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Development of a STEM-Based Science E-Module to Enhance Students' Communication and Creativity Skills on Biodiversity Material

Rini Oktavia[1*], Masriani[1], Sitti Aminah[1]

[1] Postgraduate Program in Science Education, Tadulako University, Palu,Indonesia.

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Corresponding Author:
Rini Oktavia
rinioktavia000@gmail.com

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Abstract: His study aims to develop a STEM-based science e-module to enhance seventh-grade students' communication and creativity skills in biodiversity material at MTs Negeri 1 Palu. The research employed a Research and Development (R&D) method with the ADDIE model, which includes stages of Analysis, Design, Development, Implementation, and Evaluation. Validation was conducted by content and media experts, as well as teachers and students. The developed e-module demonstrated high validity, with scores of 82% from content experts and 76.25% from media experts. Practicality testing also showed strong usability, with 86% approval from teachers and 92% from students. Implementation of the e-module led to significant improvements in student outcomes, increasing communication skills from 62% to 89% (Cohen's d = 1.99) and creativity from 59% to 93% (Cohen's d = 1.95). These results indicate that the e-module is not only valid and practical but also effective in enhancing communication and creativity skills, thus supporting the development of 21st-century competencies.

Keywords: Biodiversity; Communication; Creativity; Module; STEM

Introduction

The development of science and technology in the digital era has brought fundamental changes to learning approaches. Twenty-first century learners are required to possess essential skills such as critical thinking, effective communication, creativity, and collaboration (Adella et al., 2024; Novia et al., 2024; Thornhill-Miller et al., 2023; Tight, 2021). In the context of science education, these skills are crucial for developing a deep conceptual understanding as well as the ability to solve complex real-world problems. However, in reality, learning in many schools, including at MTs Negeri 1 Palu, still tends to be conventional and does not adequately facilitate the development of students' communication and creativity skills (Ainun et al., 2021).

This condition is reinforced by the results of interviews with science teachers, who stated that students remain passive, rarely ask questions, and have limited ability to communicate ideas or solutions both orally and in writing. Students' creativity in designing solutions to environmental problems in their surroundings is also low, as learning is not supported by contextual media or approaches (Alfira et al., 2024). Therefore, there is a need for innovative learning media that not only present content informatively but also actively and meaningfully engage students in the learning process. One of the learning strategies considered effective in fostering communication and creativity skills is the STEM (Science, Technology, Engineering, and Mathematics) approach. This approach integrates various scientific disciplines into project-based activities, experiments, and contextual problem solving, encouraging students to think systematically and creatively (Afifah et al., 2025; Juškevičienė et al., 2021; Le et al., 2023; Tight, 2021).

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Research by Sholikhah et al. (2024) has shown that the implementation of STEM-based modules can significantly improve students' critical thinking and creativity through structured and collaborative activities.

In line with this, the use of e-modules as digital learning media has become increasingly relevant amid the growing need for self-directed and technology-based learning. E-modules offer advantages over printed modules, such as interactivity, ease of navigation, and the integration of multimedia elements including videos, animations, and automatic quizzes (Cynthia et al., 2023; Fujiarti et al., 2024; Risnawati et al., 2025). Digital modules are also considered more practical, cost-effective, and capable of enhancing students' motivation and engagement in the learning process (Loukatos et al., 2022; Maulidiyah et al., 2022; Sanfilippo et al., 2022). Research by Firdaus et al. (2024) has shown that the development of learning e-modules can significantly improve students' creativity, particularly when delivered through project-based approaches and exploratory assignments.

Biodiversity material in the science curriculum is one of the topics highly relevant to be developed through the STEM approach. This material encompasses numerous concepts of ecology and conservation that can be linked to local contexts as well as global issues. However, this topic is often perceived as abstract and difficult for students to understand when it is taught solely through textbook reading or lectures (Muhartati et al., 2023). Therefore, the development of STEM-based e-modules that incorporate local content, visual simulations, and interactive activities is essential to bridge students' understanding of concepts and their application in real-life situations (Kusumawati et al., 2023).

