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E-module practicum of plant tissue culture with augmented reality to enhance lateral thinking and digital literacy

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ABSTRACT

Plant tissue culture is a course requiring both theoretical understanding and practical skills in observation and analysis. Observations at the plant tissue culture laboratory of PGRI Pontianak University indicated that many students struggled to analyze culture stages, calculate appropriate media composition, and faced equipment limitations. This study aimed to determine the validity, practicality, and effectiveness of an augmented reality-assisted e-practicum module. The research employed an R&D approach with the ADDIE model. Data were collected through validation sheets, practical questionnaires, and lateral thinking skill tests for prospective teacher students. Data analysis involved calculating validation scores, questionnaire results, and N-Gain scores. The findings showed that the AR-assisted e-practicum module was valid in material aspects with an average score of 80 and very valid in media aspects with a score of 82. Student responses indicated the module was very practical, with an average score of 82%. The effectiveness test yielded an N-Gain score of 0.71, categorized as high. These results demonstrate that the AR-assisted e-practicum module can enhance students' lateral thinking skills and digital literacy, suggesting its potential as a valuable teaching tool for future use.

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INTRODUCTION

Plant tissue culture practicums in universities are an important aspect of biotechnology development, aiming to improve students' understanding and skills. Plant tissue culture, as an application of biotechnology, plays a significant role in increasing agricultural productivity and biodiversity conservation, and can be acquired through direct practical experience. Plant tissue culture practicums in the field face several challenges, such as many high school students in Yogyakarta often encounter difficulties in learning plant tissue culture due to inadequate laboratory facilities and the lack of an adequate curriculum. These practicum activities need to be designed to

strengthen the understanding of the theories taught in class(Restiani et al., 2024). Furthermore, training for teachers in the field of plant tissue culture is also needed so that they can more effectively convey this material to students(Ali et al., 2024).

The role of hands-on practicums in higher education contexts is also understood as key to strengthening theoretical mastery(Ode et al., 2022). One crucial aspect of tissue culture practicums is contamination control, which poses a significant challenge in the development of in vitro cultures. Research conducted by (Sucahyo et al., 2023) revealed the importance of identifying contaminating microbes and implementing appropriate sterilization measures. By applying these principles, students can learn to obtain better cultural results. Furthermore, the use of natural extracts in culture media, as demonstrated by Martiwi and Wahyuni(Martiwi & Wahyuni, 2016), illustrates an innovative approach to improving tissue culture efficiency.

Problems encountered during the plant tissue culture practicum at the Tissue Culture Laboratory of Universitas PGRI Pontianak revealed that many students were still confused when analyzing the culture stages being carried out, calculating the appropriate media composition for plant growth. In addition, several types of explants experienced contamination before they could grow, so the practicum could not be continued. This could occur due to several factors, such as limited practicum equipment used and an inappropriate sterilization process. The limitations of this practicum equipment can be overcome by the use of augmented reality media during the practicum. Based on the results of a preliminary questionnaire given to 50 prospective teacher students of the Biology Education study program at Universitas PGRI Pontianak, it was found that the lateral thinking skills and digital literacy of the prospective teacher students were still relatively low. This was evident from the questionnaire distributed, if students still had difficulty finding solutions to problems encountered during the practicum. In addition, it was also known that students were still stiff in using technology as a learning resource. Students had difficulty filtering factual information or opinions related to the information obtained. This is the focus of this study, where researchers want to see the relationship between the use of augmented reality media during Plant Tissue Culture practicums with lateral thinking skills and digital literacy of prospective Biology teacher students. Lateral thinking skills and digital literacy are essential for prospective teacher students because they prepare them to face complex educational challenges in the 21st century. Lateral thinking encourages students to approach problems creatively, explore multiple perspectives, and generate innovative solutions rather than relying solely on conventional methods. For future teachers, this ability is crucial for designing engaging learning experiences, adapting teaching strategies to diverse student needs, and fostering critical and creative thinking in their own classrooms. Meanwhile, digital literacy equips teacher candidates with the competence to effectively use digital tools, evaluate online resources, and integrate technology into the learning process. In modern education, teachers are expected not only to use technology but also to guide students in navigating digital information responsibly and productively. Together, these skills support the development of adaptive, innovative, and reflective educators who can thrive in a rapidly changing educational environment and help their students do the same.

