Biodiversity Module Based on Problem-Based Learning Local Wisdom Assisted by Augmented Reality: Improving Students' Critical Thinking

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ARTICLE INFO	ABSTRACT
Keywords: Biodiversity modules PBL Lokal wisdom Augmented Reality Student Critical Thinking	**Purpose –** The purpose of this study was to develop a student teaching module for biodiversity material oriented to Problem Based Learning integrated with local wisdom and assisted by augmented reality media to improve students' critical thinking skills. **Methodology-** The research method refers to the type of ADDIE research and development. The sample in this study was students of YAPIS High School who were taken using the total sampling technique. The data collection instruments were validation sheets and questionnaires to determine the validity and student responses to student books and the provision of critical thinking skills test questions. The data analysis technique was carried out descriptively by calculating the validation results, analyzing student response questionnaires and students' critical thinking skills. **Findings –** The findings are the media and material expert validation test obtained 92.50% (very valid), the validation of critical thinking skills questions obtained 91.11% (very valid). Practicality obtained a value of 83.86% (very practical). The average value of students' critical thinking skills was 65.00 indicating that the value of students' critical thinking skills was in the good category. **Contribution –** The integration of local wisdom into PBL-oriented modules supported by augmented reality technology has great potential in improving students' critical thinking skills. Through local wisdom, students are invited to learn from cultural values related to nature conservation, while PBL allows them to actively seek solutions to relevant environmental and biodiversity problems. The biodiversity teaching module oriented to problem-based learning integrated with local wisdom and assisted by Augmented Reality that was developed can improve students' critical thinking skills

INTRODUCTION

21st century learning demands a transformation of learning methods to be in line with technological advances and student competency needs. One of the competencies that must be developed in this modern era is critical thinking skills. Critical thinking skills are one of the four main competencies needed in 21st century learning, in addition to creative thinking skills, communication skills and collaboration skills (Widya & Utami, 2023; Iwan, et al., 2023; Aris et al., 2024). Critical thinking skills are thinking skills that include behavioral tendencies and cognitive skills to solve problems, draw conclusions, consider various possibilities, and make decisions about what to believe or do. (Agustina & Fitrihidajati, 2020). Carrying out critical thinking activities will play a major role in building and developing the mind to solve various problems by providing appropriate arguments. Critical thinking skills are the ability to reflect and make wise decisions to choose reliable information and what steps to take (Tican & Deniz, 2019).

Based on the research results, it shows that students' critical thinking skills are still classified as moderate or low (Dahlia et al., 2024 ;Iwan et al., 2023). Many students do not understand the material because their critical thinking skills are still lacking, especially in biodiversity material. This fact is shown by the low involvement of students in activities related to the problem of maintaining and protecting biodiversity and the lack of understanding of the concept of biodiversity in learning. Learning that tends to still focus on memorization and theory is also the main reason why students find it difficult to understand biodiversity material in depth. The lack of contextual and relevant approaches to students' daily lives further worsens this condition (Tresnawati et al., 2021). The main challenge in improving students' critical thinking skills is the lack of interactive and relevant learning methods in the local context. Learning often only focuses on transferring knowledge without paying attention to students' active involvement in the learning process. In addition, the low use of modern technology in education is also a inhibiting factor in improving students' understanding of biodiversity issues. Students need a more challenging approach and motivate them to be directly involved in solving real problems related to environmental conservation and preservation (Endang Purnama et al., 2024; Iwan et al., 2020)

The integration of local wisdom in PBL-oriented teaching modules supported by AR technology has great potential in improving students' critical thinking skills. Through local wisdom, students are invited to learn from cultural values related to nature conservation, while PBL allows them to actively seek solutions to relevant environmental problems. AR provides strong visual support, enriching students' learning experiences and helping them understand the real impacts of human actions on biodiversity. The combination of these three elements creates an interactive, contextual, and meaningful learning environment, which is very effective in improving students' understanding of critical thinking (Tamam & Qomaria, 2023).

Augmented Reality is a technology that can enrich the learning process by combining the real world and digital objects. In the context of biodiversity, AR can be used to provide clearer and more realistic visualizations of biodiversity. For example, students can see and understand various species of flora and fauna interactively, thereby increasing their interest and engagement in learning. AR can also help students understand abstract concepts in biodiversity in a more interesting and interactive way, which can ultimately improve students' critical thinking skills significantly (Ratnasari et al., 2022) Anwar et al., 2023; Aripin & Suryaningsih, 2019).

