior high school in Baki District, Sukoharjo Regency faces several challenges, notably the students' insufficient problem-solving abilities and the lack of contextual and interactive instructional resources. Classroom observations suggest that educators continue to rely primarily on textbooks as the primary learning resource, while the integration of technology and innovative pedagogical methods remains suboptimal. The survey and interview data corroborate this conclusion, indicating that the majority of instructors are unfamiliar with the SETS approach and have not incorporated project-based learning into biotechnology curricula. Conversely, students reported challenges in comprehending scientific disciplines, particularly biotechnology studies, which are often presented theoretically and require rote memorization. The absence of practical experience and access to digital educational resources leads pupils to engage in rote memorization, disconnected from real-world circumstances, culminating in shallow and inapplicable information (Manfreda & Hodnik, 2021). The pretest findings on problem-solving skills revealed poor scores across all indicators, highlighting the necessity to enhance pupils' cognitive and analytical capabilities. The findings suggest that the development of interactive and contextual SETS-based e-modules is crucial for enhancing the effectiveness of scientific education. This assertion aligns with the viewpoint of Rodas-Silva et al. (2024), suggesting that integrating biotechnological materials with practical environmental initiatives significantly enhances students' conceptual understanding and problem-solving skills.

Figure 2
Cover of the SETS-based biotechnology e-module (in Indonesian)

Figure 3 Four aspects of the SETS indicator (A) science, (B) environment, (C) technology, and (D) society (in Indonesian)

The e-module design was created utilizing the SETS approach to link biotechnology content with real-world issues in the students' surroundings. The cover e-module design, as shown in Figure 2, features an appealing aesthetic and graphics relevant to the topics of biotechnology and eco-enzymes. The design and color scheme are carefully organized to create a professional impression and stimulate students' enthusiasm for learning. The educational resources are structured around the topic of home organic waste as a focal point in the eco-enzyme manufacturing initiative. The e-module highlights real-world situations, consistent with contextual learning theory, which posits that learning is more significant when students relate the information to their everyday experiences (Hwang et al., 2023). The e-module's learning activities are structured according to problem-solving skill indicators as

outlined by Santrock (2009), taken from Polya (1973), encompassing issue formulation, solution strategy creation, solution evaluation, and solution redefinition. This aims to enhance pupils' higher-order thinking skills (HOTS), which are essential for 21st-century education (Omar & Awang, 2021).

The creation of biotechnology e-modules utilizing the SETS technique is conducted holistically, taking into account the cognitive domain as indicated in the Learning Outcomes (LO) of the Merdeka Curriculum for phase D. The e-modules are designed to promote students' comprehension of biotechnology content while fostering higher-order thinking abilities, including analysis, evaluation, and the creation of solutions to real-world challenges. Proficiency in higher-order cognitive skills, including analysis (C4), evaluation (C5), and creation (C6), is essential for developing 21st-century competencies (Karim et al., 2021), as it empowers students to engage in critical thinking, make decisions grounded in logical reasoning, and devise innovative solutions to intricate real-world challenges.

The SETS framework is included in the biotechnology e-module content to enhance contextual and significant learning. This e-module aims to impart scientific principles, both conceptually and practically, regarding environmental challenges and technology-driven solutions pertinent to community life. In the context of science, students are familiar with the fundamental concepts underlying eco-enzyme synthesis, including fermentation and the role of microorganisms in this process. The Environmental element prompts students to assess the impact of organic waste on the ecosystem and explore alternative management strategies. The Technology component directs students to engage in the practical manufacturing of eco-enzymes, while the Society component highlights social initiatives, such as zero-waste campaigns and environmental education. Karan and Brown (2022) assert that the SETS approach effectively enhances problem-solving abilities by engaging students in project-based activities that require critical, collaborative, and reflective thinking. The four components of the SETS indicators are depicted in Figure 3.

An integral part of the e-module's evolution is its characteristics. Problem scenarios related to eco-enzyme production, supported by interactive quizzes, visual infographics, and instructional videos, all contribute to this module's capacity to facilitate PBL. According to Barut and Dursun (2022), students' intrinsic motivation may be increased when the learning process is made more engaging and not dull through the use of interactive elements, appealing graphics, films, simulations, or activities. As it is being developed, the e-module takes into account the usage of supplementary apps, pertinent content background, and interactive elements that encourage student participation and self-directed learning. An aesthetically pleasing and responsive interactive flipbook is created using the Heyzine platform to showcase the e-module. Canva is used for the e-module's visual design, and Quizziz is used for the learning assessment, which is arranged as quizzes to provide students with rapid feedback. In line with (Syafrizal & Ahmad, 2021) who argue that learning media must be tech-adaptive to be relevant to the digital generation's learning patterns, this app promotes the concept of flexible digital learning. According to Chisunum and Nwadiokwu (2024), the prepared content should use multimedia aspects while adhering to the principles of coherence and relevance. This would help students better comprehend and engage with the information.

