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Development and Expert Validation of Augmented Reality-Integrated Innovative Learning Materials on Plant Cells and Tissues for Problem-Based Learning: An Approach Using Aiken's V

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ABSTRACT

Augmented Reality (AR) has the potential to improve Problem-Based Learning (PBL) in higher education by easing the visualisation of difficult biological ideas and encouraging active participation. The purpose of this study was to assess the viability and content validity of AR-integrated teaching resources created for PBL. The study concentrated on the validation stage using the ADDIE development paradigm and included three expert validators in instructional design, educational technology, and biology education. Aiken's V was used to evaluate content validity in terms of language appropriateness, presentation viability, and topic feasibility. To enhance the teaching materials, qualitative input from validators was also examined. The findings showed strong validity across all dimensions, with Aiken's V values more than 0.85. The display of AR elements, the clarity of instructions, and the alignment of learning exercises with problem-solving objectives were the main areas of expert recommendation. The quality and usability of the updated materials were improved by incorporating these suggestions. All things considered, the AR-integrated teaching resources showed excellent content validity and viability for postsecondary education. According to the results, the products are appropriate for use in classrooms and can help students grasp difficult biological ideas through interactive, technologically enhanced learning opportunities.

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1. INTRODUCTION

The transformation of educational approaches toward emphasizing the cultivation of critical thinking and reasoning, creativity, and problem-solving skills reflects a response to the dynamic changes in society and technology. Modern society increasingly demands individuals who not only possess academic knowledge but also have adaptation and problem-solving skills to face the complexities of contemporary life. The implementation of innovative learning is essential for optimizing educational outcomes and equipping students with the competencies necessary to succeed in the evolving modern workforce (Husin et al., 2024; Tkachenko, 2024). In this context, biology education must change to become more interactive and applicable. Problem-Based Learning (PBL) and Project-Based Learning (PjBL) are recognized as effective strategies for developing 21st-century skills, including problem-solving, collaboration, and creativity (Hidayat et al., 2021; Bao & Koenig, 2019; Jabarullah & Iqbal Hussain, 2019; Maknun, 2020).

The PBL model challenges students to solve real-life problems without predetermined solutions (Fadhilah et al., 2023), thereby encouraging critical and analytical thinking. Project-Based Learning (PjBL) engages students in projects that apply theoretical knowledge to real-world contexts (Coronado et al., 2021; Fadhilah et al.,, 2023), addressing the shortcomings of traditional methods in preparing students for complex, skill-demanding professional environments. Growing research highlights the effectiveness of PBL and PjBL promotes a learner-centered approach, enhances student participation, and prepares students to confront real-life problems (Dwikoranto et al., 2024; Tkachenko, 2024).

Furthermore, incorporating technology into education, including simulation tools and online learning platforms, enhances the effectiveness of these instructional methods (Bizami et al., 2023; Campos et al., 2020). Advancing 21st-century education can also involve revising curriculum development frameworks to integrate Information and Communication Technology (ICT) and Technological Pedagogical Content Knowledge (TPACK) (Hayani & Sutama, 2022). A teacher must possess TPACK as it is a currently developing issue. TPACK is a combination of a conceptual framework of content knowledge, pedagogy, and technology that are interconnected (Ismail et al., 2022). Rapid technological developments associated with the Fourth Industrial Revolution have significantly changed how work is performed and the skill sets demanded in the modern workforce (Husin et al., 2024).

TPACK integrates content, pedagogy, and technology, focusing on the effective use of technology to teach and achieve learning goals (Turmuzi & Kurniawan, 2022). Although the positive potential of this approach is highly recognized, its implementation still faces several challenges that require serious attention. Inadequate teaching materials can make it difficult for students to understand key concepts and apply them in real-life situations. The lack of understanding of these concepts can also hinder the attainment of the intended educational outcomes. The need for the development of innovative teaching materials with PBL, PJBL, and TPACK approaches in complex units. The teaching materials can be designed by utilizing technology as a supporting tool, so that the learning process is not only informative but also engaging and relevant. Thus, students can become more engaged, dynamic, and adaptive to future needs.

The combination of Augmented Reality (AR) with PjBL, PBL, and TPACK framework in educational mvaterials on plant cells and tissues is what makes this study novel. This integration encourages problem-solving, project development, and significant technology-enhanced learning experiences in addition to making it easier to see microscopic biological structures through interactive augmented reality capabilities. AR-integrated teaching materials on plant cells and tissues that concurrently incorporate PBL, PjBL, and TPACK concepts and undergo rigorous expert validation have not been developed, despite prior studies reporting the advantages of AR in biology education (Bashri et al., 2025; Faria & Miranda, 2024). Thus, this work fills a significant void in the creation of cutting-edge biology teaching resources for postsecondary education. Augmented reality is a useful teaching tool that may be incorporated into the classroom (Bashri et al., 2022; Zulfiqar et al., 2023).

