

Developing an Eclipse Crossword-Based E-Module to Improve Students' Critical Thinking in Plant Reproduction

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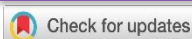
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Abstract

The integration of digital learning media in biology instruction is increasingly important for enhancing students' higher-order thinking skills, particularly in topics that involve abstract concepts and complex terminology, such as plant reproductive systems. This study aimed to develop and evaluate the feasibility, practicality, and effectiveness of a crossword puzzle-based e-module using Eclipse Crossword to improve the critical thinking skills of Grade IX students at Madrasah Tsanawiyah Negeri 01 Bandar Lampung. Employing a Research and Development design adapted from Borg and Gall, the study involved expert validation, readability testing, student response analysis, and an effectiveness test using a pretest-posttest control group design. Data were collected through validation sheets, questionnaires, observation, documentation, and critical thinking tests, and were analyzed using percentage scores, N-Gain, paired sample t-test, and independent sample t-test. The results showed that the developed e-module was highly feasible, with validation scores of 89.3% from media experts and 91.7% from material experts. The readability test indicated that 90% of students perceived the module as clear, engaging, and easy to use. The effectiveness test demonstrated a significant improvement in students' critical thinking skills, with the experimental class achieving a higher posttest mean score than the control class and a moderate N-Gain score of 0.4403, compared with 0.1371 in the control class. Students also responded positively to the module, indicating that it was interactive, challenging, and helpful for understanding biological concepts. These findings imply that Eclipse Crossword-based e-modules can serve as an innovative and practical digital learning medium to support critical thinking development in biology learning.

Keywords: Biology Learning; Critical Thinking; Eclipse Crossword; E-Module; Plant Reproductive System

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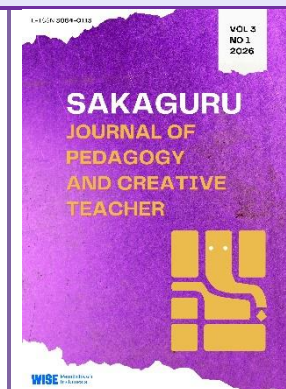
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INTRODUCTION

The advancement of science and technology has brought about significant changes across various aspects of life, including the field of education [1], [2], [3]. In the digital era, the utilization of technology has become a crucial element in supporting more effective and interactive learning processes [4], [5]. One form of technological innovation in education is the development of digital-based learning materials, such as E-Modules, which are designed to enhance the quality of instruction and promote greater student engagement [6]. In the context of 21st-century learning, critical thinking skills constitute one of the key competencies that must be developed [7], [8], [9]. When utilized optimally, digital technology can serve as a medium for fostering critical thinking through learning activities that are both challenging and meaningful [6]. However, the effectiveness of technology-based learning is highly influenced by the adequacy of infrastructure and facilities, such as the availability of computers, LCDs, projectors, internet connectivity, and smartphones [10].

Furthermore, the use of crossword puzzles within E-Modules enables the integration of instructional content with formative assessment. Each puzzle completed by learners can serve as an indicator of conceptual understanding while simultaneously providing immediate feedback on the learning process. This aligns with the principle of assessment as learning, in which learners are able to identify their strengths and weaknesses in real time [11], [12]. Teachers can also utilize the results of crossword completion as data to design more targeted instructional interventions.

One engaging and promising instructional medium for enhancing critical thinking skills is the use of crossword puzzles. Beyond their entertaining nature, crossword puzzles require learners to recall, comprehend, and connect previously learned concepts. This activity involves processes of analysis, evaluation, and decision-making, which are key components of critical thinking [6].

From an instructional design perspective, a crossword puzzle-based E-Module requires careful planning to ensure that each puzzle accurately reflects the intended learning competencies [13], [14]. Therefore, the development of this module must be guided by clearly defined learning indicators, while also taking into account the level of difficulty and the meaningfulness of each item. Developers must also ensure that the visual design and navigation of the module support a comfortable learning experience, particularly for learners who are not yet familiar with digital media. The alignment among content, media, and learning objectives is a key factor in the successful implementation of this E-Module. Furthermore, when learners are given the opportunity to construct their own crossword puzzles, their creative and divergent thinking skills are also fostered [15].