In response to this need, the present study aims to develop a STEM-based science e-module to enhance seventh-grade students' communication and creativity skills in learning biodiversity at MTs Negeri 1 Palu. Utilizing the ADDIE development model, the research evaluates the e-module's validity, practicality, and effectiveness. The findings are expected to contribute to the advancement of innovative learning resources that foster technology-integrated education aligned with 21st-century skill development.

Several theories support the urgency of this research. Constructivist Learning Theory (Piaget, 1972; Vygotsky, 1978) emphasizes that knowledge is actively constructed by learners through interaction with their environment. This aligns with the design of STEM-based e-modules that facilitate exploration and problem-solving. In addition, the 21st Century Skills Framework (P21, 2019) places communication and creativity at the core of essential skills for global competitiveness. The Technology Acceptance Model (Davis, 1989) also provides a theoretical foundation, suggesting that students' acceptance of e-modules depends on perceived usefulness and ease of use, making design quality and interactivity critical factors for success. Moreover, Project-Based Learning theory underlines that student engagement in real-world problem solving enhances creativity and communication skills (Afriana et al., 2016).

This study is conducted based on several reasons. First, empirical evidence from MTs Negeri 1 Palu shows that students' communication and creativity skills remain low, requiring innovative interventions. Second, the conventional approach in teaching biodiversity does not adequately connect the material with real-life contexts, reducing students' engagement and motivation. Third, integrating STEM into digital e-modules provides an alternative learning strategy that is not only innovative but also responsive to the challenges of the digital era and aligned with the Merdeka Belajar curriculum reform policy (Kemendikbud, 2020). Finally, this research aims to contribute to the development of valid, practical, and effective learning resources that can improve the quality of science education and foster the achievement of 21st-century competencies among students.

Method

This study employs a Research and Development (R&D) approach aimed at developing and testing the effectiveness of an educational product, namely a STEM-based science e-module designed to improve students' communication and creativity skills. The development model used is the ADDIE model, which consists of five main stages: analysis, design, development, implementation, and evaluation. The selection of the ADDIE model is based on its strengths in providing a systematic, flexible, and continuously improvement-oriented framework, making it highly suitable for developing digital and interactive learning products such as this e-module.This study was conducted at MTs Negeri 1 Palu, Central Sulawesi, a digital-based madrasah school equipped with science laboratory facilities and online learning networks. The research subjects were 60 seventh-grade students from classes VII-G and VII-H, selected because they were already accustomed to using digital devices in learning activities. The research was carried out during the even semester of the 2024/2025 academic year, taking into account the readiness of the infrastructure and the alignment with the relevant curriculum integration.

The first stage in the ADDIE model is analysis. In this stage, the researcher conducted interviews with science teachers to identify problems related to

biodiversity learning. The analysis revealed that the learning process was still conventional, did not sufficiently involve active student participation, and had not yet maximized the use of the STEM approach. Teachers also indicated the need for learning media that are more engaging, interactive, and compatible with technological developments as well as the characteristics of today's students.

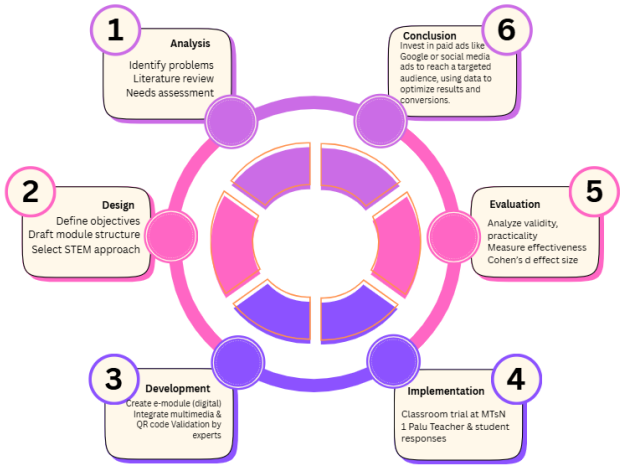

Figure 1. Research flow diagram

The next stage was the design of the e-module. In this stage, the researcher developed the structure and content of the e-module, which included learning objectives, competency indicators, instructional materials, learning activities, and assessment. The module was designed by integrating elements of science, technology, engineering, and mathematics within the context of biodiversity, and was equipped with visual media, interactive quizzes, and problem-based projects.