This study focuses on the development and validation of innovative learning materials integrated AR tailored for students, prospective teachers, teachers, and lecturers studying biology education on plant cells and tissues. The development of innovative learning materials integrated AR in the context of the Biology Education study program is a strategic step to support the achievement of the desired graduate competencies. The learning materials developed in this research differ from previously existing PBL materials in their strong, structured problem-solving, and context-based challenges that directly relate to students' real environments. Unlike earlier PBL resources that often present generic problems and limited guidance, the materials in this study offer clearer step-by-step support, authentic cases derived from local contexts, and interactive components that strengthen students' engagement.

This innovation allows the materials to address previous gaps in PBL implementation, making them more practical for teachers and more meaningful for students in navigating complex learning situations. Therefore, this research aims to fill this gap by developing innovative learning materials integrated AR that can address the challenges in problem-based learning processes. In addition, this development is also expected to provide effective support for teachers in guiding and developing students' potential. This research aims to to create and validate AR-integrated teaching resources on plant cells and tissues that incorporate the TPACK framework, Project-Based Learning (PjBL), and Problem-Based Learning (PBL). In order to verify that the instructional resources are feasible for use in higher education, the validation focuses on the content, language, structure, and organization of the materials.

2. METHODS

The study focused on the validation step, employing the ADDIE development model and three expert validators in instructional design, educational technology, and biology education. Content validity was assessed using Aiken's V in terms of topic feasibility, presentation viability, and language appropriateness. Qualitative feedback from validators was also used in order to improve the instructional materials. The research and development process in this study is guided by the ADDIE model. Branch (2009) states that the ADDIE model is a methodical approach to creating educational experiences through a number of intentional stages meant to promote controlled and meaningful learning. Although its implementation can be tailored to individual settings or demands, the model's fundamental components remain consistent (Rahmah et al., 2025). The development of innovative learning materials integrated AR is carried out through 5 stages. The design stage can be seen in Figure 1.

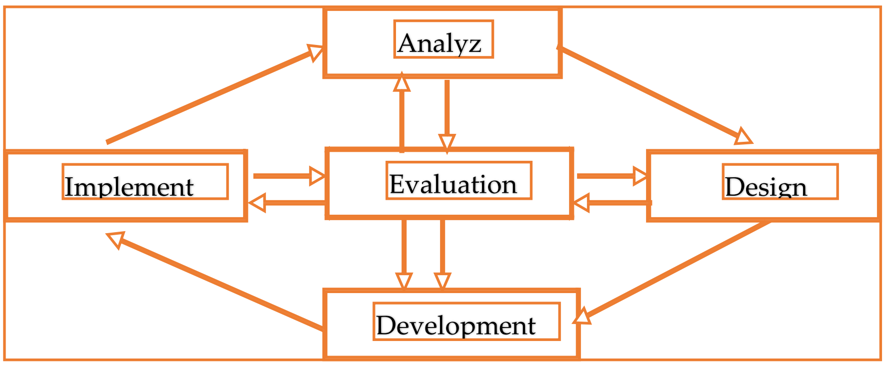

Figure 1. Research design of teaching materials based on the ADDIE model

Analysis Stage

The Analysis Stage is as follows 1) the development team conducts an analysis of the competencies required of students and lecturers; 2) conducting an analysis of the characteristics of Biology students related to the comparison of learning capacity, understanding of the material, skills in using teaching materials, and other related aspects; 3) analyzing the material that aligns with the competencies or achievement demands.

Design Stage

In this stage, the team develops the research framework, such as for whom the teaching materials are intended and the purpose of studying innovative learning materials integrated AR through these teaching materials, how the material is presented, what skills students acquire, and how to assess and evaluate the mastery of the material achieved by each student and lecturer.

Development Stage

The Development Stage is the stage of developing teaching materials, which includes gathering teaching materials, determining courses, selecting innovative learning multimedia, creating images that illustrate the material being presented, composing scripts, and editing teaching materials.

Implementation Stage

The creation of instructional materials from cutting-edge learning content, their implementation as a final manuscript, and a validity test of the materials are the outcomes of the implementation stage. Expert review involving experts in linguistic appropriateness, structural coherence, and content accuracy will validate the content. This validation meets the needs of the students and is in line with the biology education curriculum. The goal of the expert evaluation is to improve the educational value and applicability of learning resources that use augmented reality. This analytical procedure facilitates a rigorous examination of the validity of the AR–based instructional materials developed in this study. The measurement indicators for each construct were evaluated for validity and reliability using criteria such as convergent validity, construct reliability, AVE, discriminant validity, cross-loadings, and unidimensionality. Indicators meeting these standards were considered acceptable, the collected data serve as the basis for evaluating the validity of the AR–integrated innovative learning materials. Next, the researchers evaluate the validity of the innovative learning teaching materials using the Aiken V formula. The assessment of each indicator's v value and the mean V value was conducted by the researchers according to Aiken's validity classification scheme. If both the individual indicator V values and the average V value are ≥ 0.60, they are considered acceptable (Sanusi & Larisang, 2023). the innovative learning teaching materials are considered valid. On the other hand, if these values are below 0.60, the innovative learning teaching materials are considered invalid. Products found to be invalid necessitate revision and reassessment of validity before deployment or additional use in educational activities.