A crossword puzzle is a word-based game consisting of a grid of small squares that must be filled with letters to form words or phrases corresponding to given clues or definitions [16], [17]. As an instructional method, crossword puzzles represent a creative and interactive approach that can be effectively applied in biology education to facilitate students' understanding of biological concepts. In practice, teachers can design crossword puzzles containing questions related to the biology topics being studied. Students are then required to identify the correct answers and fill in the grid with letters that form the appropriate words or phrases [18].

The use of crossword puzzles in biology learning offers several benefits. First, they serve as an engaging and enjoyable tool to motivate students in the learning process. Second, crossword puzzles assist students in remembering and understanding biological concepts, as they are required to think critically in order to determine the correct answers. Third, they promote problem-solving and lateral thinking skills, which are essential for a deeper understanding of biological concepts [19].

The crossword puzzle-based learning approach is aligned with Lev Vygotsky's theory of social constructivism, which emphasizes the importance of meaningful activities in constructing knowledge through interaction and problem-solving [20]. In the digital era, games such as crossword puzzles have evolved from printed formats into more practical and engaging digital applications, such as Eclipse Crossword. This application enables the development of interactive E-Modules that can enhance learning motivation and promote a deeper understanding of concepts [15].

From a technological perspective, Eclipse Crossword is selected due to its ease of use and flexibility in designing crossword items aligned with instructional content. This application enables researchers and teachers to create crossword puzzles that can be integrated into E-Module formats such as HTML or PDF, allowing access both offline and online. Its interactive features also support gamification-based learning, which has been shown to be effective in enhancing student engagement and learning retention [21].

Eclipse Crossword is a free software application designed to facilitate users in creating crossword puzzles in an interactive and practical manner [22]. This program is widely used among teachers, researchers, and educational media developers due to its simple interface and its ability to generate crossword puzzles that can be printed or played directly on a computer. Eclipse Crossword is lightweight and can be run on the Windows operating system without requiring complex installation procedures. Users simply need to input a list of words along with their definitions, and the software will automatically generate an appropriate crossword puzzle. The output can be saved in various formats, including interactive HTML files, printable PDFs, or embedded into presentations.

Moreover, the application supports multiple languages, making it suitable for creating puzzles in Indonesian, English, or other languages. In an educational context, this software can be utilized to assess students' conceptual understanding, for instance through terms in plant reproductive systems such as pistil, stamen, pollination, and rhizome. These puzzles can also function as a medium for reflection or reinforcement of learning material, where students complete them as part of formative assessment. Furthermore, Eclipse Crossword can be integrated into game-based learning approaches, such as Contextual Teaching and Learning (CTL) modules supported by platforms like Educaplay or interactive presentations using Microsoft PowerPoint, thereby making the learning process more engaging and meaningful [23].

Overall, the development of crossword puzzle-based E-Modules supported by digital applications such as Eclipse Crossword represents an innovative approach to addressing the challenges of 21st-century

learning. This medium not only enriches instructional strategies but also provides a learning experience that is both engaging and meaningful. This study is expected to make a significant contribution to the development of adaptive and contextual learning media, with a particular emphasis on strengthening students' critical thinking skills at the Madrasah Tsanawiyah level [24].

The use of crossword puzzles in biology learning provides significant benefits in enhancing the quality of students' learning processes. As an interactive and enjoyable approach, crossword puzzles stimulate cognitive activity through problem-solving and answer-seeking tasks that require learners to think critically and actively engage with biological information. The process of responding to clues encourages reflective thinking and strengthens the mastery of key concepts within the subject matter. In addition, crossword puzzles contribute to the enrichment of students' vocabulary, particularly in understanding and retaining biological terms in a contextual and engaging manner. The activities of word searching and puzzle solving help learners expand their comprehension of complex biological terminology [25].

From an affective perspective, crossword puzzles can enhance learning motivation due to their game-like, educational nature. Students are more likely to engage actively and demonstrate greater enthusiasm in participating in the learning process, thereby fostering a more dynamic and participatory classroom environment [26]. Crossword puzzles are also effective as a medium for reviewing learning materials, enabling students to consolidate their understanding of topics that have been previously taught. In this way, crossword puzzles function not only as an informal assessment tool but also as a strategy for reinforcing conceptual understanding [27].