The development stage represents the realization of the e-module design that had been prepared. In this stage, the researcher produced the initial version of the e-module and conducted validation of both its content and design. The validation was carried out by two content experts and two media experts. The content validation focused on the accuracy of the material, its relevance to the curriculum, and the integration of STEM elements, while the media validation assessed aesthetics, navigation, and practical usability. The validation results indicated that the e-module was in the "highly valid" category, with several suggestions for improvement, such as adding illustrations and refining language structure.

After revisions were made, the e-module was tested with students during the implementation stage. In this stage, the e-module was used directly in the learning process over three class sessions. The teacher facilitated students in using the e-module and monitored learning activities that included group discussions, project assignments, and presentations. During the implementation, the researcher also observed student engagement and collected data through questionnaires and observation sheets.

The final stage is evaluation. The evaluation was conducted in two forms: formative evaluation, which was carried out throughout the development process to improve product deficiencies, and summative evaluation, which was conducted after implementation to assess the effectiveness of the e-module. The summative evaluation used quantitative analysis of observation and questionnaire data, including the calculation of effect size using Cohen's d formula to measure improvements in students' communication and creativity skills.

Data collection was conducted through various techniques, including interviews, observations, validation questionnaires, and practicality questionnaires. The instruments used in this study comprised expert validation questionnaires, teacher and student response questionnaires, and observation sheets assessing skills. All instruments were validated by experts prior to use to ensure the accuracy and validity of the data. Data were analyzed descriptively and quantitatively, with the interpretation of results based on criteria for validity, practicality, and effectiveness of the module. With systematic stages and the support of validated instruments, this research method successfully produced a STEM-based science e-module that is not only valid and practical but also effective in improving students' communication and creativity skills in science learning, particularly in biodiversity topics.

Result and Discussion

The STEM-based science e-module on biodiversity was evaluated by content and media experts to ensure its quality before implementation. Table 1 presents the content expert validation results. Two subject-matter experts reviewed the e-module for content accuracy, alignment with curriculum, STEM integration, and relevance to 7th-grade students. The first validator gave a score of 76 out of 92 points (83%), and the second gave 75/92 (82%). This yields an average content validity of 82%, which falls in the "Valid" category. In other words, the e-module's content is appropriate and meets curriculum standards, is relevant to student characteristics, and integrates STEM principles effectively. Experts provided several suggestions to further improve the content, including refinements to concept explanations, addition of illustrative examples, clearer integration of STEM aspects in activities, and simplification of language for better student

comprehension. These inputs were incorporated to enhance the module's clarity and relevance.

Table 1. Content Expert Validation Results

Validator 1 Score	Validator 2 Score	Average (%)	Category
83 %	82%	82%	Valid

The e-module's media/design aspects were also validated by two instructional media experts (Table 2). They examined the module's interface design, visual appeal, readability, and interactivity. The media experts awarded scores of 62/80 (77.5%) and 60/80 (75%), with an average of 76.3%, also in the "Valid" category. This indicates that the e-module's layout, navigation, and multimedia elements are of good quality and suitable for classroom use. The validators did recommend minor improvements to maximize usability. Key suggestions included enhancing the visual layout (e.g. improving page balance and reducing dense text), increasing color contrast between text and background for readability, choosing student-friendly fonts, adding interactive navigation buttons (e.g. "Next"/"Back"), and structuring content with bullet points or subheadings for clarity. After revisions addressing these points, the e-module's design was judged to be attractive, easy to read, and effectively interactive for students.

Table 2. Media Expert Validation Results

Validator 1 Score	Validator 2 Score	Average (%)	Category
77.5 %	75%	76.3%	Valid

Overall, the expert validation phase confirms that the developed e-module is highly valid in both content and media aspects. With strong scores from subject matter and media validators, the module meets the criteria for quality content and functional design. These results indicate the e-module is well-founded scientifically and technically, and is suitable for use as a learning resource to improve student communication and creativity skills. This aligns with findings from previous studies that STEM-oriented e-modules tend to receive positive expert evaluations due to their integrative, engaging, and contextually relevant content.

After validation, a practicality test was conducted to assess the e-module's ease of use and usefulness in an actual classroom setting. The practicality was evaluated through questionnaires administered to science teachers and students at MTs Negeri 1 Palu after using the e-module in learning activities.

