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Development of TPACK-based E-Modules on Explant Sterilization and Somaclonal Diversity as Learning Media for Biology Students

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Article Info	Abstract
	This study aims to determine the feasibility of TPACK-based E-Modules on the subject of Explant Sterilization and Somaclonal Diversity as learning media for biology students. The assessment is conducted based on evaluations by subject matter experts, media experts, and learning experts. In addition, this study seeks to gauge the responses of lecturers and students to the developed E-Modules and to test their effectiveness. This research utilizes a Research and Development (R&D) methodology following the 4D model, which includes the stages of defining, designing, developing, and disseminating. The effectiveness of the TPACK-based E-Module was assessed using N-Gain analysis. The results of the study indicate that the feasibility of the E-Module, according to subject matter experts, is rated at 85.83% (very valid), media experts at 82.79% (very valid), and learning experts at 92.75% (very valid). Faculty responses achieved an average percentage of 91.72% (highly feasible). Student responses were divided into three stages: individual trials at 93.05% (highly feasible), small group trials at 89.58% (highly feasible), and large group trials at 91.97% (highly feasible). Based on the N-Gain test, a value of 0.69 was obtained, which falls into the moderate category. Therefore, the developed TPACK-based E-Module is deemed suitable and sufficiently effective for use as a learning medium for biology students.

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INTRODUCTION

Technology has the potential to significantly enhance learning effectiveness, yet its use in higher education remains limited, particularly in courses requiring in-depth conceptual understanding and practical skills, such as Tissue Culture. Students often find the material in tissue culture difficult to grasp, as it requires both a deep understanding of theory and optimal practical skills (Harahap et al., 2020). Furthermore, limited and inadequate laboratory facilities often hinder students from delving deeper into the practical aspects of the subject. Thus, addressing these challenges requires learning media that can facilitate student understanding of tissue culture (Batubara, 2017). In the context of higher education, teaching materials for tissue culture often rely on conventional learning media such as PowerPoint presentations, textbooks, and modules (Fitriasih, 2020).

Limited laboratory facilities are among the most significant external factors hindering the learning of practical materials like biotechnology, particularly tissue culture. Inadequate laboratory facilities, in terms of both completeness and management, prevent students from exploring the material directly. This limitation hinders the ideal learning process, where students are expected to understand concepts through direct experience. Additionally, insufficient time allocated for practical work poses another constraint. As a result, students tend to rely solely on theory without the support of practical experience, leading to poor conceptual understanding and retention (Rahmadani et al., 2017).

Based on the results of an interview with a lecturer of the Tissue Culture course, it was noted that the current learning media are not fully capable of supporting student learning outcomes as per the applicable curriculum. According to Yahya (2014), the learning media utilized during the process are inadequate due to limited teaching methods, a lack of direct practice, low student activity and creativity, and the need for improvement in the effectiveness of learning media. To achieve the expected curriculum, specifically the OBE curriculum (Outcome-Based Education), which emphasizes a focus on learning outcomes rather than solely on the material presented (Puspita et al., 2022), innovation in teaching methods and the adoption of more interactive and applicable media are essential. The lack of learning media that facilitates direct practicum activities has resulted in suboptimal learning outcomes in the Tissue Culture course. Consistent with this, Hartini et al. (2019) reported that developing a Virtual Laboratory for plant tissue culture offers an effective alternative, demonstrating strong validity (84.72% in the material aspect) and a considerable improvement in student achievement, as reflected by an N-Gain score of 0.74.

TPACK can help design e-modules that not only provide theoretical content but also integrate appropriate pedagogical approaches and utilize technology to create a more immersive learning experience, especially in courses involving laboratory practices such as Explant Sterilization and Somaclonal Diversity (Octariani & Sembiring, 2023). By integrating TPACK into the material on Explant Sterilization and Somaclonal Diversity, students will gain not only content knowledge (CK) namely a deep understanding of the teaching material, but also pedagogical knowledge (PK) that fosters active student involvement in the learning process. This approach enables students to collaborate with classmates in discussions and group activities, which are necessary to replace direct practicums, thereby enriching their learning experience (Musdalifa & Dimpudus, 2024). Additionally, technological knowledge (TK) can be harnessed through E-Modules, which can enhance student interaction and engagement with complex materials (Suyamto et al., 2020).

The results of the E-Module need analysis questionnaire for UNIMED students enrolled in tissue culture courses reveal that students encounter challenges in comprehending the subjects of Explant Sterilization and Somaclonal Diversity, with 68% of them indicating that this difficulty arises from the abstract nature of the content. This suggests a pressing need to improve the quality of learning by adopting a more interactive and understandable approach. Conversely, 98% of students stated that the Tissue Culture E-Module would make it easier for them to access the material anytime and anywhere, underscoring that flexibility of access is one of the main advantages of the E-Module. Most students are familiar with using technology such as laptops and smartphones during class and have the ability to access and utilize various

digital education platforms. This demonstrates that students are prepared to use TPACK-based E-Modules as learning supports because they are interested in technology-based media and prefer visual and interactive formats.