When completed collaboratively, crossword puzzles can promote cooperation and communication among students. In the process of solving the puzzles, they engage in discussion, exchange ideas, and develop shared strategies, which ultimately strengthens their social and collaborative skills [28]. This interaction aligns with the cooperative learning approach, which emphasizes the importance of teamwork in constructing knowledge collectively.

Overall, the use of crossword puzzles in biology learning not only enriches teachers' instructional strategies but also provides meaningful learning experiences for students. By integrating cognitive, affective, and social dimensions, crossword puzzles represent a promising medium for supporting the development of 21st-century competencies, particularly in critical thinking, communication, and collaboration [28]. Therefore, the integration of crossword puzzles into E-Modules or other digital media represents a strategic step in innovating biology instruction that is aligned with the characteristics of today's learners.

In this context, crossword puzzles are applied to the topic of plant reproductive systems, which constitute essential mechanisms that enable plants to reproduce and sustain the continuity of their species [29]. Plants can reproduce both sexually and asexually [30].

Several verses in the Qur'an explain aspects of plant reproductive systems, particularly plant propagation and their role in maintaining the balance of nature. One such example is found in Surah Al-An'am, verse 95. It means: "Indeed, it is Allah who causes seeds and fruit kernels to split and sprout. He brings forth the living from the dead and brings forth the dead from the living. That is Allah; so how are you deluded?" [31].

Sexual reproduction involves the process of pollination, which is the transfer of pollen grains from the anther to the stigma, followed by fertilization within the ovule. This process results in the formation of seeds that contain the embryo of a new plant [30]. In contrast, asexual reproduction occurs without the involvement of gametes, for example through cuttings, buds, or rhizomes, and produces offspring that are genetically identical to the parent plant. The reproductive organs of flowering plants consist of male parts (stamens) and female parts (pistils), each of which plays a role in the reproductive process. External factors such as wind, water, and animals also play important roles in facilitating pollination and seed dispersal. Through this diversity of reproductive systems, plants are able to adapt and spread across various environments, thereby maintaining ecosystem balance and providing essential resources for other living organisms [30].

The topic of plant reproductive systems taught in Grade IX at Madrasah Tsanawiyah Negeri 01 Bandar Lampung is considered a complex subject and is often perceived as difficult by students. Concepts such as pollination, fertilization, and both vegetative and generative reproduction require instructional approaches that are concrete and engaging. Therefore, the development of a crossword puzzle-based E-Module using Eclipse Crossword serves as a strategic alternative to bridge the gap between conceptual abstraction and interactive learning experiences [6].

This study aims to examine the feasibility of using a crossword puzzle-based E-Module in teaching the topic of plant reproductive systems, as well as its contribution to improving students' critical thinking skills. The findings of this study are expected to contribute to the innovation of instructional methods that are aligned with students' characteristics and the demands of the contemporary era.

METHODS

This study was conducted at Madrasah Tsanawiyah Negeri (MTsN) 1 Bandar Lampung, located at Jl. KH. Ahmad Dahlan No. 24–22, Pahoman, Teluk Betung Utara District, Bandar Lampung City, Lampung Province. The research was carried out in July 2025. This study employed a Research and Development (R&D) approach using the development model proposed by Walter R. Borg and Meredith D. Gall. This model consists of ten systematic steps aimed at producing educational products that are valid, effective, and adaptive through continuous processes of evaluation and revision.



Figure 1. The Steps for Implementing the Research and Development (R&D) Method According to Walter R. Borg and Meredith D. Gall

The first stage is a preliminary study, which includes needs analysis, literature review, and small-scale research to obtain initial data that support product development. This is followed by the planning stage, in which the research objectives are formulated, resource requirements are estimated, and the roles of the researchers are determined. Subsequently, the researcher develops the initial product design in the form of a hypothetical model and prepares a field-testing scenario. The product is then subjected to limited testing to obtain initial feedback, followed by revisions based on the results of this trial. The next stage involves large-scale field testing to examine the effectiveness of the product using an experimental approach. Based on these findings, an operational product revision is carried out using a quantitative approach with a pretest–posttest design. Finally, a large-scale feasibility test is conducted to evaluate the overall effectiveness and adaptability of the product, involving prospective users directly. The model proposed by Walter R. Borg and Meredith D. Gall is selected because it provides a comprehensive framework for developing educational products grounded in needs analysis and empirical evaluation [32]. As stated by Walter R. Borg and Meredith D. Gall (1983), “The R&D cycle begins with research and information gathering, followed by planning, development, field testing, revision, and dissemination” (p. 772), which underscores the importance of sequential stages in producing a product that is ready for practical implementation in the field [32].