Evaluation Stage

The final stage is Evaluation, where data from each stage of the research is collected and used to draw descriptive conclusions about the implementation of the Teaching Materials. In addition, to ensure the success of innovative learning materials integrated AR, validation in the context of biology education is very important. This validation ensures that the PBPL model materials comply with academic standards and effectively support achieving learning objectives (Kalogiannakis et al., 2021). The primary instrument for data collection is a carefully designed validity questionnaire.

Table 1. Indicators for evaluating innovative learning teaching materials.

Indicator	Aspect
Presentation Feasibility (P)	P1. Appearance aspect P2. Layout aspect P3. Aspect of the image
Content Feasibility (C)	C1. Aspects of content alignment with the curriculum C2. Material aspect C3. Aspect of Teaching Material Content C4. Bibliography
Language Feasibility (L)	L1. Language use L2. The Use of Terms L3. Systematics of teaching materials

3. FINDINGS AND DISCUSSION

Findings

The focus of this research is the validation of AR enhanced innovative instructional materials, a resource that is not only designed but specifically created to facilitate students in conducting problem-based learning. Teaching materials that include the characteristics of cooperative learning models, scientific models, CTL models, Discovery models, Inquiry models, PBL models, PjBL models, and TPACK models presented in an easy and engaging manner for students to learn independently. The concept of the material presented can be followed by students, making it easier to understand the material in a real and complete manner for specific learning outcomes. The teaching materials contain innovative learning content based on problem-solving to address learning challenges as the content taught to biology education students.

Innovative Learning Teaching Materials

The teaching materials have been developed using the ADDIE model steps. The Analysis Stage produced several key findings. First, the development team successfully identified the essential competencies required of both students and lecturers. This included an assessment of learning capacity, levels of material comprehension, students' familiarity with instructional materials, and other relevant characteristics specific to Biology education. In addition, the team concluded that the selected course content was well aligned with competency requirements and targeted learning outcomes.

The Design Stage resulted in a comprehensive and well-structured initial blueprint for the teaching materials. During this stage, the development team identified the primary users Biology students and lecturers, and formulated the main objectives for creating innovative instructional materials. The team also determined the presentation format, including the learning sequence, visual components, and integration of innovative learning models. Moreover, the design stage produced a clear specification of the skills expected to be developed by students such as problem-solving, critical thinking, and independent learning along with the development of assessment instruments to measure mastery of the material. These outcomes served as the foundation for the subsequent development stage.

The Development Stage produced both initial and revised versions of the teaching materials. At this stage, relevant content was compiled, courses were selected, and appropriate innovative learning multimedia were incorporated to support the presentation of the material. Visual illustrations were created to enhance conceptual understanding, scripts were drafted to ensure clarity, and the teaching materials were edited to improve coherence and readability. The outcome of this stage was a complete set of instructional materials ready for expert validation and further evaluation.

The teaching materials developed consist of five chapters, namely: a) chapter 1 innovative learning, b) chapter 2 TPACK learning, c) chapter 3 PBL, d) chapter 4 PjBL, and e) chapter 5 development of learning planning to address the challenges of PBL processes. Title Page: The cover page of the innovative learning teaching materials includes important information such as cover of the innovative learning materials integrated AR that have been developed (See Figure 2). Content of Teaching Materials: This section outlines the activities and materials included in the teaching materials to enhance students' practical understanding based on problem-solving. Learning activities align with a structured framework and encourage active student engagement in problem-solving (See Figure 3).

Figure 2. Cover of the innovative learning materials that have been developed.


Bashri, et al., 2024. Bahan Ajar Pembelajarn Inovatif untuk Menjawab Tantangan Proses Belajar Berbasis Penyelesaian Masalah

BAB 1
PEMBELAJARAN INOVATIF

A. Bahan Ajar Pembelajaran Inovatif

Figure 3. The content section of the innovative learning materials that have been developed.

Eligibility Based on Expert Validation

The Implementation Stage represents the phase in which the developed innovative teaching materials are applied and systematically examined to determine their feasibility for practical use in instructional activities. At this stage, the completed instructional materials transition from conceptual design to practical validation, ensuring that every component aligns with pedagogical standards and supports the intended learning outcomes. Feasibility data through expert validation is used to ensure that the developed teaching materials are suitable to confirm the appropriateness of the developed materials as innovative instructional resources integrated AR. The validation results from three expert validators are shown in the following Table 2.