The application of Augmented Reality (AR) in educational contexts has gained significant momentum, particularly in the formulation of e-modules that enhance the learning experience. This integration leverages the interactivity and immersive characteristics of AR technology to facilitate a more engaging educational environment. The literature presents strong evidence that AR-based e-modules can significantly improve student achievement, motivation, and cognitive skills in various disciplines, particularly science. Studies have shown that AR enhances learning by providing an interactive environment where students can visually grasp complex concepts. AR can improve student achievement and foster positive attitudes toward learning in subjects such as science through interactive practice(Riyanti et al., 2022). Furthermore, AR also plays a crucial role in

simplifying abstract concepts and facilitating better visualization and interaction with complex scientific ideas such as electromagnetism(Faridi et al., 2021). This aligns with the findings of Alam et al. (2020), who demonstrated that AR applications lead to improved academic performance and motivation in biology learning. These indications highlight that AR not only aids knowledge retention but also enhances the overall learning experience, as students interact with both real and virtual components of the learning materials, in line with insights from (Verkhova et al., 2019). Furthermore, various studies have shown that AR not only enhances individual learning but also fosters collective learning experiences. AR transforms classrooms into engaging environments that not only engage students but also encourage peer collaboration, ultimately leading to better outcomes. The interactive nature of AR applications requires teamwork, thus contributing to students' social skills in addition to their academic abilities(Alam et al., 2020).

Lateral thinking skills and their enhancement through the integration of augmented reality (AR) technology represent a significant area of educational innovation. Lateral thinking, as defined by Edward de Bono, emphasizes a non-linear approach to problem-solving that requires creativity and innovative thinking beyond traditional deductive reasoning(Azrai et al., 2023). The use of augmented reality can significantly enhance these skills by providing an interactive and immersive learning environment where students can explore scenarios that stimulate creative problem-solving (Anggraini et al., 2024; Sari Dewi & Kuswanto, 2023).

The effectiveness of augmented reality in promoting critical thinking—a skill closely related to lateral thinking—has been documented. For example, research shows that AR learning media can improve critical thinking skills across a range of subjects, including physics and biology (Bakri et al., 2020; Hidayat et al., 2024). The real-time interaction provided by AR allows students to manipulate visual elements, fostering an environment conducive to exploring multiple solutions to a problem while encouraging creative outcomes (Ramadhani et al., 2022). By enhancing constructive dialogue within the learning experience, AR not only helps students engage with content at a deeper cognitive level but also fosters the innovative thinking required for effective lateral thinking (Nusroh et al., 2022; Usmaedi et al., 2020).

Furthermore, through augmented reality worksheets and digital textbooks, students are encouraged to apply their creative thinking skills in a structured format. This method has been shown to facilitate a better understanding of complex concepts, encouraging learners to analyze and synthesize information in new ways(Lismaya et al., 2022). Research shows that integrating AR elements into educational materials allows students to visualize abstract concepts, leading to improved lateral thinking skills as they make new connections between ideas(Muhammad, 2022). Furthermore, augmented reality's ability to create engaging and interactive learning experiences can increase student motivation, which is crucial for creating an environment conducive to the development of lateral thinking skills(Wedyan et al., 2022). The immersive nature of AR encourages students to experiment with different approaches and solutions, often resulting in unexpected and creative outcomes that align with the principles of lateral thinking(Bakri et al., 2020).

In summary, the integration of augmented reality (AR) technology offers significant potential for enhancing students' lateral thinking skills. By providing interactive, engaging, and real-time learning opportunities, AR fosters a deeper understanding of educational content while encouraging the exploration of creative solutions to problems. Further research in this area could yield further insights into effective pedagogical strategies that utilize augmented reality to support students' cognitive skill development (Alkhattabi, 2017).

Digital literacy is a crucial competency for students in today's technology-driven educational environment. Digital literacy encompasses multiple dimensions, including informational, technological, multimedia, and communicative competencies, underscoring the multifaceted nature

of digital competencies crucial for successful engagement in higher education contexts (Zhao et al., 2021). These competencies contribute not only to academic success but also to preparing students to engage in the rapidly evolving digital world. Furthermore, as the demand for comprehensive digital literacy skills among students increases, universities are being encouraged to integrate these competencies into their curricula (Srivastava & Dangwal, 2021). This need is particularly pressing among faculty members, as evidenced by research showing significant differences in digital literacy skills across age groups. Younger lecturers tend to demonstrate higher proficiency and use of ICT tools compared to older lecturers, highlighting potential disparities in teaching efficacy and student engagement (Soomro et al., 2020). Therefore, there is a clear need for targeted professional development for educators in higher education to enhance their digital pedagogical skills (Mardiana, 2024).

Furthermore, initiatives such as the establishment of digital literacy training programs and the implementation of new technologies, such as e-modules and online platforms, are crucial to equip students with the necessary skills to navigate the digital landscape effectively (Okoye et al., 2023) . The convergence of educational technology with curriculum development is crucial to enable students to access, evaluate, and utilize information proficiently (Mufidah et al., 2023). This alignment not only improves learning outcomes but also prepares students for the demands of the labor market, where digital competency is increasingly considered a fundamental asset.