Table 1. Media Product Validation Categories

No.	Percentage Scale	Validity Level
1.	85,01%-100%	Highly valid, or can be used without revision.
2.	70,01%-85%	Sufficiently valid, or can be used with minor revisions.
3.	50,01%-70%	Less valid; it is not recommended for use as it requires major revisions.
4.	01,00%-50%	Invalid, or not suitable for use.

Table 1 presents the criteria used to interpret the validity percentage of the developed media product. A validation score ranging from 85.01% to 100% indicates that the product is highly valid and can be used without revision. A score between 70.01% and 85% signifies that the product is sufficiently valid but may require minor revisions. Meanwhile, a score ranging from 50.01% to 70% indicates low validity, meaning that the product requires major revisions before it can be implemented. Products obtaining a validation score between 1.00% and 50% are categorized as invalid and are considered unsuitable for use. These categories serve as the basis for determining the feasibility of the media product based on expert validation results.

RESULT AND DISCUSSIONS

Result

The results of this study encompass three main stages: expert validation, readability testing, and effectiveness testing of the use of a crossword puzzle-based E-Module in improving the critical thinking skills of Grade IX students at MTsN 1 Bandar Lampung. In the expert validation stage, the evaluation was conducted by two media experts and one subject-matter expert. The findings indicate that the crossword puzzle-based E-Module is highly feasible for use in instruction, with an average score of 89.3% from media experts and 91.7% from the subject-matter expert. This assessment covers aspects of content appropriateness, visual design, interactivity, and ease of navigation, all of which support the implementation of digital-based learning.



Figure 2. E-Module product

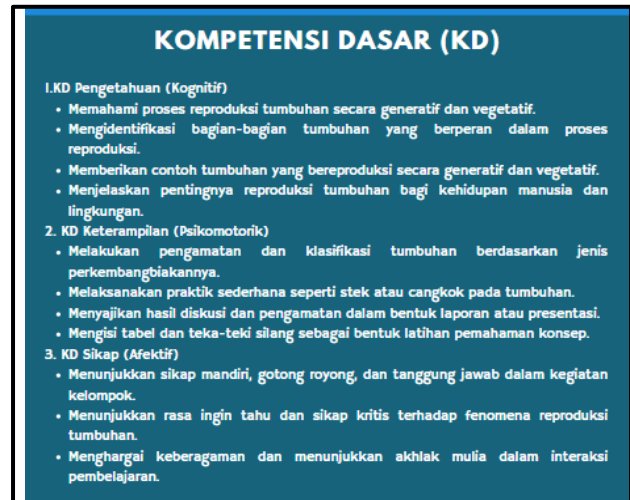


Figure 3. Basic Competencies

Subsequently, a readability test was conducted with ten students as initial respondents. The results indicate that 90% of the students perceived the E-Module as easy to understand, engaging, and helpful in facilitating a more concrete understanding of the concept of plant reproductive systems. This finding suggests that the developed module meets readability standards and is capable of bridging the abstract nature of the material with an enjoyable and interactive learning experience.