Table 2. Score of validation results

Indicator	Score
Presentation Feasibility Components (P)	
P1. Appearance Aspect	
The cover design reflects the content	4
Color proportion suitability	4
Displaying innovative learning to address the challenges of problem-based learning as the main topic	4
P2. Layout Aspect	
The proportion of layout suitability (text and image layout)	4
The appropriateness of font type and size selection	4
Consistency in page numbering	3
Attractive presentation (color and design)	4
P3. Aspect of the Image	
Clear image (not blurry)	4
The image corresponds to the main topic	4
The image is accompanied by a source	4
Content Feasibility Component (C)	
C1. Aspect of Content Alignment with the Curriculum	
The competencies targeted in the teaching materials refer to the learning outcomes of the course	4
Using operational verbs that can be measured/observed	4
The concept is presented in an orderly and systematic manner	4
C2. Material Aspect	
The suitability of innovative learning materials to address the challenges of problem-based learning	4
The scope/depth of the material shapes an accurate understanding of the concept	4
Presenting the truth of concepts based on innovative learning to address the challenges of problem-based learning processes	4
C3. Aspect of Teaching Material Content	
The teaching materials include an explanation of innovative learning	4
The teaching materials include an explanation of TPACK learning	4
The teaching materials include an explanation of Problem-Based Learning (PBL).	4
The teaching materials include an explanation of Project Based Learning (PjBL).	4
The teaching materials include an explanation of the development of learning planning to address the challenges of problem-based learning processes	4
C4. Bibliography	
Written consistently	4
The references used support the material in the Teaching Materials	4
Language Feasibility (L)	
L1. Language Use	
Using communicative sentences	4
According to PUEBI	4
Does not create multiple meanings	4
Coherence of sentences between paragraphs	4

L2. The Use of Terms	
Using appropriate and precise biological terms	4
Using terms consistently	4
Scientific names use the correct writing conventions	4
L3. Systematics of Teaching Materials	
The title of the teaching material corresponds to the topic	4
There is the author's name	4
There are cover, preface, table of contents, and discussion points on innovative learning, TAPCK learning, PBL, PJBL, and the development of learning planning to address the challenges of problem-based learning in teaching materials	4
Overall component mode	3,9

According to the validation findings presented in Table 2, which show that the mode score for the 10 validated components is very good (score 3.9). The outcomes indicate that the developed instructional resources are suitable for use as innovative problem-based learning materials for students.

Table 3. Outer loading analysis results for innovative learning materials indicators

Indicators	Presentation	Content	Language	Item Conclusion
P1	0.799			V
P2	0.766			V
P3	0.700			V
C1		0.792		V
C2		0.673		iV (Revisied-Valid)
C3		0.853		V
C4		0.798		V
L1			0.749	V
L2			0.778	V
L3			0.893	V
0.844				V

Description: V=Valid, iV= Invalid

Table 4. Reliability and validity metrics for innovative learning materials integrated AR

Indicators	Cronbach's Alpha	rho_A	Composite Realibility	Average variance Extracted (AVE)
Presentation	0.785	0.795	0.862	0.612
Content	0.738	0.792	0.850	0.654
Language	0.637	0.648	0.800	0.572
Average	0.720	0.745	0.837	0.613

Table 4 illustrates the metrics assessing both the reliability and validity of the Innovative Learning Teaching Materials construct: presentation feasibility, content feasibility, and linguistic feasibility. These measures serve to guarantee that the constructs are reliably and validly assessed. The reported statistics include CA, rho A, CR, and AVE, compared against standard acceptability thresholds. For the average of all indicators regarding presentation feasibility, content, and language, the total average value of CA (0.720), rho A (0.745), CR (0.837), and AVE (0.613). Strong internal consistency, reliability, and convergent validity are demonstrated by the results, which surpass the suggested thresholds of 0.7 for reliability and 0.5 for AVE, indicating that the items successfully represent the construct (Husin et al., 2024). With Cronbach's Alpha, rho A, and Composite Reliability above 0.7 and AVE above 0.5, the presentation, content, and language elements of AR-integrated innovative learning materials satisfy reliability and validity requirements.

Table 5. The discriminant validity of the constructs using the fornell-larcker criterion

Indicators	Presentation	Content	Language
Presentation	0.782		
Content	0.622	0.809	
Language	0.440	0.576	0.756

Table 5 demonstrates the construct discriminant validity within the PBPL model, a fundamental element in research rigor, using the Fornell-Larcker approach. Discriminant validity, assessed using the Fornell-Larcker criterion, ensures that each construct shares more variance with its indicators than with other constructs (Fadhilah et al., 2023; Husin et al., 2024). The square roots of AVE for presentation, content, and language constructs are 0.782, 0.809, and 0.756, respectively, while their correlations with other constructs remain lower, confirming strong discriminant validity and reinforcing the reliability and validity of the measures.

Eligibility Based on Expert Validation

The Evaluation Stage represents the final phase of the development process, in which all data generated from the previous stages are systematically reviewed to determine the overall quality, feasibility, and effectiveness of the innovative teaching materials. At this stage, the focus shifts from development and implementation to a comprehensive assessment that ensures the materials meet academic standards, support learning objectives, and provide meaningful benefits for both students and lecturers.