Three science teachers used the STEM-based e-module in their classes and then rated its practicality. Table 3 summarizes the teachers' responses. Each teacher's score is calculated as a percentage of the maximum possible score on the teacher practicality questionnaire. All three teachers gave very high ratings: two teachers scored 83% and one scored 92%. The mean teacher practicality rating is 86%, which is classified as "Very Practical." This indicates that teachers found the e-module to be highly usable and effective in facilitating learning. They noted that the module was easy to implement within the existing class schedule and required minimal additional effort or resources. An average above 80% suggests the e-module can be readily integrated into teaching with positive reception by instructors.

Table 3. Teacher Responses on E-Module Practicality

Teacher 1	Teacher 2	Teacher 3	Average (%)	Category
83%	83%	92%	86%	Very Practical

The module's practicality was also analyzed from the students' perspective using a student response questionnaire. Table 4 presents the average results for each indicator of the student questionnaire, along with the overall average. All ten practicality indicators were rated very positively by the students. Notably, students responded that the e-module content is organized clearly and systematically (Indicator 1, 90% agreement), the learning activities are clear and align with science principles (Indicator 2, 88%), and the module provides opportunities for them to communicate and be creative (Indicator 3, 88%). They also felt the e-module made them actively engaged and helped them organize information (95%), and it increased their motivation to learn biodiversity (the highest rating at 98% for Indicator 5). The assessment components in the module are clearly presented (90%), and the provided time allocation is effective for completing tasks (95%). Additionally, students agreed that the observation instruments in the module align with the targeted communication and creativity skills (88%), and that the non-cognitive diagnostic assessments are clearly designed (93%). They found the language used in the module to be appropriate and easy to understand, conforming to standard language rules (95%). The overall average student practicality rating is 92%, which falls in the "Very Practical" category. In summary, students found the STEM-based e-module highly practical – it was engaging, easy to follow, and supportive of their learning process.

These practicality results demonstrate that the e-module is not only theoretically sound but also feasible and effective in real classrooms. Both teachers and students responded enthusiastically, indicating the module is easy to use and enhances the learning experience. According to the criteria by Afifah et al. (2025), a development product is considered practical if it scores above 60% on practicality measures. In this study, the e-module far exceeds that threshold, confirming its high practicality. The consistently high

student ratings across all indicators suggest the module's design successfully addresses various aspects of the learning process, from clarity of content and activities to motivation and appropriate use of language. Thus, the developed STEM-based e-module is validated as both valid and practical for use in teaching biodiversity material to 7th graders.

Table 4. Student Practicality Questionnaire Results

Indicator (Practicality Aspect)	Average (%)
The e-module components are presented in a structured and clear manner	90%
The learning steps are clear and follow standard science learning principles	88%
The activities provide opportunities for students to communicate and be creative	88%
The activities engage students actively and allow them to organize the information learned	95%
The science learning activities motivate students in learning the biodiversity material	88%
The assessments in the STEM e-module are clearly structured	93%
The allocated time is effectively used for the learning activities	96%
The observation instruments align with the targeted communication and creativity skills	88%
The non-cognitive diagnostic assessments are clearly designed	95%
The language used in the module is appropriate and follows standard grammar/spelling	95%
Overall Average	92% (Very Practical)

To evaluate the effectiveness of the STEM-based e-module, the study measured students' communication skills before and during its implementation. Communication skill was observed over three class meetings (lessons) using a validated communication skill instrument. The instrument assessed oral communication (organization of ideas, clarity, expression) and written communication (organization, clarity, and language accuracy) aspects. Table 5 shows the total communication skill scores obtained by students at each meeting, along with the percentage of the maximum score.

Table 5. Student Communication Skill Scores Across Learning Meetings

Meeting 1	Meeting 2	Meeting 3
62%	78%	92%

Students' communication abilities improved markedly over the course of using the e-module. In the first meeting, the class average communication score was 561 out of 912, which is 62%. This initial stage mostly involved introducing basic biodiversity concepts and limited group discussion. Students were still adapting to the STEM-based learning format, which requires active problem-solving and data-driven communication. At this point, their oral communication was not yet well-developed – for example, the Oral Organization indicator was only 58%, and Oral Clarity 59% in Meeting 1 – indicating students struggled to logically organize and clearly express ideas at the outset.