Interview results and student needs questionnaires further reveal that students face difficulties in understanding practicum procedures, particularly regarding explant sterilization and the concept of somaclonal diversity. This observation is supported by a lecturer's statement indicating that not all materials can be practiced due to limited learning media and laboratory facilities. In the learning process, students are required not only to master theory but also to comprehend the practicum steps, which are often not implemented optimally. Key concepts such as sterilization procedures and an understanding of somaclonal diversity must therefore be presented clearly and systematically. Consequently, the preparation of materials in the E-Module should focus on supporting the achievement of learning competencies, encompassing knowledge, skills, and the application of technology in learning.

Due to the gap between the need for effective learning regarding the materials of Explant Sterilization and Somaclonal Diversity and the current learning media, as well as the potential for technology integration through the TPACK framework, the development of "TPACK-Based E-Modules on the Material of Explant Sterilization and Somaclonal Diversity as Learning Media for Biology Students" is essential.

RESEARCH METHOD

The research conducted is classified as research and development (R&D). The creation of the E-Module relies on the TPACK framework and adheres to the Four-D (4D) development model, which consists of four stages: define, design, develop, and disseminate. More detailed steps related to this research model are outlined in the following work procedures. The subjects in this study included expert validators consisting of material experts, media experts, and learning experts. Additionally, the subjects comprised lecturers from the Tissue Culture Department and students from the Biology Department at Medan State University. This research design employs both quantitative and qualitative approaches. The quantitative approach was used to obtain questionnaire scores from material experts, media experts, learning experts, lecturers, and students, as well as the pretest and posttest that were conducted. Meanwhile, the qualitative approach provides insights into the assessment results from material experts, media experts, and learning experts, alongside lecturers' responses and students' feedback regarding the development of a TPACK-based e-module as a learning medium after using the E-module. The data collection techniques used in this development research included interviews, questionnaires, and tests.

The data analysis methods used in this study included both descriptive and qualitative-quantitative approaches. Information was gathered through questionnaires containing statements aimed at assessing the feasibility of the learning media. The data processing involved converting qualitative data from the questionnaires into quantitative data. The data analyzed in this study included validation questionnaire data, lecturer and student response questionnaires, as well as pretest–posttest data to examine the effectiveness of the E-Module through the N-Gain test.

RESULTS AND DISCUSSION

The outcome of this research is a TPACK-based E-Module that focuses on the topics of Explant Sterilization and Somaclonal Diversity, intended as a learning resource for biology students. The TPACK-based E-Module was developed using the 4D development model. This model was chosen for its relevance and effectiveness in meeting the research objectives, as well as its capacity to produce high-quality products. The 4D development model consists of four phases: define, design, develop, and disseminate.

Develop

This stage involves producing a development product after undergoing a process of improvement. Once the draft of the TPACK-based E-Module is generated in the design stage, it is then reviewed by the supervising lecturer and validated by experts to produce Draft I. The steps in the development stage are as follows:

1. **Feasibility of TPACK-Based E-Modules by Experts**

This stage is conducted to provide an assessment and suggestions for improvements to the TPACK-based E-Module being developed, allowing for further revisions to enhance its content. With assessments from subject matter experts, media experts, and learning experts, it is hoped that the material in this E-Module will be delivered accurately, effectively, and reliably.

Table 1 Results of the TPACK-Based E-Module Assessment by Material Experts

No	Assessment Aspects	Percentage	Criteria
1	Content Suitability	77,5%	Valid
2	Eligibility of Independent Learning Aspects	100%	Very Valid
3	Presentation Eligibility	80%	Valid
Overall Rating		**85,83%**	**Very Valid**

According to the data in Table 1, the average percentage provided by the material experts for the feasibility of the material content is 77.5% (valid), the feasibility of the independent learning aspect is 100% (very valid), and the feasibility of the presentation is 80% (valid). From these three aspects, the total average value is 85.83%, categorized as very valid. Based on the assessment from the validator, suggestions and input were received, which were used to enhance the TPACK-based E-Module that was developed. The feedback suggested that the TPACK-based E-Module is appropriate for use in the trial process, considering the adjustments that have been implemented.