To assess the validity of Innovative Learning Teaching Materials, Indicators under presentation, content, and language feasibility were assessed using Aiken's V to determine content validity based on expert evaluations. Scores above 0.85 indicate strong validity, confirming the strength of the Innovative Learning Teaching Materials. Table 6 presents the Aiken's V values for each indicator and the category averages, and the conclusion regarding the validity of the Innovative Learning Teaching Materials. Here are the Aiken's V scores from the validation.

Table 6. Overview of aiken's V values and validity conclusions for each indicator

Indicator	Aspect	Aiken's Value	Average	Conclusion
Presentation Feasibility (P)	P1	0.963	0.956	V
	P2	0.917		
	P3	1.000		
Content Feasibility (C)	C1	0.926	0.956	V
	C2	1.000		
	C3	0.956		
	C4	0.944		
Language Feasibility (L)	L1	0.917	0.948	V
	L2	0.926		
	L3	1.000		

Description: V=Valid

The validity of indicators in three categories presentation, content, and linguistic feasibility is confirmed by Aiken's V analysis. Strong validity is demonstrated by the Presentation Feasibility indicators (P1–P3) (0.917–1.000; average 0.956). Additionally, the content feasibility indicators (C1–C4) show strong expert agreement and high validity (0.944–1.000; average 0.956). Despite having the lowest score (0.750), indicator C5 still exceeds the minimal validity threshold, demonstrating the validity and reliability of the Content construct. Strong expert agreement and highly appropriate and relevant language are indicated by the Language construct's average Aiken's V of 0.948 (L1–L5: 0.917–1.000) (Hiden et al., 2024). The results confirm both the reliability and high relevance of the content aspect. All categories of AR-integrated innovative learning materials (presentation, content, and language feasibility) exhibit average Aiken's V values above 0.85, indicating strong expert consensus and validating these components for effective use in higher education.

Limitations and Future Directions

The study is limited by its focus on a specific expert sample, potentially restricting generalizability, and by relying solely on expert evaluations, which may omit end-user perspectives. This study validates AR-integrated innovative learning materials without examining their implementation. Additional research is needed to examine the sustained effects on learning and career readiness, consider contextual factors, enhance resource usability, and assess scalability across disciplines.

Qualitative studies exploring student and instructor experiences can further inform implementation and effectiveness, complementing the validation findings in higher education contexts. The effectiveness of improving problem-solving skills can be based on several factors, one of which is the validity and reliability of the model and instruments that meet valid criteria through empirical tests of validity and reliability, so that the model learning instruments can later be applied in the classroom (Jatmiko et al., 2024).

Discussion

The study evaluated the content validity of AR-integrated innovative learning materials, which were found to meet established criteria for content and construct validity, underscoring the importance of validation in learning model development. Validation is essential for ensuring the reliability and applicability of the developed learning model (Castiglioni et al., 2021; Davis et al., 2020). The results demonstrate that AR-integrated innovative learning materials are valid and reliable for higher education, with mode score analysis further confirming the strong validity.

These results align with prior studies, highlighting the importance of construct validity in ensuring that evaluation instruments accurately measure their intended concepts (Maknun, 2020; Yonanda et al., 2024). The developed teaching materials have been packaged in an innovative learning format, facilitating students' learning flexibly according to their learning progress. Students receive responses to the learning materials or information according to their desired actions, allowing them to learn more independently.

The meaning of innovative learning in teaching materials is not only in the content that has characteristics of using multimedia and inviting students to interact, but is also shown in the feedback feature within those innovative learning materials integrated AR. This multimodal approach supports diverse learning styles and helps students better understand complex concepts (Mališů & Šaloun, 2020; Yonanda et al., 2024). Students can progress according to their own pace, revisit materials as needed, and receive support tailored to their learning progress, which is especially beneficial for learners with varying abilities and backgrounds (Chang et al., 2023; Dai & Kang, 2025; Yonanda et al., 2024).

The developed teaching materials incorporate the characteristics of cooperative learning, scientific learning, PBL, PjBL, and TPACK models, presented in a clear and engaging manner to support students' independent learning. These methods promote deeper content engagement and develop critical reasoning, collaborative abilities, and imaginative thinking (Bao & Koenig, 2019; Jabarullah & Iqbal Hussain, 2019; Maknun, 2020). Learning through the PjBL model has been shown to enhance a wide range of abilities, including observation, idea generation, innovation, creativity, and social or value-based competencies (Rukmana et al., 2024), while also providing students with greater autonomy in their learning environment (Muzaini et al., 2024).

Similarly, the PBL model has a positive and significant effect on students' critical thinking skills (Sari et al., 2024). The TPACK model has demonstrated strong effectiveness in enhancing students' cognitive achievement (Aldalalah et al., 2025). The findings are consistent with prior studies indicating that TPACK-based learning efficiently integrates technology, pedagogy, and material, allowing students to become more active and engaged in the learning process (Wulandari et al., 2025). The TPACK model, as a relatively recent instructional framework, has been recognized as an innovative approach capable of improving overall learning quality (Handayani et al., 2023), and TPACK-based PBL has demonstrated strong efficiency and has significantly improved learning outcomes (Chaidam & Poonputta, 2022).