By the second meeting, the average communication score rose to 708 (78%). This significant improvement coincided with learning activities emphasizing problem solving and project planning for biodiversity conservation. Students became more engaged in group discussions, interpreting visual data from the e-module, and articulating their ideas in a structured way. Notably, both Oral Organization and Oral Clarity scores jumped to 79% by Meeting 2, and Oral Expression (confidence and communication style) improved to 71%. These gains suggest that as students grew familiar with the e-module and collaborative STEM tasks, they communicated their thoughts more confidently and coherently.

In the third meeting, when students completed and presented their final projects (e.g. in poster or infographic form), the average communication score reached 812 (89%). At this culminating stage, student communication was effective and well-developed. During Meeting 3, every aspect of communication showed high achievement: Oral Organization averaged 88%, Oral Clarity 87%, and Oral Expression 87%. Written communication skills similarly improved, with Written Organization and Written Clarity both at 89%. Students not only spoke with clearer structure and confidence, but also produced well-organized written outputs that adhered to proper language conventions. This comprehensive improvement illustrates that the e-module learning experience enabled students to articulate scientific ideas more clearly, both verbally and in writing.

The overall effect of the e-module on communication skill was quantitatively very large. A paired analysis from the first to third meeting yields Cohen's d = 1.99, indicating a very large effect size for the improvement in communication skills (based on common interpretation thresholds). Such a high effect size suggests that the STEM-based e-module had a strong and significant impact on students' communication abilities. Students progressed from relatively passive communicators to active participants able to discuss, explain, and present scientific information effectively.

In addition to communication, the study also tracked student creativity skills throughout the e-module implementation. Creativity was evaluated via an observation sheet (validated by experts) focusing on three key dimensions of creative thinking: fluency (generating many ideas), originality (producing novel or unique ideas), and elaboration (developing and detailing ideas). Students' creative performance was observed in each of the three class meetings. Table 6 summarizes the creativity scores across the meetings, including the total score achieved out of the maximum and the corresponding percentage.

Table 6. Student Creativity Skill Scores Across Learning Meetings

Meeting 1	Meeting 2	Meeting 3
59%	83%	93%

The results show a steep improvement in creativity from Meeting 1 to Meeting 3. In the first meeting, the average creativity score was 544 out of 912, which is 59%. At this initial stage, students' creative thinking was at a beginning level. Many students were relatively passive in proposing new ideas or formulating solutions independently. This is understandable, as the first exposure to STEM-based, project-oriented learning required them to adjust to a new, integrative approach combining science, technology, engineering, and math concepts. In other words, during Meeting 1, students were just starting to engage in creative thought processes and needed time to adapt.

By the second meeting, the creativity score jumped to 760 (83%), indicating a substantial development in students' creative skills. This meeting involved students actively generating solutions and designing their biodiversity conservation projects. The largest gains were observed in the fluency and elaboration dimensions. Students became more adept at rapidly producing a variety of ideas (fluency) and expanding on those ideas in detail (elaboration). The use of the e-module facilitated this process by helping learners structure their brainstorming and encouraging them to express ideas more confidently. For instance, students could map out their thoughts using the module's prompts and resources, leading to more structured and inventive project plans.

In the third meeting, the creativity score further increased to 850 (93%). At this point, students demonstrated mature creative thinking skills. Of the three dimensions, fluency showed the highest achievement with an average of 94%, meaning students were very fluent in pouring out numerous ideas. The originality dimension also improved to 85%, reflecting that students proposed more unique, non-conventional ideas by the end of the project. Meanwhile, elaboration reached 91%, indicating students were able to thoroughly develop and refine their ideas with significant detail and depth. By the conclusion of the e-module implementation, learners were not only generating many ideas but also ensuring those ideas were novel and well-elaborated – a clear sign of enhanced creativity.