Therefore, it is important to develop an augmented reality-assisted Plant Tissue Culture practicum e-module so that important concepts related to tissue culture techniques can be achieved to support the learning outcomes of the Plant Tissue Culture course. By deepening students' practicum experiences in the augmented reality-assisted practicum e-module, it is hoped that students will be more connected with the relationship between tissue culture techniques and biotechnology concepts, and that their lateral thinking skills and digital literacy will improve. In addition, it is hoped that students will be better prepared to face complex scientific and social challenges in the future. Therefore, this study aims to develop an augmented reality-assisted practicum e-module specifically designed to improve students' lateral thinking skills and digital literacy. This study was conducted to determine the validity, practicality, and effectiveness of the augmented reality-assisted practicum e-module that has been developed.

RESEARCH METHODS

Research Design

This research is a development research. The development model used in this study is the ADDIE model developed by Dick and Carey (1996). The ADDIE model is a development model that includes Analysis, Design, Development, Implementation, and Evaluation. The ADDIE research model was chosen because of its flexibility, which allows adjustments at each stage based on needs. The ADDIE research model also focuses on achieving development goals, ensuring that learning modules are relevant and effective. The evaluation stage also helps ensure product quality. In addition, the ADDIE research model has evaluations that are carried out not only at the end (summative) but also during the development process (formative), ensuring that each step has been carried out in accordance with the objectives.

Population and Samples

The population in this study consisted of 130 students from the Biology Education Study Program, Universitas PGRI Pontianak. The research sample used a purposive sampling technique with several criteria, namely students who have taken the Plant Tissue Culture course, so that students who meet the criteria are semester VII students of the 2022/2023 intake as many as one

class, with a total of 33 students. There are three media expert validators and three material expert validators who will validate the products created.

Instruments

The instruments in this study used a validation sheet modified from (Departemen Pendidikan Nasional, 2008), student response questionnaires, and pretest & posttest questions in essay format consisting of 10 questions using lateral thinking skill indicators. The pretest and posttest questions used have been declared valid and reliable for use in this study. This research instrument was first validated by three material experts, namely lecturers from the Biology Education study program. The validation sheet indicators observed were: compliance with CPMK, material accuracy, material up-to-date, suitability to student development, compliance with language rules, ability to support students' lateral thinking skills, and ability to support students' digital literacy. In addition, the e-module will also be validated by three media experts, namely lecturers from the information technology and information systems education study program. The validation sheet indicators observed were: visible, interesting, simple, useful, accurate, legitimate, and structured. The student response questionnaire was filled out by students who had taken the Plant Tissue Culture course, namely, semester VII students. There are several indicators, namely: presentation of material, language, design, benefits, empowerment of lateral thinking skills, and empowerment of digital literacy. Pretest and posttest were also used in this study to see the effectiveness of using augmented reality-based practical e-modules.

Procedures

The first stage begins with collecting information, analyzing materials, and studying literature related to students' teaching material needs. In the second stage, the researcher designed a practical e-module work assisted by augmented reality. The third stage is to validate with validation with three material experts and three media experts, which is continued with revisions if there are suggestions and input. The fifth stage is to conduct trials and implementations on semester VII students. After large and small-scale trials have been conducted, the next stage is to analyze the questionnaire data on the practicality and effectiveness of the product created.

Data Analysis

Data analysis techniques in this study consist of 3 types, namely expert validation analysis, practicality of the practical e-module, and effectiveness of the practical e-module. Validity calculations were carried out by 3 material experts and 3 media experts. The practicality analysis of the practical e-module using augmented reality is obtained from the response questionnaire given to students. The calculation of validity and student response questionnaires is calculated using the Excel application using the formula from Riduwan (2020).

$$P = ((\sum X))/((\sum Xi)\ ) \text{ x } 100\%$$

P = Percentage of scores obtained
$\sum X$ = total score for each item
$\sum Xi$ = ideal score (highest score)

After calculating, the next step is to determine the criteria. The criteria of validity are in Table 1, and the criteria of the response questionnaire are in Table 2.

Table 1. Criteria of validity

No	Value (%)	Criteria
1	81-100	Very Valid
2	61-80	Valid
3	41-60	Quite Valid
4	21-40	Less Valid
5	0-20	Not Valid

Source:(Astuti et al., 2023).

Table 2. Criteria of response questionnaire

Value (%)	Criteria
80 < Response Value ≤ 100	Very Practical
60 < Response Value ≤ 80	Practical
40 < Response Value ≤ 60	Quite Practical
20 < Response Value ≤ 40	Weak
0 < Response Value ≤2	Impractical

Source: (Manisa & Sari, 2025).

The effectiveness analysis of the augmented reality-based practical e-module was obtained from the results of the analysis of tests given to students before and after using the practical e-module. These scores were then calculated using the N-Gain formula.

$$\text{N Gain} = \frac{\text{Skor Posttest} - \text{Skor Pretest}}{\text{Skor Ideal} - \text{Skor Pretest}}$$

The effectiveness criteria for the augmented reality-based practical e-module are shown in Table 3.