The structure and conceptual clarity of the teaching materials enable students to follow the content more easily and understand concepts in a comprehensive and authentic manner. Furthermore, the materials incorporate innovative, problem-solving-oriented learning content designed to address learning challenges for biology education students, thereby supporting self-paced learning, helping students identify areas for improvement, and encouraging independent problem-solving (Carless, 2020). The developed teaching materials support problem-based learning, addressing the growing demand for graduates capable of applying knowledge to solve complex and enhancing problem-solving skills, especially in biology education (Wai & Lovett, 2021; Bashri et al., 2025). The PjBL model has been shown to effectively accommodate both reflective and impulsive cognitive styles (Cintamulya et al., 2024), while also enabling students to be more active, develop effective problem-solving abilities, and enhance their critical and creative thinking skills (Rukmana et al., 2020).

Notably, an increasing emphasis has been placed on integrating PBL and PjBL approaches into STEM education, as this integration has demonstrated potential in improving critical thinking, problem-solving skills, and student engagement (Dwikoranto et al., 2024). Evidence from research shows that PBL supports academic success and the acquisition of soft skills, including problem-solving, communication, and teamwork, play a vital role in today's work environment (Maker, 2022). Educators may consider incorporating activities that encourage students to reflect on how they solve problems and recognize the benefits of intuitive steps and systematic reasoning (Henra et al., 2024).

4. CONCLUSION

The AR-integrated creative learning materials on plant cells and tissues that use the TPACK framework, Project-Based Learning (PjBL), and Problem-Based Learning (PBL) were effectively designed and verified in this study. With Aiken's V values over 0.85 in the content, presentation, and language dimensions, the validation results showed high levels of content validity and substantial expert agreement about the calibre, applicability, and viability of the educational resources. Revisions that enhanced the display of AR features, the clarity of instructions, and the alignment of learning exercises with problem-solving objectives were made possible by qualitative input from the three expert validators.

These results imply that the created materials are appropriate for use in higher education and offer a methodical way to create and verify technology-enhanced biology teaching resources. The study advances cutting-edge learning materials that facilitate interactive and problem-oriented learning experiences by incorporating AR, PBL, PjBL, and TPACK within the subject of plant cells and tissues.

This study was restricted to expert validation and did not include large-scale deployment with students. Future studies should therefore assess the products' usefulness, efficacy, and user perceptions in various educational contexts as well as how they affect students' comprehension of plant cell and tissue concepts.

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REFERENCES

Aldalalah, O. M. A., Wardat, Y., Al-Omari, A. A. H., & Khodair, R. M. (2025). The Effectiveness of interactive digital content based on the TPACK model in developing the skills of educational aids production and improving cognitive achievement among early childhood university students. *Contemporary Educational Technology, 17*(2). https://doi.org/10.30935/cedtech/16046

Bashri, A., Puspitawati, R. P., & Prastiwi, M. S. (2022). Implementasi media pembelajaran berbasis augmented reality. *Jurnal ABDI: Media Pengabdian Kepada Masyarakat, 7*(2), 212-217. https://doi.org/10.26740/abdi.v7i2.17111.

Bashri, A., Susantini, E., Rahayu S. R., Rukmana, R., Indana, S., Faizah, U., Afnan, M. Z. (2025). Student worksheet based on AR cells and tissues to train spatial thinking and problem solving. *Journal of Curriculum and Teaching*, *14*(3), 308-318. https://doi.org/10.5430/jct.v14n3p308

Bao, L., & Koenig, K. (2019). Physics education research for 21st century learning. *Disciplinary and Interdisciplinary Science Education Research*, *1*(1), 2. https://doi.org/10.1186/s43031-019-0007-8

Bizami, N. A., Tasir, Z., & Kew, S. N. (2023). Innovative pedagogical principles and technological tools capabilities for immersive blended learning: a systematic literature review. *Education and Information Technologies, 28*(2), 1373–1425. https://doi.org/10.1007/s10639-022-11243-w

Branch, R. M. (2009). Instructional design: The ADDIE approach. *Springer US*. https://doi.org/10.1007/978-0-387-09506-6

Campos, N., Nogal, M., Caliz, C., & Juan, A. A. (2020). Simulation-based education involving online and on-campus models in different European Universities. *International Journal of Educational Technology in Higher Education, 17*, 1–15. https://doi.org/10.1186/s41239-020-0181-y

Carless, D. (2020). From teacher transmission of information to student feedback literacy: Activating the learner role in feedback processes. *Active Learning in Higher Education*, *23*, 143 - 153. https://doi.org/10.1177/1469787420945845

Castiglioni, I., Rundo, L., Codari, M., Di Leo, G., Salvatore, C., Interlenghi, M., Gallivanone, F., Cozzi, A., D'Amico, N. C., & Sardanelli, F. (2021). AI applications to medical images: from machine learning to deep learning. *Physica Medica*, *83*, 9–24. https://doi.org/10.1016/j.ejmp.2021.02.006