The solution offered to improve students' critical thinking skills is to integrate PBL-oriented local wisdom into the learning module. Local wisdom contains values that have been inherited by ancestors related to the preservation of nature and the environment. By integrating local wisdom into learning, students can learn ways that have been proven effective in maintaining biodiversity. PBL can encourage students to engage in solving real problems related to biodiversity issues. Through this approach, students are encouraged to think critically, analyze, and solve problems that are relevant to their living environment (Damopolii et al., 2024, ; Regala, 2019)

So far, the problem of learning media is still categorized as simple media, this is less effective in its application because biology needs special media, such as original media showing parts of living things that are easily seen inside and outside the classroom (Nuraisyah et al., 2021). Therefore, it is necessary to compile

a biology teaching module based on augmented reality (Rahma Sari et al., 2023). The increasingly difficult challenges and needs of education in today's modern world require interactive learning (Lintangesukmanjaya et al., 2024). The limitations of teaching modules with learning media that utilize technology result in less than optimal student grades (Maulana et al., 2022). It is necessary to develop teaching materials with learning media that can support learning by utilizing technology, one of which is augmented reality-based learning media (Kumalasari & Fikroh, 2023).

One of the teaching materials that will be developed in this study is a student teaching module that is integrated with local wisdom through a problem-based learning model of biodiversity material by utilizing augmented reality media (Julianti et al., 2022). The purpose of this study is to develop a student teaching module that is integrated with local wisdom oriented to problem-based learning and the use of augmented reality media technology to improve students' critical thinking skills.

The novelty of this study is that previous studies have focused on the application of PBL or AR separately in science learning. However, this study combines both with local wisdom, thus providing a more contextual, problem-based, and relevant approach to students' lives. Most biodiversity learning is still based on text and static images. In this study, AR is used to display 3D models of local flora and fauna species, allowing students to interact with virtual objects and understand their characteristics more deeply. In addition to measuring conceptual understanding, this study also evaluates how the integration of PBL and AR based on local wisdom contributes to critical thinking skills.

The contribution of this study is to provide learning strategies that can be applied by teachers in teaching biodiversity more interactively and based on local culture. Produce AR-based learning media that can be used by schools to increase student engagement in learning.

METHODOLOGY

Research Design

This research is a type of research and development that refers to the ADDIE model which consists of five stages, namely Analyze, Design, Development, Implementation, and Evaluation (Branch, 2009). The stages of the ADDIE model development research include (1) Analyze. Through the analysis of student book needs, information was obtained that student books used so far are still limited to ordinary books. The media used are still limited to simple visual and audio-visual media. (2) Design. Learning media are designed using the Assemblr Application. The assessment instrument for student literacy skills uses formative tests in the form of pre-tests and post-tests utilizing AI-based media (Quiziz). (3) Development. After becoming a prototype, the Student Book and the conservation literacy assessment instrument will be validated by the Learning Expert and Media Expert validators. (4) Implementation. Trial to implement the Student Book and instruments that are declared feasible. At this stage, everything that has been developed will be tested in actual conditions. The trial stage obtains data on the implementation of the use of student books in learning. (5) Evaluation. Evaluation will be carried out at the end of each development stage.

Participant

The population in this study is defined as all elements that include objects and people who have characteristics that are the focus of the study. The population of this study includes 29 students of class X of SMA. The sampling technique used is total sampling, which includes the entire population as a research sample including all students of class X of SMA YAPIS Manokwari..

Data Collection and Instrument

The instrument in this study was a validation instrument using a 5-point response format from a Likert scale. The answers to each item of the development instrument had a gradation from (1) very bad, (2) bad, (3) good enough (4) Good (5) very good (Sugiyono, 2015). The Questionnaire instrument was used to determine students' responses to student books integrated with local wisdom and Augmented Reality media. The final test instrument (post-test) was used to determine the extent of students' understanding of critical thinking

skills, and was done by students individually. The type of critical thinking skills test questions used were multiple choice questions consisting of 20 questions.

Data Analysis

Analysis of research data is grouped into two, namely validity and practicality. The table shows the category of learning device validity based on the final score attained on a scale (0-100).