Table 3. N-Gain score and its Interpretation

Normalized N-Gain	Interpretation
g > 0,7	High
0,3 ≤ g ≤ 0,7	Moderate
g < 0,3	Low

RESULTS

The research results can be seen in Tables 4, 5, 6, and 7. Table 4 shows the results of the validation by material experts, with the final conclusion that each indicator obtained an average score of 80 with valid criteria.

Table 4. Results of expert validation of material from the practical e-module

Indicators	Percentage Score (%)	Criteria
Compliance with CPMK	78	Valid
Material accuracy	82	Very Valid
Material up-to-dateness	76	Valid
Suitability for student development	87	Very Valid
Compliance with language rules	73	Valid
Ability to support lateral thinking skills	80	Valid
Ability to support student digital literacy	86	Very Valid
Average	80	Valid

Table 5 shows the results of media expert validation, with the final conclusion that each indicator obtained an average score of 82, with very valid criteria.

Table 5. Media expert validation results from the practical e-module

Aspects	Indicators	Percentage Score (%)	Criteria
Visible	Visual Display	87	Valid
	3D object display	73	Valid
Interesting	Learning Presentation	80	Valid
	Clear Instructions	80	Valid
	Interesting 3D Models	93	Very Valid
Simple	In accordance with student development	73	Valid
	Ease of operation	87	Very Valid
Useful	Ease of use and navigation	93	Very Valid
Accurate	Material accuracy	80	Valid
Legimate	Complies with Indonesian language rules	73	Valid
Structured	Material coverage	80	Valid
Average		82	Very Valid

Table 6 shows the results of the practicality test, with the conclusion being that each indicator in the small-scale trial achieved an average score of 79, categorized as practical. The large-scale trial achieved an average score of 82, categorized as very practical.

Table 6. Results of the student response questionnaire analysis

Aspects	Indicators	% Score of Small-Scale Trials	Score Category	% Score of Large-Scale Trials	Score Category
Presentation of material	Clarity of material delivery	84	Very Practical	86	Very Practical
	Ease of understanding the material	80	Practical	83	Very Practical Practical
	Effectiveness in remembering material	78	Practical	80	Practical
	Data accuracy	85	Very Practical	81	Very Practical
	Average	82	Very Practical	83	Very Practical
Language	Compliance with EYD	84	Very Practical	85	Very Practical
	Ease of understanding the information conveyed	79	Practical	83	Very Practical

Aspects	Indicators	% Score of Small-Scale Trials	Score Category	% Score of Large-Scale Trials	Score Category
	Clarity of the sentences presented	79	Practical	82	Very Practical
	Average	81	Very Practical	83	Very Practical
Design	Use of font type, size, and color	75	Practical	81	Very Practical
	Clarity of layout placement	79	Practical	81	Very Practical
	Use of color	76	Practical	83	Very Practical
	Clarity of presented images	81	Very Practical	81	Very Practical
	Clarity of captions on each AR media	77	Practical	82	Very Practical
	Accuracy of 3D AR media	87		81	Very Practical
	Ease of use of presented navigation	80	Practical	84	Very Practical
	Average	79	Practical	82	Very Practical
Benefits	Easy to use as a learning resource	77	Practical	80	Practical
	Easy-to-understand user instructions	76	Practical	81	Very Practical
	Easy to access anytime, anywhere	76	Practical	79	Practical
	Increases learning motivation	82		82	Very Practical
	Beneficial in broadening knowledge, especially in lateral thinking skills and digital literacy	84		83	Very Practical
	Average	79	Practical	81	Very Practical
Empowering Lateral Thinking Skills	Recognize the dominant idea of the problem	82		82	Very Practical
	Look for different ways of looking at things	77	Practical	81	Very Practical
	Loosen rigid thinking	74	Practical	81	Very Practical
	Use random ideas to bring up new ideas	75	Practical	78	Practical

Aspects	Indicators	% Score of Small-Scale Trials	Score Category	% Score of Large-Scale Trials	Score Category
	Average	**77**	Practical	**80**	Practical
Empowering Digital Literacy	Media literacy	84		82	Very Practical
	Communication & collaboration	79	Practical	81	Very Practical
	Career & identity management	78	Practical	81	Very Practical
	ICT literacy	76	Practical	82	Very Practical
	Learning skills	84		81	Very Practical
	Digital scholarship	81		80	Practical
	Information literacy	84		80	Practical
	Average	79	Practical	82	Very Practical
Total Average		80	Practical	82	Very Practical

Table 7 shows the results of the effectiveness test using pretest and posttest questions with the final conclusion of obtaining an average N-gain score of 0.71 with high criteria.