Chaidam, O., & Poonputta, A. (2022). Learning achievement improvement of 1st grade students by using problem-based learning (PBL) on TPACK model. *Journal of Education and Learning*, *11*(2), 43-48. https://doi.org/10.5539/jel.v11n2p43

Chang, D. H., Lin, M. P., Hajian, S., & Wang, Q. Q. (2023). Educational design principles of using AI chatbot that supports Self-Regulated learning in education: goal setting, feedback, and personalization. *Sustainability*, *15*(17), 12921. https://doi.org/10.3390/su151712921

Cintamulya, I., Warli, & Mawartiningsih, L. (2024). The Development of project-based learning models that accommodate the reflective and impulsive cognitive style. *Studies in Learning and Teaching, 5*(1), 59-72. https://doi.org/10.46627/silet.v5i1.279

Coronado, J. M., Moyano, A., Romero, V., Ruiz, R., & Rodríguez, J. (2021). Student long-term perception of project-based learning in civil engineering education: an 18-year ex-post assessment. *Sustainability, 13*(4), 1949. https://doi.org/10.3390/su13041949

Dai, W., & Kang, Q. (2025). Improvement of flipped classroom teaching in colleges and universities based on virtual reality assisted by deep learning. *Scientific Reports*, *15*(1), 3204. https://doi.org/10.1038/s41598-025-87450-5

Davis, K. D., Aghaeepour, N., Ahn, A. H., Angst, M. S., Borsook, D., Brenton, A., Burczynski, M. E., Crean, C., Edwards, R., & Gaudilliere, B. (2020). Discovery and validation of biomarkers to aid the development of safe and effective pain therapeutics: challenges and opportunities. *Nature Reviews Neurology, 16*(7), 381–400. https://doi.org/10.1038/s41582-020-0362-2

Dwikoranto, Dawana, I. R., & Setiani, R. (2024). Research Trend of PBL and PjBL in Bibliometric Analysis: Implications for a Better Future of Physics Education. *Studies in Learning and Teaching, 5*(2), 296-308. https://doi.org/10.46627/silet.v5i2.359

Fadhilah, F., Husin, M., & Fadia Raddhin, R. (2023). PjBL vs PBL models in higher education: a comparative study using analysis of covariance. *JIPF (Jurnal Ilmu Pendidikan Fisika), 8*(1), 85–93. https://doi.org/10.26737/jipf.v8i1.3700

Faria, A., & Miranda, G. L. (2024). Augmented Reality in Natural Sciences and Biology Teaching: Systematic Literature Review and Meta-Analysis. *Emerging Science Journal*, *8*(4), 1666–1685. https://doi.org/10.28991/esj-2024-08-04-025

Handayani, S., Hussin, M., & Norman, M. (2023). Technological Pedagogical content knowledge (TPACK) model in teaching: a review and bibliometric analysis. *Pegem Journal of Education and Instruction, 13*(3), 176–190. https://doi.org/10.47750/pegegog.13.03.19

Hayani, S. N., & Sutama, S. (2022). Pengembangan perangkat dan model pembelajaran berbasis TPACK terhadap kualitas pembelajaran daring. *Jurnal Basicedu, 6*(2), 2871–2882. https://doi.org/10.31004/basicedu.v6i2.2512

Henra, K., Budayasa, I. K., Ismail, & Liu, M. (2024). What is the room for guessing in metacognition? Findings in mathematics problem solving based on gender differences. *Perspektivy nauki i obrazovania – Perspectives of Science and Education, 69*(3), 469–482. http://dx.doi.org/10.32744/pse.2024.3.28

Hidayat, H., Tasrif, E., Jaya, P., Muhammad, Anwar., Thamrin, Zulwisli, Hadi, A., Budayawan, K., Husin, M., & Asmara, D. (2021). The empirical analysis of industrial work challenges in the industrial revolution 5.0 towards a grade point aver. *International Journal of Online and Biomedical Engineering (IJOE)*, *17*(09), 21–34. https://doi.org/10.3991/ijoe.v17i09.25679

Husin, M., Masdi, H., Simatupang, W., & Hendriyani, Y. (2024). Validation of the project-based problem learning (PBPL) model book in higher education. *Multidisciplinary Science Journal, 7*(4), 2025222-2025222. https://doi.org/10.31893/multiscience.2025222

Ismail, M., Zubair, M., Alqadri, B., & Basariah, B. (2022). Analisis kebutuhan technological pedagogical and content knowledge (TPACK) dalam pembelajaran PPKn. *Jurnal Ilmiah Profesi Pendidikan, 7*(4b), 2442-2447. https://doi.org/10.29303/jipp.v7i4b.1027

Jabarullah, N. H., & Iqbal Hussain, H. (2019). The effectiveness of problem-based learning in technical and vocational education in Malaysia. *Education+Training*, *61*(5), 552–567. https://doi.org/10.1108/ET-06-2018-0129