Figure 4. Learning Process

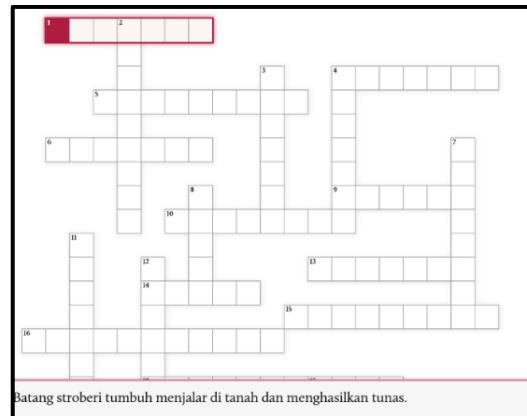


Figure 5. Crossword Puzzle

The final stage involved an effectiveness test using a one-group pretest-posttest design. Prior to the implementation of the E-Module, students obtained an average pretest score of 58. After engaging in learning activities using the crossword puzzle-based E-Module, the average posttest score increased to 82. This improvement indicates that the use of crossword puzzle-based instructional media makes a significant contribution to enhancing students' critical thinking skills. The activities of solving and constructing crossword puzzles encourage students to actively recall, connect, and analyze concepts.

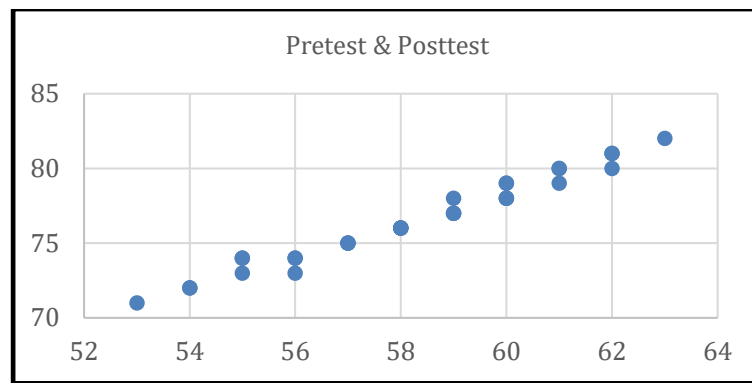


Figure 6. Pretest and Posttest Results

The pretest and posttest data are presented in Figure 6, which illustrates an overall increase in students' scores after the implementation of the crossword puzzle-based e-module. This improvement indicates that the learning activities embedded in the module were able to support students in processing biological concepts more actively and meaningfully. The increase in posttest scores also suggests that crossword puzzle-based instructional media can facilitate critical thinking processes through activities that require students to identify key concepts, interpret clues, recall prior knowledge, connect related terms, and evaluate the accuracy of their answers. Thus, the e-module developed using Eclipse Crossword does not merely function as a supplementary learning medium but also serves as a structured learning tool that encourages students to engage with the topic of plant reproductive systems in a more analytical and reflective manner.

Discussion

The findings of this study indicate that the development of a crossword puzzle-based e-module has a positive contribution to improving students' critical thinking skills. The module was designed by integrating interactive, contextual, and game-based elements that enabled students to participate more actively in the learning process. In the context of biology learning, especially on the topic of plant reproductive systems, students are often required to understand abstract processes and specific scientific terminology, such as pollination, fertilization, vegetative reproduction, generative reproduction, pistil, stamen, ovule, seed, and embryo. Through crossword puzzle activities, these concepts are not presented merely as memorized terms but are reconstructed through clues, problem-solving tasks, and meaningful associations. This process allows students to strengthen conceptual understanding while simultaneously practicing higher-order thinking skills.

The activities of constructing and solving crossword puzzles require students to recall information, classify concepts, analyze relationships among biological terms, and determine the most appropriate answers based on the clues provided. These learning activities are closely related to the development of critical thinking because students are not only asked to remember factual information but also to interpret, compare, and verify their responses. In this sense, crossword puzzles encourage students to move beyond passive reception of material toward active cognitive engagement. This supports the argument that well-designed crossword puzzle-based learning can promote higher-order thinking processes, particularly when the puzzle items are aligned with learning indicators and critical thinking components [33].

These findings are also consistent with the principles of social constructivism proposed by Lev Vygotsky, which emphasizes that knowledge is constructed through meaningful activities, interaction, and guided learning experiences. In the present study, crossword puzzles functioned as a learning scaffold that helped students connect new information with their prior knowledge. When students worked individually, the crossword puzzle encouraged self-regulated learning, independent reasoning, and reflective thinking. When implemented collaboratively, the activity also provided opportunities for discussion, peer explanation, and shared problem solving. Therefore, the crossword puzzle-based e-module can be understood not only as a digital learning product but also as a pedagogical strategy that supports knowledge construction through active engagement and interaction [27].