Table 1. Categories of Learning Media Validity

Interval (%)	Category
81-100	Completely
61-80	Valid
41-60	Less valid
21-40	Invalid
0 – 20	Completely Invalid

Products are tested to see student responses. The interactive e-module will then be analyzed using student response data. Student response criteria to see the practicality of interactive e-modules can be seen in Table 2.

Table 2. Response Questionnaire Criteria

Interval (%)	Category
81-100	Very Good
61-80	Good
41-60	Good enough
21-40	Not good
0- 20	Not very good

Table 3. Critical thinking skills category

| Interval (%)	Category
80-100	Very Good
61-80	Good
41-60	Sufficient enough
21-40	Less
0- 20	Very Less

Sumber : (Rahmawati et al., 2023)

FINDINGS

The presentation of research and development results is as follows. At the analysis stage, data and information were obtained regarding the limitations of teaching materials based on local wisdom, oriented towards problem-based learning and the difficulty of utilizing learning media technology such as augmented reality. The teaching materials used by teachers are still limited to ordinary textbooks without being developed by the teachers themselves according to the needs of the students so that students' critical thinking skills are still low, especially on biodiversity material. Therefore, it is necessary to design teaching books based on local wisdom and utilizing augmented reality media technology.

Based on the results of the analysis of the needs of local wisdom-based teaching materials, it shows that 80% of teachers have not integrated teaching modules with local wisdom in biology learning. Therefore, teachers really want the application in learning that integrates local wisdom. Likewise, the use of technology such as Augmented reality has never been done on biodiversity material. Therefore, based on the results of these needs, it is necessary to develop teaching modules that integrate local wisdom assisted by augmented reality media in problem-based learning, especially biodiversity material.

Next, at the stage of the learning process, a prototype of a student teaching module is obtained that is integrated with local wisdom oriented to problem-based learning assisted by augmented reality media on biodiversity material in accordance with learning outcomes. At this stage, a critical thinking skills question instrument has also been produced by utilizing Quiziz. The following is an example of a design image that has been designed.

| Cover | Augmented Reality (3D) |
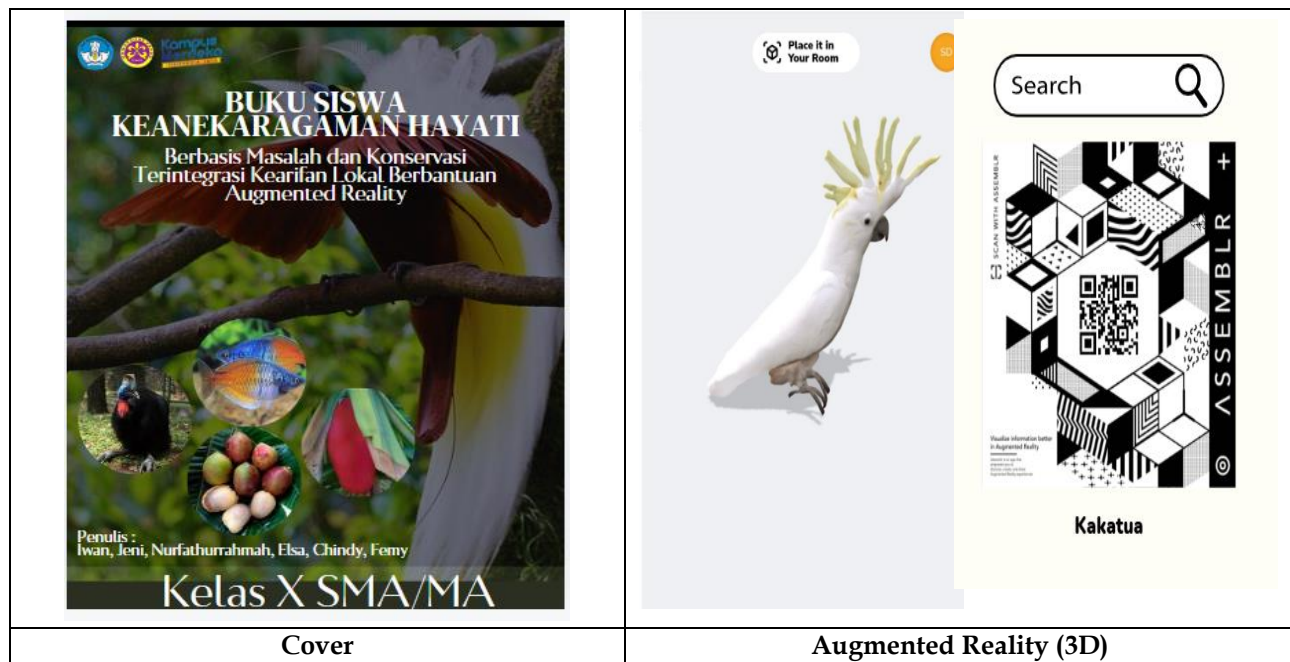
Figure 1. The Design