Suggestions and revisions based on expert evaluations concerning the excessive use of bold font have been eliminated to create a cleaner and more readable text. The term "Learning Instructions" was also eliminated, and the CPMK, objectives, and learning methods were moved to the beginning of each chapter or material to ensure that important information is immediately visible. The second enhancement pertains to the introduction, which should include an explanation of cell theory, the concept of totipotency as outlined in CPMK 1, and the role of plant tissue as a source of explants. To facilitate clarity for readers on how to proceed to Chapters I and II, directional guidance has been provided. The third enhancement involves adding further details about the purpose of explant sterilization in the materials section to help readers grasp the reasons and advantages of this process. Improvements in these three images encompass aspects of the appropriateness of the material content. According to previous research by Nurfitasari et al. (2024), the content of the E-Module material is considered valid if it meets the needs of students and teaching materials, is scientifically accurate, clear, systematic, aids understanding, is useful in increasing insight, and guides students in each learning activity.

Table 2 Results of the TPACK-Based E-Module Assessment by Media Experts

No	Assessment Aspects	Percentage	Criteria
1	Eligibility of Independent Learning Aspects	75%	Valid

2	Visual Appearance Eligibility E-module	89,29%	Very Valid
3	Authorization Qualification	84,09%	Very Valid
Overall Rating		**82,79%**	**Very Valid**

According to the data in Table 2, it can be observed that the average percentage given by media experts for the feasibility aspect of independent learning is 75% (valid), the feasibility aspect of the visual display is 89.29% (very valid), and the feasibility aspect of E-Module management is 84.09% (very valid). From these three aspects, the total average value obtained is 82.79%, which falls into the very valid category. Based on the assessment provided by the validator, suggestions and input were gathered and used as material for improvements to the TPACK-based E-Module that was developed. The validator stated that the TPACK-based E-Module was suitable for use in the trial process, following the revisions made.

Suggestions and revisions from media experts suggested modifying the color scheme of the front and back covers to enhance their visual appeal and reduce monotony. The previously dominant green was enhanced by the addition of orange, creating a fresher and more varied impression. Improvements to both images focus on the suitability of visual appearance. The choice of color combinations in the design can effectively visualize objects, thus creating a pleasant atmosphere for readers (Harahap et al., 2020).

Table 3 Results of the TPACK-Based E-Module Assessment by Learning Experts

No	Assessment Aspects	Percentage	Criteria
1	Learning Outcomes	93,75%	Valid
2	Introduction	87,5%	Very Valid
3	Core Activities	95%	Very Valid
4	Closing	93,75%	
5	TPACK Assessment	93,75%	
Overall Rating		**92,75%**	**Very Valid**

According to the data in Table 3, the average percentages provided by learning experts for various aspects are as follows: the learning achievement aspect is rated at 93.75%, the introduction aspect at 87.5%, the core activity aspect at 95%, the closing aspect at 93.75%, and the TPACK assessment aspect also at 93.75%. The average percentage for these five aspects is categorized as very valid, with a total average percentage of 92.75% reflecting the same classification. The integration of TPACK in education is expected to address challenges by incorporating digital technology into classroom teaching and learning activities, thereby facilitating more meaningful learning experiences for students (Agustina et al., 2023). In this assessment, the validator stated that all learning aspects of the TPACK-based E-Module developed are considered valid, allowing for the trial process to proceed without any revisions.

2. Product Trial

This stage aims to obtain feedback in the form of reactions, responses, and comments from observers regarding the developed TPACK-based e-module. This feedback will determine whether the e-module is practical and useful compared to the learning media previously used by students. The trial was conducted by distributing response questionnaires to both lecturers and students.

Table 4 Results of Lecturers' Responses to the TPACK-based E-Module

No	Assessment Aspects	Percentage	Criteria

1	Content of the E-Module	90,63%	Very Feasible
2	Presentation	91,67%	Very Feasible
3	Media Quality	92,67%	Very Feasible
Overall Rating		**91,72%**	**Very Feasible**

Table 5 Results of Individual Trial

No	Assessment Aspects	Percentage	Criteria
1	Content of the E-Module	91,66%	Very Feasible
2	Presentation	97,22%	Very Feasible
3	Media Quality	91,66%	Very Feasible
Overall Rating		**93,05%**	**Very Feasible**

Table 6 Results of Small-Group Trial

No	Assessment Aspects	Percentage	Criteria
1	Content of the E-Module	89,58%	Very Feasible
2	Presentation	90,83%	Very Feasible
3	Media Quality	88,33%	Very Feasible
Overall Rating		**89.58%**	**Very Feasible**

Table 7 Results of Large-Group Trial

No	Assessment Aspects	Percentage	Criteria
1	Content of the E-Module	91,97%	Very Feasible
2	Presentation	91,04%	Very Feasible
3	Media Quality	92,9%	Very Feasible
Overall Rating		**91,97%**	**Very Feasible**

After the TPACK-based e-module was declared to meet the eligibility criteria by expert lecturers, the next stage was to conduct a product trial by collecting responses from lecturers and students regarding the e-module. Lecturer responses to the assessed aspects in this activity consisted of the e-module content aspect, which received a percentage of 90.63%; the presentation aspect, which received a percentage of 91.67%; and the quality aspect, which received a percentage of 92.86%. All three aspects were included in the very feasible category. According to Budiarti et al. (2021), lecturers gave a very positive response to the e-module, indicating high practicality, including relevant content, attractive presentation, and communicative language quality. Overall, lecturer responses to the developed product were categorized as very feasible, with an average percentage of 91.72.