Table 7. N-Gain Score Result

Average of Pretest	**51**
Average of Posttest	86
Average of N-Gain Score	0,71
Criteria	High

DISCUSSION

Validation of the practical e-module was conducted by three subject matter expert validators and three media expert validators. This activity was carried out to assess the product's validity and provide input for improvement. The validation conducted by the subject matter expert validators assessed seven aspects: compliance with CPMK, material accuracy, material up-to-date, suitability to student development, compliance with language rules, ability to support students' lateral thinking skills, and ability to support students' digital literacy (Table 4). The validation results with material experts were declared valid overall with an average score of 80. The validation results with media experts, with an assessment of seven aspects, stated that the developed practical e-module was declared very valid with an average score of 82. The aspects assessed were: visible, interesting, simple, useful, accurate, legitimate, and structured (Table 5).

Table 4 shows the effectiveness of the augmented reality-assisted lab e-module in terms of the content experts, which includes material accuracy, suitability to student development, and the ability to empower students' digital literacy, was declared very valid with an average score of above 80% for each aspect. The aspects of suitability with CPMK, material sophistication, compliance

with language rules, and the ability to empower students' lateral thinking skills were declared valid with an average score between 71-80%.

The application scope of AR in educational contexts is extensive; it not only aids in visualizing abstract concepts but also promotes engagement through gameplay and interactivity. Mustaqim discusses the transformative potential of AR to enrich educational experiences by creating a blended learning atmosphere that enhances both cognitive skills, such as critical thinking, and soft skills, such as collaboration and communication (Mustaqim, 2016). Furthermore, research indicates that AR technologies can motivate students and improve their academic performance, offering a more stimulating environment for subject matter that is traditionally challenging, such as natural sciences (Petrov & Atanasova, 2020).

Table 5 shows that the augmented reality-assisted e-practicum module, from the perspective of media experts, was rated highly valid by the attractiveness of the 3D models displayed and ease of operation and navigation, with an average score above 87%. Meanwhile, aspects of visual appearance, clarity of instructions, relevance to student development, accuracy of material, comprehensiveness of material, and adherence to language rules were rated valid by the media experts, with scores ranging from 73-80%.

Augmented Reality (AR) has become a significant tool in education, particularly in higher education. With proper implementation, AR-based learning media not only enhances student interaction but also enriches their learning experience. Various studies have shown that the use of AR in learning has a positive impact on understanding complex concepts, learning interest, and student engagement. For example, research by Suttrisno et al. found that the use of interactive AR media in science learning resulted in a 92% expert assessment, indicating excellent quality (Suttrisno et al., 2024). In a similar context, Pawitan et al. developed valid AR learning media for animal metamorphosis, demonstrating its relevance and effectiveness in an educational context (Gumilang Pawitan et al., 2023). The research and development (R&D) methods used in creating AR applications present a systematic approach. For example, Atikah et al. used the ADDIE model to develop AR-based learning media, resulting in high validation from media and material experts, with a 91.25% assessment for the very feasible criteria (Atikah et al., 2023). Furthermore, the development of AR media provides an alternative for teachers to address the lack of physical teaching aids. Yuniar et al. highlight the use of AR as a means to help students understand sensory devices, where the application allows students to learn interactively (Yuniar et al., 2024). This is crucial in higher education institutions, which often face limited resources for physical teaching aids that use conventional learning methods.

The practicality of the e-practical module can be seen in Table 6. The results obtained are the result of small-scale trials and large-scale trials. The aspects assessed were material presentation, language, design, usability, digital literacy empowerment, and lateral thinking skill empowerment. Overall, the developed product received a response in the very practical category with an average score of 82 in the large-scale trial, and students gave a practical response with an average score of 80 in the small-scale trial.

One study showed that learning modules integrating AR were not only valid but also practical. Almubarak et al. reported that their module achieved a validity score of 3.45 and a practicality score with an average teacher learning management score of 92.89, classified as "very high" (Almubarak et al., 2021). Furthermore, Prasetio et al. emphasized that classical methods are often less engaging for students, whereas the use of AR can enhance the visual appeal of learning materials, such as in the introduction to the solar system, which has the potential to improve student understanding of the material being taught (PRASETIO et al., 2019). The use of AR helps students see objects in real life and interact with learning elements, improving material retention.