Results from validation by subject-matter experts indicate that the biotechnology e-module, built on the SETS technique, is well-suited for educational purposes. Introduction, learning, content, and evaluation are the four key areas that professionals in the field evaluate. Follow this breakdown of the percentage scores for each component, The following percentages fall within the very feasible category: introduction (93.8%), learning (95.5%), content (85.8%), and assessment (89.3%). The total average is 91.1% (Table 3). The e-module content has been well-structured, aligned with the curriculum, and can accommodate the development of 21st-century skills, such as problem-solving, according to this validation. This agrees with the view expressed by Ng et al. (2024), who emphasize the importance of subject-matter expert validation in ensuring the correctness and comprehensiveness of educational development products' content.

In addition to quantitative ratings, subject-matter experts gave qualitative feedback. They affirmed that the e-module promotes contextual and meaningful learning by integrating biotechnology content with real-life issues. The focus on eco-enzyme production addresses environmental challenges. Experts noted that the material is systematic, supported by coherent visuals, and includes problem-based tasks. These tasks enhance students' critical and analytical thinking. They also stated that aligning with the SETS framework helps students connect science with societal applications and fosters higher-order thinking. Experts offered constructive feedback as well. They suggested simplifying some concept explanations, refining the sequence of eco-enzyme production steps, and improving visual consistency. Additionally, they recommended more contextual examples and interactive features to strengthen the SETS orientation and engage students. These suggestions align with Stanciulescu et al. (2024), who emphasize the importance of curriculum-aligned and contextually relevant digital resources. They also echo Sun and Choi (2024), who highlight that interactive, coherent media can increase learning motivation.

Table 3 Results of expert material validation

No.	Aspect	Percentage	Criteria
1.	Introduction	93.8%	Very feasible
2.	Learning	95.5%	Very feasible
3.	Content	85.8%	Very feasible
4.	Assessment	89.3%	Very feasible
Average		**91.1%**	**Very feasible**

Simultaneously, media specialists conducted validation to evaluate the design quality, functionality, and appropriateness of the e-module. The results showed that the design quality achieved a score of 90%, functionality 83.4%, and material suitability 87.5%, with an overall average of 86.9%, categorizing the e-module as very feasible (Table 4). These findings confirm that the e-module meets the principles of effective digital learning design, is user-friendly, and maintains consistency with the instructional content. Chen and Mokmin (2024), emphasize that effective learning media must fulfill criteria such as visual aesthetics, intuitive navigation, and seamless integration of media components with material to optimize students' learning experiences.

In addition to the quantitative scores, qualitative feedback from media validators offered constructive insights directly related to the design and usability of the e-module. They recommended clarifying specific visual elements, improving layout consistency, and refining the sequencing of eco-enzyme production steps to ensure a smoother navigation experience. Furthermore, validators suggested adding more contextual illustrations and interactive features to strengthen the SETS orientation and enhance student engagement. These recommendations reflect the central role of media experts in ensuring visual clarity, intuitive navigation, and engaging interactivity in digital learning products. Such feedback is consistent with Lu and Hanim (2024), who emphasize that consistent and interactive visual elements significantly enhance learning motivation, and with McLaughlin-Borlace et al. (2024), who stress the importance of designing engaging and contextually relevant digital resources to foster active student participation.

Table 4 Results of media expert validation

No.	Aspect	Percentage	Criteria
1.	Design quality	90%	Very feasible
2.	Functionality	83.4%	Very feasible
3.	Suitability of the teaching materials	87.5%	Very feasible
Average		**86.9%**	**Very feasible**

Table 5 Results of the teacher's practical work

No.	Aspect	Percentage	Criteria
1.	Content quality	97.9%	Very practical
2.	Presentation and language quality	93.8%	Very practical
3.	Design and technical quality	91.7%	Very practical
Average		**94.5%**	**Very practical**

The produced teaching resources are efficient to use in the science learning process, as assessed by both instructors and students, according to the results of the practicality test of the biotechnology e-module based on the SETS approach. The teacher response questionnaire reveals that the following characteristics are assessed: content quality (97.9%), presentation and language quality (93.8%), and design and technical quality (91.7%). The total average score is 94.5%, which is classified as very practical (Table 5). In addition to being user-friendly for educators, these results show that the e-module facilitates the integration of media, presentation, and information. This aligns with Lubis et al. (2023) view that the usefulness of learning materials depends on how easy they are to use, how explicit the content is, and how effectively they help students achieve their learning goals. Qualitative feedback from teachers indicated that the e-module provides clear guidance and is easy to implement in classroom practice. It supports contextual learning activities. Teachers noted that the systematic presentation of materials helps them deliver lessons more effectively. They added that the interactive features encourage students to participate actively during instruction. Teachers also emphasized that the integration of SETS elements makes the material more meaningful. It connects scientific concepts with real-life applications, particularly environmental issues. This is consistent with Nguyen et al. (2022), who argue that teachers value digital resources that are practical, contextually relevant, and aligned with classroom needs. It also aligns with Haerawan et al. (2024), who highlight that interactive digital media can enhance

teacher effectiveness and increase student engagement. However, some teachers recommended incorporating a broader range of formative assessments to more effectively address the diverse abilities of students.