The effect size analysis for creativity confirms the module's strong impact. The improvement from Meeting 1 to Meeting 3 corresponds to Cohen's d = 1.95, which is categorized as a very large effect. This very high effect size signifies that the STEM-based e-module had a powerful influence on boosting students' creative thinking skills. The pedagogical approach of integrating project-based STEM activities clearly provided a positive stimulus for students to think more creatively and take intellectual risks in a supportive environment.

In sum, the STEM-oriented e-module was effective in significantly improving both communication and creativity skills among 7th-grade science students. The progressive increases in scores and the large effect sizes for both skill sets demonstrate that this digital module achieved its developmental goals. By the end of the implementation, students were communicating scientific ideas more effectively and showcasing comprehensive creative thinking. These quantitative outcomes suggest that incorporating STEM principles into a science e-module can simultaneously enhance content understanding and foster important 21st-century skills.

High expert validation scores confirm the STEM-based biodiversity e-module is valid in content (82%, "Valid") and design (~76%, "Valid"). Experts confirmed the content aligns well with curriculum standards, integrates STEM concepts effectively, and is relevant to real-world contexts. The design aspects—appearance, navigation, clarity, and interactivity—also meet high quality standards. These findings align with prior studies (e.g., Sari et al., 2024) highlighting that effective STEM e-modules typically integrate contextually relevant content with engaging multimedia features. Minor suggestions for visual improvements were implemented, further enhancing the module's practical usability in classroom settings.

The practicality results demonstrate that the STEM e-module is highly practical and readily implementable in real teaching settings. Teachers' responses gave an average practicality score of 86%, which is interpreted as very practical (Table 3). This indicates that teachers found the e-module easy to use, fitting well within their lesson plans, and not demanding excessive preparation or resources. Importantly, the teachers observed that the module actively engaged students and complemented their teaching of biodiversity, rather than causing any technical or classroom management difficulties. From

the students' perspective, the module was also deemed very practical, with an overall student rating of 92% (Table 4). Students enjoyed using the e-module and found it straightforward to navigate and understand. They responded positively to each aspect of the module's practicality – from the clear organization of material to the motivating activities and the appropriate pacing and language.

According to Afifah et al. (2025), a development product is considered practical if it achieves above 60% in practicality assessments. The e-module in this study far exceeded this criterion, confirming its high practicality for both teachers and students. The consistently strong student agreement on the practicality indicators (Table 4) underscores that the module design effectively addressed user needs. For instance, nearly all students agreed the module motivated them and got them actively involved in learning biodiversity. This outcome is crucial for an educational intervention, as even a valid module would fail to produce impact if students and teachers could not or would not use it easily. The present findings align with the view of Eviota et al. (2020) that a systematically developed, technology-based learning module can result in a product that is practical, effective, and significantly enhances learning outcomes and skills. In other words, thoughtful integration of pedagogy with digital design (as done in this module) yields a resource that not only looks good on paper but also works smoothly in practice, engaging users and encouraging them to fully participate in the learning process.

The implementation of the e-module led to a marked improvement in students' communication skills, which is a central objective of this research. Over the three sessions using the module, students' communication abilities progressed from basic to highly competent, as evidenced by the increase in average communication score from 62% to 89% (Table 5). In the first meeting, students were adjusting to the new STEM-based learning format and were relatively reticent in discussions. By the third meeting, however, they were confidently presenting project findings with clear, well-organized arguments both orally and in writing. All five measured indicators of communication (three oral, two written) showed substantial gains (many reaching the high 80s in percentage by the end). This comprehensive skill growth suggests that the module's features – such as interactive content, group problem-solving tasks, and opportunities for presentation – effectively cultivated both oral and written communication competencies in science.

The very large effect size (Cohen's $d \approx 1.99$) calculated for the improvement in communication skills is notable. It indicates that the use of the STEM e-module had a powerful effect on how well students communicate scientific ideas. Such a result is supported by findings in the literature. Purnamasari et al. (2020) reported that using STEM-based modules helps students integrate science concepts with process skills and improves scientific communication. In the present study, the e-module required students to discuss data, explain concepts to peers, and present solutions – all of which likely contributed to their improved clarity and confidence in communication. Sumanti et al. (2025) similarly found that project-based science learning via e-modules significantly enhanced students' oral and written communication, by providing authentic contexts in which students must actively explore information and convey their understanding. Our results mirror these conclusions: as students engaged with the module's project (designing a biodiversity conservation plan), they had to frequently communicate, thereby practicing and honing their skills in a meaningful context.