Student responses to the developed e-module were obtained through three stages of testing: individual, small-group, and large-group trials. The assessment emphasized three main aspects: content, presentation, and overall quality. The individual trial, conducted with three students, produced an average score of 93.05%, placing it in the very feasible category. Similarly, the small-group trial involving 10 students yielded an average of 89.58% and was also categorized as very feasible. The large-group trial, with 27 participants, recorded an average of 91.97%, again indicating a very feasible outcome. Overall, students gave highly positive feedback on the e-module. They considered it innovative, with an appealing cover design that

increased their motivation to engage with the material. The content was presented clearly and supported by case studies drawn from daily life, which encouraged active learning and strengthened students' understanding of the subject (Zahara, 2023).

Disseminate

The dissemination stage, which represents the final phase of the 4D development model, was carried out to evaluate the effectiveness of the developed TPACK-based e-module. At this stage, an effectiveness test was conducted on the e-module covering explant sterilization and somaclonal diversity as learning materials for biology students. The evaluation was implemented through pretests and posttests consisting of 10 identical items. Data obtained from these tests were analyzed using the N-Gain method to measure product effectiveness. The average pretest score of students was 35.64%, categorized as medium, while the posttest average increased to 80%, falling into the high category. Furthermore, the analysis showed that the mean N-Gain score for 27 students in the PSPB 2022 D cohort was 0.69, which is classified as medium. These results indicate a significant improvement in student learning outcomes after the use of the e-module. Details of the N-Gain test analysis are presented in Tables 8 and 9.

Table 8 Results of the N-Gain Test

N-Gain Classification	Average N-Gain	Criteria
High		
Medium	0,69	Medium
Low		

Table 9 Results of the N-Gain Effectiveness Interpretation of the Developed TPACK-Based E-Module

N-Gain Percentage (%)	Category
69	Moderately Effective

The effectiveness of the TPACK-based E-Module on explant sterilization and somaclonal diversity was evaluated using the N-Gain percentage obtained. An N-Gain percentage of 69% indicates a moderate level of effectiveness. From these findings, it can be concluded that the TPACK-based E-Module has shown to be quite effective as a learning resource for biology students. Thus, incorporating the TPACK-based E-Module into the learning process for explant sterilization and somaclonal diversity is crucial, as it offers an interactive educational experience while enhancing students' understanding. By integrating elements of technology, pedagogy, and relevant content, this learning medium presents material in a more structured and comprehensive manner, aligning with current learning needs (Amalia, 2023). Additionally, this E-Module effectively combines theory and practice, which is especially helpful for students when laboratory facilities are limited, ensuring that the learning process continues to run optimally and comprehensively (Musdalifa & Dimpudus, 2024).

After the learning media product is in the form of an E-Module based on TPACK regarding the material of Explant Sterilization and Perfect Somaclonal Diversity, it will be distributed online through social

media with a Flipbook link. Consequently, this product can be widely accessed by students and lecturers at UNIMED and other institutions, thereby expanding access and opening up opportunities for discussion and feedback from users. The developed TPACK-based e-Module can be accessed through this link: https://heyzine.com/flip-book/d9e03fbe39.html.

CONCLUSION

The findings from the research and development of the TPACK-based E-Modules indicate that their feasibility regarding the topics of Explant Sterilization and Somaclonal Diversity as learning resources for biology students is quite high. The responses from material experts received an average percentage of 85.83%, indicating a very valid category. Media experts provided an average percentage of 82.79%, also falling into the very valid category, while learning experts scored an average of 92.75%, categorizing it as very valid as well. The feedback from Tissue Culture course lecturers regarding the use of TPACK-based E-Modules on the material of Explant Sterilization and Somaclonal Diversity resulted in an average percentage of 91.72%, which is considered very feasible. Furthermore, student responses to the TPACK-based E-Modules on the same topics showed positive results, with an average percentage of 93.05% in individual trials, 89.58% in small group trials, and 91.97% in large group trials, all of which are categorized as very decent. The N-Gain test results obtained a score of 0.69, with an N-Gain percentage of 69%, which falls into the moderate and quite effective category. Therefore, the developed TPACK-based E-Module is considered quite effective in improving biology students' learning outcomes on the material of Explant Sterilization and Somaclonal Diversity.

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