The effectiveness test results of the e-practicum module using pretest and posttest questions were declared high with an n-gain score of 0.71 (Table 7). Research shows that e-practicum modules assisted by augmented reality can significantly improve lateral thinking skills of students. (Sani et al., 2023) explained that the development of AR learning integrated with ethnoscience can strengthen scientific literacy and student learning interest. The results of this study showed that the use of AR learning media can increase the average N-gain to 0.73, which is included in the high category. This indicates that AR not only facilitates better understanding but also encourages students to participate more actively in the teaching and learning process. The development of AR-based learning modules proved practical and effective, with an average N-gain value reaching 0.76, which reflects a substantial increase in cognitive learning outcomes. The effectiveness of AR in education is also supported by the results of a meta-analysis conducted by Yu-Peng and Yu, who noted the real positive impact of AR in interactive learning environments, including reduced cognitive load and increased academic achievement (Lin & Yu, 2023). AR can strengthen students' mastery of geometric concepts, increasing conceptual and procedural knowledge that is closely related to their n-gain scores (Nadzri et al., 2024).

CONCLUSION

Overall, the validation results with the material experts of the augmented reality-assisted practicum e-module were declared valid with an average score of 80. The validation by media experts obtained a score of 82 with a very valid category. The practicum e-module was declared very practical with a score of 82 in large-scale trials and practical with an average score of 80 in small-scale trials. The effectiveness of the practicum e-module was declared high with an N-Gain score of 0.71. The e-module practicum of plant tissue culture with augmented reality was proven to be valid, practical, and effective in enhancing students' lateral thinking skills and digital literacy. The integration of AR technology provided an engaging and interactive learning experience that helped overcome practicum limitations and improved students' conceptual understanding. This innovation can serve as an alternative learning resource in plant tissue culture courses and a model for developing other technology-based practicum modules to support future teacher education in the digital era.

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REFERENCES

Alam, F., Iqbal, K., Sattar, M. Z., & Nazir, S. (2020). Using Augmented Reality for Teaching Chemistry. *International Journal of Experiential Learning & Case Studies*, *5*(2). https://doi.org/10.22555/ijelcs.v5i2.49

Ali, A., Lodang, H., Rante, H., & Yusuf, Y. (2024). Peningkatan Kompetensi Guru SMA dan MA di Sulawesi Melalui Pelatihan Kultur Jaringan Tumbuhan. *Paramacitra Jurnal Pengabdian Masyarakat*, *1*(02), 69–76. https://doi.org/10.62330/pjpm.v1i02.77

Alkhattabi, M. (2017). Augmented Reality as E-learning Tool in Primary Schools' Education: Barriers to Teachers' Adoption. *International Journal of Emerging Technologies in Learning (IJET)*, *12*(02), 91. https://doi.org/10.3991/ijet.v12i02.6158

Almubarak, A., Nawidi, M. F., Nurrusshobah, N., & Sadiah, S. D. (2021). Validitas & Praktikalitas: Modul Kibas Asah (Kimia Berbasis Lahan Basah) Terintegrasi AR-Sparkol Pada Materi Larutan Penyangga sebagai Media Pembelajaran Inovatif. *Journal of*

Mathematics Science and Computer Education, *1*(1), 1. https://doi.org/10.20527/jmscedu.v1i1.3398

Anggraini, A., Siahaan, S. M., & Fathurohman, A. (2024). The Student Worksheets Assisted by Augmented Reality on Critical Thinking Skills in High School Physics: Study of Teacher Perceptions in Indonesia. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, *10*(1), 139–146. https://doi.org/10.21009/1.10112

Astuti, D. N., Wigati, I., & Asnilawati. (2023). Pengembangan e-modul sistem peredaran darah berbasis gender untuk kelas VIII MTs. *Jurnal Penelitian, Pendidikan Dan Pengajaran: JPPP*, *4*(2), 144–152.

Atikah, C., Rusdiyani, I., & Ridela, R. (2023). Pengembangan Media Pembelajaran Berbasis Augmented Reality pada Tema Binatang Purba Untuk Meningkatkan Kemampuan Kognitif Anak Usia Dini Kelompok B (5-6) Tahun di TK Tunas Insan Kamil Kota Serang. *JEA (Jurnal Edukasi AUD)*, *9*(2), 89–101. https://doi.org/10.18592/jea.v9i2.9326

Azrai, E. P., Rini, D. S., Kurnianto, M. B., & Ampang, J. (2023). Ar sinaps: augmented reality learning media to enhance critical thinking ability. *International Journal of Education*, *16*(2), 109–122. https://doi.org/10.17509/ije.v16i2.50329

Bakri, F., Wulandari, S., & Muliyati, D. (2020). Students worksheet with augmented reality media: scaffolding higher order thinking skills of high school students on uniform accelerated motion topic. *Journal of Physics: Conference Series*, *1521*(2), 022040. https://doi.org/10.1088/1742-6596/1521/2/022040

Departemen Pendidikan Nasional. (2008). *Panduan Pengembangan Bahan Ajar*.