Through a series of steps, students evaluate the practicality of the biotechnology e-module using the SETS approach. This method measures how well the e-module supports students' learning. The practicality testing process consisted of three phases: one-on-one, small-group, and field. At each level, students summarize their evaluations, including thoughts on content quality, design, usability, and the effect on learning and motivation. In the initial One-to-One Trial, two students with different academic backgrounds work side by side. The test findings at this stage are highly applicable. In the second round, the Small Group Trial, six students participated. Based on the overall average at this point, the e-module is considered extremely practical. The third and final stage is the Field Trial, which is a real-world evaluation with 32 students from the experimental class. Based on the results, several factors were significant: content and learning quality (85.2%), design and simplicity of use (91.4%), and motivation and learning advantages (84.2%). Table 6 shows that students are encouraged to learn independently and feel helped in grasping the biotechnology content. An overall average of 86.9% places the e-module in the very practical category. Students also suggested adding more real-world examples and interactive features to strengthen the SETS orientation and make learning more engaging. They recommended clearer guidance in problem-solving tasks and more visual explanations to simplify complex concepts. These insights align with Sun and Choi (2024), who note that interactive and contextually relevant media can enhance motivation and deepen learning. Lu and Hanim (2024) also emphasize that visual clarity and interactive design support effective digital learning. Fink et al. (2023), state that making learning enjoyable and helping students grasp concepts are two essential qualities in practical learning media. The e-module is both aesthetically pleasing and functionally sound, as demonstrated by field trial results, which show increased motivation (84.2%), improved content understanding (85.2%), and very practicality (86.9%) (Table 6). These outcomes demonstrate its effectiveness in enhancing students' motivation, conceptual mastery, and problem-solving abilities.

Table 6 Results of the students' practical work

No.	Aspect	Percentage	Criteria
1.	Content and learning quality	85.2%	Very practical
2.	Design and simplicity of use	91.4%	Very practical
3.	Motivation and learning advantages	84.2%	Very practical
Average		**86.9%**	**Very practical**

By incorporating real-world examples, such as eco-enzyme manufacturing, the biotechnology e-module from SETS enhances the standard of scientific education. Environmental consciousness, scientific reasoning, and practical concept understanding are all emphasized in the classroom (AlAli & Al-Barakat, 2024). In line with the Merdeka Curriculum's emphasis on competences and the investigation of learning experiences, project activities contribute to the development of skills appropriate to the modern world (Simarmata & Mayuni, 2023).

In addition to quantitative results, the product development process incorporated detailed qualitative feedback from material specialists, media professionals, and teachers. The experts provided targeted suggestions, including clarifying concept explanations, refining the sequence of eco-enzyme production steps, and enhancing the e-module's layout and readability. Media professionals emphasized the importance of intuitive navigation, consistent visuals, and interactive elements that reflect students' digital literacy. Teachers recommended adding contextual examples from students' daily experiences to reinforce the SETS orientation. Based on this input, revisions were systematically implemented at each development stage using the ADDIE model, including updates to content delivery, visual structure, and interactivity. This process ensured the final e-module not only achieved feasibility standards but also integrated expert input to maximize its impact on students' problem-solving skills (Ng et al., 2024; Lubis et al., 2023). This iterative revision process aligns with the principle of R&D development, which emphasizes formative evaluation at each stage of development.

D. Conclusion

This study developed a SETS-based interactive biotechnology e-module focused on eco-enzyme production, demonstrating both feasibility and practicality for classroom use. The e-module incorporates multimedia components, videos, animations, quizzes, and visuals that present biotechnology principles in a more relevant and engaging manner. Validation and usability assessments confirmed its effectiveness, with expert evaluations rating the content at 91.1% and the media at 86.9%. Meanwhile, teacher and student practicality ratings reached 94.5% and 86.9%, respectively. These

results indicate that the e-module is a validated and practical instructional tool, perceived as supportive for enhancing students' motivation, facilitating conceptual understanding, and promoting problem-solving activities. Scientifically, this study advances the integration of environmental biotechnology and digital learning, offering a model that fosters the development of essential 21st-century skills. Future research may expand its use in diverse educational contexts and assess its long-term influence on students' critical and creative thinking.

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