By the final presentation stage, students in our study were using scientific terms appropriately, articulating their ideas logically, and responding to feedback – clear signs of effective communication skill development. This outcome reinforces the idea that STEM-oriented, collaborative learning environments can foster critical communication skills in science education. Moreover, the success of the module in improving communication underscores its alignment with 21st-century learning goals. As noted by Eviota et al. (2020), technology-enhanced modules developed through a systematic approach yield significant impacts on learners' essential skills, including communication, because they actively engage students in the learning process. In conclusion, the improvement in communication skills observed in this study demonstrates the e-module's educational value beyond content mastery – it also builds students' confidence and ability to express scientific ideas, which is vital for their ongoing academic and personal development.

In tandem with communication, students' creative thinking skills showed significant enhancement through the use of the STEM-based e-module. Creativity is a crucial competency in science learning, allowing students to generate innovative ideas and solutions. The results revealed that students' creativity, measured across fluency, originality, and elaboration dimensions, improved from an initial 59% average to 93% by the end of the module implementation (Table 6). This is a dramatic rise, reflecting that the learning activities in the module effectively nurtured creativity. Initially, many students were hesitant to propose ideas (a common scenario when first encountering open-ended STEM problems). However, as the module guided them through problem-solving exercises and project design, students became progressively more comfortable thinking outside the box. By the project's culmination,

learners were producing a variety of ideas with confidence – as evidenced by the fluency score reaching 94% – and developing those ideas in depth (elaboration 91%). The slight lag in the originality score (85% by Meeting 3) compared to fluency and elaboration is understandable; while students generated many ideas and expanded them well, truly novel ideas can be more challenging to achieve. Nonetheless, the upward trend in all three creative thinking indicators confirms a well-rounded growth in student creativity.

The effect size for creativity skill improvement (Cohen's d ≈ 1.95) was, like communication, extremely large. This underscores that the e-module had a substantial impact on fostering creativity. The module's project-based STEM approach likely played a key role: students were tasked with designing solutions to a real-world problem (biodiversity conservation), which encouraged them to brainstorm, experiment, and refine their ideas in a supportive environment. These findings are in line with prior research on educational strategies to boost creativity. Ritonga (2024) reported that differentiated instruction strategies can increase student engagement and creativity by addressing individual needs and allowing unique expressions of understanding. In our study, the e-module allowed for some differentiation in that students could pursue their own project ideas and express their creativity in project outputs (posters, infographics), catering to their interests and strengths. Yolanda et al. (2024) similarly found that project-based learning drives learners to produce a wider variety of ideas and more in-depth thinking, as students take ownership of complex tasks. Additionally, research by Sa'ida (2023) and by Ramadhan et al. (2023) has emphasized that product differentiation in learning – where students can create unique final products – enables them to express ideas creatively and inventively. Our e-module followed this principle by culminating in a student-designed product, thereby providing a platform for unique creative expression by each group.

The consistency of our findings with the literature supports the general conclusion that innovative, student-centered learning interventions can substantially improve creativity. By integrating science content with technology and engineering design tasks, and by encouraging mathematical and logical reasoning in context, the STEM e-module engaged multiple facets of students' thinking. This holistic engagement is key to stimulating creativity. Ultimately, the successful enhancement of creativity in this study demonstrates that the e-module not only helped students learn science, but also empowered them to think creatively and critically, skills that are indispensable in the 21st century.

The module's effectiveness in boosting creativity confirms its value as a pedagogical tool that goes beyond factual knowledge, preparing students to tackle problems resourcefully and imaginatively.

Conclusion

The newly developed STEM-based science e-module on biodiversity is validated with an average validity above 70% (content and media), and shows high practicality ratings of 86% (teachers) and 92% (students). The implementation significantly improved students' communication skills (from 62% to 89%, Cohen's d = 1.99) and creativity skills (from 59% to 93%, Cohen's d = 1.95). These results indicate the developed e-module is valid, highly practical, and significantly effective, making it suitable and representative for enhancing communication and creativity skills among students at MTs Negeri 1 Palu.

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