Faridi, H., Tuli, N., Mantri, A., Singh, G., & Gargrish, S. (2021). A framework utilizing augmented reality to improve critical thinking ability and learning gain of the students in Physics. *Computer Applications in Engineering Education*, *29*(1), 258–273. https://doi.org/10.1002/cae.22342

Gumilang Pawitan, Yunus Abidin, & Rendi Restiana Sukardi. (2023). Rancang bangun media pembelajaran digital berbasis augmented reality card pada materi metamorfosis hewan di kelas IV SD. *INVENTA*, *7*(2), 121–139. https://doi.org/10.36456/inventa.7.2.a7201

Hidayat, A. L. N., Ahmad, N., Ridlo, Z. R., Putra, P. D. A., & Yusmar, F. (2024). Developing an Augmented Reality-Based Textbook on Heat and Transfer Materials to Improve Students Critical Thinking Skills. *Jurnal Penelitian Pendidikan IPA*, *10*(4), 2102–2109. https://doi.org/10.29303/jppipa.v10i4.6714

Lin, Y., & Yu, Z. (2023). A meta-analysis of the effects of augmented reality technologies in interactive learning environments (2012–2022). *Computer Applications in Engineering Education*, *31*(4), 1111–1131. https://doi.org/10.1002/cae.22628

Lismaya, L., Priyanto, A., & Ayu, P. (2022). APPLICATION OF AUGMENTED REALITY THROUGH A SCIENTIFIC APPROACH TO STUDENTS' CRITICAL THINKING ABILITY. *Indonesian Journal of Learning and Instruction*, *5*(1). https://doi.org/10.25134/ijli.v5i1.5874

Manisa, T., & Sari, M. (2025). Development of SETS-based modules for understanding zoological concepts on Lemukutan Island. *BIO-INOVED : Jurnal Biologi-Inovasi Pendidikan*, *7*(2), 154. https://doi.org/10.20527/bino.v7i2.20977

Mardiana, H. (2024). Perceived Impact of Lecturers' Digital Literacy Skills in Higher Education Institutions. *Sage Open*, *14*(3). https://doi.org/10.1177/21582440241256937

Martiwi, I. N. A., & Wahyuni, E. S. (2016). Penambahan Ekstrak Pegagan (Centella asiatica) Sebagai Anti kontaminan pada Medium In Vitro Alternatif Perkecambahan Anggrek Dendrobium macrophyllum A. Rich. *Jurnal MIPA*, *5*(2), 85. https://doi.org/10.35799/jm.5.2.2016.13103

Mufidah, A., Indana, S., & Arifin, I. S. Z. (2023). E-Module Based on Blended Learning Type Flipped Classroom on Climate Change Materials to Train Students' Digital Literacy Ability. *International Journal of Current Educational Research*, *2*(1), 1–16. https://doi.org/10.53621/ijocer.v2i1.204

Muhammad, M. (2022). Review of Trends in Learning Media of Augmented Reality Integrated with STEM Approach to Improve Students' Creative Thinking Skill. *Journal of Physics: Conference Series*, *2377*(1), 012084. https://doi.org/10.1088/1742-6596/2377/1/012084

Mustaqim, I. (2016). Pemanfaatan augmented reality sebagai media pembelajaran. *Jurnal Pendidikan Teknologi Dan Kejuruan*, *13*(2). https://doi.org/10.23887/jptk.v13i2.8525

Nadzri, , A. Y. N. M., Ayub, , A. F. M., Zulkifli, , N. N., & Salim, , N. R. (2024). Implications of AR Modules on Geometry Conceptual and Procedural Knowledge among Primary School Students. *Malaysian Journal of Mathematical Sciences*, *18*(1), 51–72. https://doi.org/10.47836/mjms.18.1.04

Nusroh, H., Khalif, M. A., & Saputri, A. A. (2022). Developing Physics Learning Media Based on Augmented Reality to Improve Students' Critical Thinking Skills. *Physics Education Research Journal*, *4*(1), 23–28. https://doi.org/10.21580/perj.2022.4.1.10912

Ode, A., Sampulawa, S., & Hulopi, F. (2022). Pemanfaatan Ekstrak Kunyit (Curcuma domestica Val.) sebagai Pewarna Alami Pembuatan Preparat Awetan Jaringan Tumbuhan dalam Praktikum Biologi Sel. *Bioscientist : Jurnal Ilmiah Biologi*, *10*(2), 756. https://doi.org/10.33394/bioscientist.v10i2.5979

Okoye, K., Hussein, H., Arrona-Palacios, A., Quintero, H. N., Ortega, L. O. P., Sanchez, A. L., Ortiz, E. A., Escamilla, J., & Hosseini, S. (2023). Impact of digital technologies upon teaching and learning in higher education in Latin America: an outlook on the reach, barriers, and bottlenecks. *Education and Information Technologies*, *28*(2), 2291–2360. https://doi.org/10.1007/s10639-022-11214-1

Petrov, P. D., & Atanasova, T. V. (2020). The Effect of Augmented Reality on Students' Learning Performance in Stem Education. *Information*, *11*(4), 209. https://doi.org/10.3390/info11040209