The significant increase in students' posttest scores shows that the use of the e-module contributed not only to factual understanding but also to the development of analytical and reflective abilities. Students were required to understand the meaning of each clue, relate it to relevant biological concepts, and evaluate whether the selected answer corresponded to the available letter patterns in the crossword grid. This repeated process of interpretation and verification trained students to be more careful, logical, and systematic in solving problems. Consequently, the e-module helped create a learning

environment that encouraged students to think critically while still experiencing learning as enjoyable and challenging.

The interactivity embedded in the e-module also played an important role in enhancing students' learning engagement. Unlike conventional printed materials that tend to present information in a linear and passive format, the crossword puzzle-based e-module provided opportunities for students to interact directly with the content. The presence of digital navigation, visual displays, contextual clues, and game-based tasks made the learning process more attractive and student-centered. This condition is important because students' active involvement in learning activities can improve attention, motivation, and learning retention. In other words, the e-module provided a learning experience that combined cognitive challenge, visual support, and interactive practice.

These findings corroborate the study by Halim et al., which suggests that digital technology can serve as an effective medium for developing students' competencies when it is designed in a contextual, interactive, and learner-oriented manner [6].

In the context of teaching plant reproductive systems, the crossword puzzle-based e-module helped bridge the gap between abstract biological concepts and concrete learning experiences. The use of clues and visualized puzzle structures enabled students to organize concepts more systematically, while the game-based format reduced the monotony often associated with memorizing scientific terminology. Therefore, the developed e-module can be considered relevant for supporting biology learning that requires conceptual understanding, terminology mastery, and analytical thinking.

The results of this study also strengthen the view that gamification elements in learning media can increase student motivation and participation. The crossword puzzle format introduced elements of challenge, curiosity, and achievement into the learning process. Students were encouraged to complete the puzzle accurately, identify missing terms, and revise their answers when inconsistencies appeared in the grid. These activities indirectly trained persistence, accuracy, and problem-solving habits. In addition, the crossword puzzle format may reduce students' anxiety toward difficult biology material because learning is presented through a more familiar and enjoyable activity. This supports the idea that game-based learning media can create a more engaging learning atmosphere while still maintaining academic objectives [18]. From a pedagogical perspective, the crossword puzzle-based e-module also supports formative assessment practices. The students' responses to crossword clues can provide teachers with immediate information about the extent to which students understand key concepts. Incorrect answers may indicate misconceptions, incomplete understanding, or difficulties in distinguishing related biological terms. Therefore, teachers can use the results of crossword completion as diagnostic information to provide feedback, clarification, or enrichment activities. In this regard, the e-module does not only function as a learning medium but also as an assessment tool that supports continuous monitoring of students' conceptual development.

The implications of this study suggest that teachers can utilize crossword puzzle-based e-modules as an alternative digital learning medium to support the principles of the Merdeka Curriculum. The module is relevant to student-centered learning because it provides opportunities for learners to explore concepts, solve problems, and engage actively with learning materials. It can also support project-based learning, formative assessment, differentiated learning, and the development of 21st-century skills, particularly critical thinking, creativity, collaboration, and communication. In biology learning, this medium is especially useful for topics that contain complex terminology and conceptual relationships. However, its application is not limited to biology; similar crossword puzzle-based e-modules may also be adapted for subjects such as mathematics, physics, history, language learning, and civics education, particularly for materials that require conceptual mastery and analytical understanding.

Nevertheless, several limitations should be acknowledged. First, the study was conducted in a limited context and involved students from only one madrasah, so the findings cannot be generalized broadly to all educational settings. Second, if the study used a one-group pretest-posttest design, the absence of a control group limits the ability to determine whether the improvement in students' scores was caused solely by the use of the e-module or was influenced by other factors, such as teacher explanation, repeated testing, student familiarity with the topic, or external learning support. Third, the implementation of digital e-modules depends on the availability of adequate technological infrastructure, including devices, electricity, internet access, and students' digital literacy. In schools with limited facilities, the use of this medium may require additional technical preparation and teacher assistance.