Jatmiko, B., Prahani, B. K., Saphira, H. V., & Siswanto, J. (2024). Investigation-based multiple representation online model to improve students' problem-solving skills. *Perspektivy nauki i obrazovania – Perspectives of Science and Education, 69*(3), 621–636. Online: https://doi.org/10.32744/pse.2024.3.38

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A.-I. (2021). Gamification in science education. a systematic review of the literature. *Education Sciences, 11*(1), 22. https://doi.org/10.3390/educsci11010022

Maker, C. J. (2022). From leading to guiding, facilitating, and inspiring: a needed shift for the 21st century. *Education Sciences*, *12*(1), 18. https://doi.org/10.3390/educsci12010018

Maknun, J. (2020). Implementation of guided inquiry learning model to improve understanding physics concepts and critical thinking skill of vocational high school students. *International Education Studies*, *13*(6), 117–130. https://doi.org/10.5539/ies.v13n6p117

Mališů, P., & Šaloun, P. (2020). Multimedia and interactivity in educational materials. *Technium Soc. Sci. J.*, 13, 47. https://doi.org/10.47577/tssj.v13i1.1818

Muzaini, M., Rahayuningsih, S., Akib, I., & Kamaruddin, R. (2024). CPjBL versus PjBL instruction: the practice of reviewing literature from reputable journals. *Studies in Learning and Teaching, 5*(3), 581-594. https://doi.org/10.46627/silet.v5i2.375

Rahmah, A. N., Rochyadi, E., Nadiyah'Ufairah Muqsithah, A. M., Sari, W. A., & Tanbrin, N. N. I. (2025). Developing an inclusive numeracy assessment for a blind student in using the ADDIE model. *EDUKASIA Jurnal Pendidikan dan Pembelajaran,* *6*(2), 867-878. https://doi.org/10.62775/edukasia.v6i2.1625

Rukmana, R., Susantini, E., & Bashri, A. (2020). The effectiveness of student worksheet (project-based learning) based on the values of islamic boarding school for the biotechnology subject to train high school students with bioentrepreneuship skills. *Jurnal Inovasi Pembelajaran Biologi, 1*(1), 35-43. https://doi.org/10.26740/jipb.v1n1.p35-43

Rukmana, R., Susantini, E., Raharjo, R., & Borhan, M. T. (2024). Development of PjBL teaching module based on Jombang's local wisdom for training science entrepreneurship skills. *Edubiotik: Jurnal Pendidikan, Biologi dan Terapan*, *9*(02), 154-168. https://doi.org/10.33503/ebio.v9i02.243

Sanusi, S. A. B., & Larisang, A. H. (2023). Validity and reliability tests to determine critical indicators for coconut supply chain sustainability. *International Journal of Progressive Sciences and Technologies*, *41*(1), 376–386. https://doi.org/10.52155/ijpsat.v41.1.5698

Sari, N. A., Dasna, I. W., Kusumaningrum, S. R., & Sitanggang, I. (2024). Effect of problem-based learning model on critical thinking skills in civic education learning. *Studies in Learning and Teaching, 5*(3), 595-606. https://doi.org/10.46627/silet.v5i3.433

Tkachenko, A. (2024). Innovations in higher education: new approaches and teaching technologies. *Economic Analysis*, *34(3)*, 110–121. https://doi.org/10.35774/econa2024.03.110

Turmuzi, M., & Kurniawan, E. (2021). Kemampuan mengajar mahasiswa calon guru matematika ditinjau dari technological pedagogical and content knowledge (TPACK) pada mata kuliah micro teaching. *Jurnal Cendekia: Jurnal Pendidikan Matematika, 5*(3), 2484-2498. https://doi.org/10.31004/cendekia.v5i3.881

Wai, J., & Lovett, B. J. (2021). Improving gifted talent development can help solve multiple consequential real-world problems. *Journal of Intelligence, 9*(2). https://doi.org/10.3390/jintelligence9020031

Wulandari, W., Muliatik, S., & Arianto, A. (2025). The Influence of the RADEC learning model based on the TPACK Approach on the Improvement of cultural literacy for SMP/MTs students. *EDUKASIA Jurnal Pendidikan dan Pembelajaran,* *6*(2), 1095-1108. https://doi.org/10.62775/edukasia.v6i2.1706

Yonanda, D. A., Islahuddin, I., Ramadhani, F. A., Febriyanto, B., Saputra, D. S., Yuliati, Y., & Nurhidayat, E. (2024). Improving Motivation and Learning Outcomes of Elementary School Students with Multimedia-Based Interactive Media. *Profesi Pendidikan Dasar*, *11*(3), 197–210. https://doi.org/10.23917/ppd.v11i3.5761

Zulfiqar, F., Raza, R., Khan, M. O., Arif, M., Alvi, A., & Alam, T. (2023). Augmented Reality and its Applications in Education: A Systematic Survey. *IEEE Access, 11*, 143250-143271. https://doi.org/10.1109/access.2023.3331218