Prasetio, A., Nurhadi, N., & Mulyadi, M. (2019). Perancangan aplikasi augmented reality pengenalan tata surya berbasis android pada SD Negeri 139/IV kota Jambi. *Jurnal Processor*, *14*(2), 94–104. https://doi.org/10.33998/processor.2019.14.2.645

Ramadhani, F., Sjaifuddin, S., & Kurniasih, S. (2022). Efficiency of creative thinking ability in augmented reality-based learning media the acid rain theme. *Jurnal Pena Sains*, *9*(2), 8–16. https://doi.org/10.21107/jps.v9i2.14116

Restiani, R., Kaban, S., Sekar, A., Matheos, J., & Galgani, G. (2024). Kultur jaringan tumbuhan dasar sebagai upaya peningkatan pengetahuan dan keterampilan siswa. *Jurnal Pembelajaran Pemberdayaan Masyarakat (Jp2m)*, *5*(2), 339–348.

Riduwan. (2020). *Dasar-dasar statistika*. Alfabeta.

Riyanti, I., Copriady, J., & Linda, R. (2022). Student Needs Analysis for The Development of Augmented Reality Integrated E-Modules about Particles in Science Learning. *Unnes Science Education Journal*, *11*(2), 115–122. https://doi.org/10.15294/usej.v11i2.58309

Sani, S. A., Wulandari, R. D., Nurroniah, Z., Kusumaningtyas, N. C., Sefanda, S. K., & Nuraini, L. (2023). Pengembangan augmented learning berbasis etnosains tari lahbako untuk literasi sains dan minat pada konsep gerak melingkar. *EDUSAINS*, *15*(2), 164–175. https://doi.org/10.15408/es.v15i2.35194

Sari Dewi, P., & Kuswanto, H. (2023). The effectiveness of the use of augmented reality-assisted physics e-module based on pedicab to improve mathematical communication and critical

thinking abilities. *Journal of Technology and Science Education, 13*(1), 53. https://doi.org/10.3926/jotse.1714

Soomro, K. A., Kale, U., Curtis, R., Akcaoglu, M., & Bernstein, M. (2020). Digital divide among higher education faculty. *International Journal of Educational Technology in Higher Education, 17*(1), 21. https://doi.org/10.1186/s41239-020-00191-5

Srivastava, S., & Dangwal, K. L. (2021). Digital Competence: Where do the Higher Education Teachers Stand? *Universal Journal of Educational Research, 9*(10), 1765–1772. https://doi.org/10.13189/ujer.2021.091005

Sucahyo, A. I., Manalu, K., & Nasution, R. A. (2023). Isolasi dan Identifikasi Mikroba Penyebab Kontaminasi dari Udara di Laboratorium Kultur Jaringan Tumbuhan UIN-SU Medan. *Jurnal Biologi, 1*(1), 1–12. https://doi.org/10.47134/biology.v1i1.1931

Suttrisno, Mahruzah Yulia, N., & Putri, D. D. L. (2024). Pengembangan media interaktif assemblr edu berbasis augmented reality dalam meningkatkan literasi sains siswa kelas 6. *Jurnal Pendidikan Dasar Flobamorata, 5*(3), 410–419. https://doi.org/10.51494/jpdf.v5i3.1267

Usmaedi, U., Fatmawati, P. Y., & Karisman, A. (2020). Pengembangan media pembelajaran berbasis teknologi aplikasi augmented reality dalam meningkatkan proses pengajaran siswa sekolah dasar. *Jurnal Educatio FKIP UNMA, 6*(2), 489–499. https://doi.org/10.31949/educatio.v6i2.595

Verkhova, G., Akimov, S., & Kotelnikov, M. (2019). Markerless augmented reality technology in modern education. *Problems of Information Technology, 10*(2), 29–35. https://doi.org/10.25045/jpit.v10.i2.05

Wedyan, M., Falah, J., Elshaweesh, O., Alfalah, S. F. M., & Alazab, M. (2022). Augmented Reality-Based English Language Learning: Importance and State of the Art. *Electronics, 11*(17), 2692. https://doi.org/10.3390/electronics11172692

Yuniar, W., Hadi, A., Huda, A., & Samala, A. D. (2024). Pengembangan Media Pembelajaran Kerja Alat Sensor Berbasis Augmented Reality Kelas XI Teknik Elektronika. *Voteteknika (Vocational Teknik Elektronika Dan Informatika), 12*(1), 62. https://doi.org/10.24036/voteteknika.v12i1.125660

Zhao, Y., Pinto Llorente, A. M., & Sánchez Gómez, M. C. (2021). Digital competence in higher education research: A systematic literature review. *Computers & Education, 168*, 104212. https://doi.org/10.1016/j.compedu.2021.104212