For future research, it is recommended that similar studies involve a larger number of schools and students from different social, geographical, and institutional backgrounds. Future studies should also employ a stronger experimental design, such as a quasi-experimental pretest-posttest control group design, to obtain more valid evidence regarding the effectiveness of crossword puzzle-based e-modules compared with conventional learning methods. In addition, future researchers may examine other variables, such as learning motivation, creativity, collaboration, science literacy, learning independence,

and long-term retention. The development of future e-modules may also include more advanced digital features, such as automatic scoring, instant feedback, adaptive difficulty levels, interactive animations, learning analytics, and gamified reward systems. These improvements are expected to enrich students' digital learning experiences and strengthen the contribution of crossword puzzle-based e-modules to innovative biology learning.

CONCLUSION

This study concludes that the crossword puzzle-based e-module developed using Eclipse Crossword is feasible, practical, and effective in supporting biology learning on the topic of plant reproductive systems for Grade IX students at MTsN 01 Bandar Lampung. The expert validation results indicated that the e-module met the criteria for high feasibility in terms of media design, content suitability, interactivity, and ease of use, while the readability test showed that students perceived the module as clear, engaging, and helpful for understanding abstract biological concepts. The increase in students' posttest scores and the moderate N-Gain result indicate that the e-module contributed positively to the development of students' critical thinking skills, particularly through activities that required them to recall, connect, analyze, and evaluate biological concepts in a structured and meaningful way. The integration of crossword puzzle activities also created a more interactive, enjoyable, and student-centered learning experience, thereby supporting motivation, conceptual understanding, and active participation. However, because this study was conducted in a limited context and did not involve a control group, the findings should be interpreted cautiously and cannot be generalized broadly. Future studies are recommended to involve larger and more diverse samples, apply a quasi-experimental design with a control group, and integrate advanced digital features such as automatic scoring, instant feedback, adaptive difficulty levels, and gamified learning analytics to strengthen the effectiveness of crossword puzzle-based e-modules in science learning.

LIMITATIONS

This study has several limitations that should be acknowledged. First, the research was conducted in a limited setting involving Grade IX students from only one madrasah, namely MTsN 01 Bandar Lampung. Therefore, the findings cannot be broadly generalized to students from different school levels, institutional contexts, or geographical areas. Second, the effectiveness test employed a one-group pretest–posttest design without a control group. As a result, the improvement in students' critical thinking skills cannot be attributed solely to the use of the crossword puzzle-based e-module, since other factors such as teacher explanation, repeated exposure to the material, students' prior knowledge, and external learning support may also have influenced the results. Third, the implementation of the e-module depended on the availability of digital devices, students' digital literacy, and classroom technological readiness. These factors may affect the consistency and effectiveness of the module when applied in schools with limited infrastructure. Fourth, the study focused only on the topic of plant reproductive systems, so the effectiveness of the crossword puzzle-based e-module for other biology topics or other subject areas still requires further investigation. Finally, this study measured students' critical thinking skills over a relatively short period; therefore, it did not examine the long-term retention of concepts or the sustained impact of the e-module on students' learning motivation and higher-order thinking skills. Future research should involve larger and more diverse samples, apply a quasi-experimental design with a control group, and examine additional variables such as motivation, creativity, collaboration, science literacy, and long-term learning retention.

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AUTHOR CONTRIBUTION

AH contributed to the conceptualization of the study, research design, supervision, product validation, and final review of the manuscript. DA contributed to product development, instrument preparation, data collection, data analysis, and writing the original draft. MZ contributed to school coordination, learning implementation support, and field data collection. RO contributed to methodology refinement, instructional media development, and manuscript revision. NBH contributed to academic supervision, theoretical strengthening, validation, and critical review of the manuscript. ADK contributed to data interpretation, visualization, and editing of the manuscript. LP contributed to literature review, documentation, and language refinement. IR contributed to data organization, reference management, and final manuscript formatting. All authors have read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF USE OF AI IN SCIENTIFIC WRITING

During the preparation of this manuscript, the authors used AI-assisted writing tools to support language refinement, improve sentence clarity, and enhance the academic readability of the manuscript. The AI tool was not used to generate research data, conduct statistical analysis, alter research findings, or replace the authors' intellectual contribution. All content, arguments, interpretations, data analysis, and conclusions were reviewed, verified, and approved by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the final manuscript.

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