After obtaining the initial prototype in the form of a teaching module product that is integrated with local wisdom and oriented to problem-based learning and assisted by Augmented reality media for biodiversity material. Furthermore, at this design stage, a validation test was carried out to assess the feasibility of the teaching module by Learning Media experts and material experts on the teaching module that had been developed. Validation includes construct validation and content validation as well as readability validation. The following data from the validation results by experts are presented in table 4.

Table 4. Results of Material and Media Expert Assessment

| Component | Indicator | Validators | | |
		V1	V2	Total
Design (landing page, header, navigation, footer)	1. The appearance of layout elements on the media looks attractive	2	4	6
	2. Proportion of header component placement and content layout (body)	4	3	7
	3. Harmonious color selection clarifies function	4	4	8
	4. Attractive media color combination	4	4	8
	5. Contrast between text color and background color	4	3	7
	6. Placement of titles, text, illustrations/images does not interfere with understanding.	3	4	7
	7. Placing decorations as a background does not interfere with the title or text	4	3	7

Aspect		V1	V2	Total
Ease of use	8. Placement of layout elements is consistent based on the pattern	4	3	7
	9. Easy for users to learn Biodiversity	4	4	8
	10. Users feel the need for Users to easily learn about Biodiversity	4	4	8
	11. Design the module according to the type of learning media.	3	4	7
Information Quality	12. The Biodiversity Module contains relevant information	4	4	8
	13. The Biodiversity Module provides detailed content	3	4	7
	14. The Biodiversity Module contains accurate information.	3	4	8
Linguistics	15. Language that is easy for students to understand	4	4	8
	16. Conformity with good and correct Indonesian language rules	4	4	8
	17. Accuracy of sentence structure	3	4	7
	18. Standardization of terms	3	4	7
In accordance with student development	19. Encourage students to have a sense of curiosity	4	4	8
	20. Encourage students to improve conservation literacy	3	4	7
Total				148
Percentage (%)				92,50

Based on Table 4, it shows that the validation results of the teaching module obtained a value of 92.50% (very valid).

Table 5. Critical Thinking Skills Validation Results

Aspect	Validators		Total
	V1	V2	
1. Content Validation			
a. Suitability of questions to indicators of learning achievement	4	5	9
b. Clarity in formulating instructions for working on questions	4	5	9
c. Clarity of the purpose of the question	4	5	9
d. Scoring guidelines are clearly stated	4	4	8
e. The answer to the question is clear	4	5	9
f. Suitability of the time for completing the questions	4	4	8
2. Language			0
a. The suitability of the language used in the questions with Indonesian language rules	5	5	10
b. The question sentence does not contain double meanings	5	5	10
c. The formulation of communicative questions uses simple language for students, is easy to understand, and uses language that students are familiar with.	5	5	10
Total			82
Average			41
Percentage (%)			91,11

In Table 5. The validator's assessment of the critical thinking skills questions was 91.11% (Very Valid), indicating that the critical thinking skills questions were in the very valid category.

After the teaching module product meets the eligibility criteria, the next step is to test the AR-assisted local wisdom integrated teaching module on biodiversity material. At this stage, the devices and instruments that have been developed will be tested in real conditions. Real class trials are obtained through observations of the implementation of the problem-based teaching module assisted by Augmented Reality and integrated with local wisdom.

Evaluation is carried out at the end of each Analyze, Design, Development and Implementation stage. Furthermore, at the end of the stage, a summative evaluation will be carried out to see the success of the development of the AR-assisted biodiversity teaching module product on biodiversity material on students' critical thinking skills.

The following presents the value of students' critical thinking skills after the implementation of the Augmented Reality integrated local wisdom teaching module in table 6.

Table 6. Results of student Crtitical Thinking Skills

Respondens	Critical Thinking Skills Score	Kategori
S1	65	Good
S2	65	Good
S3	70	Good
S4	50	Enough
S5	65	Good
S6	70	Good
S7	65	Good
S8	65	Good
S9	75	Good
S10	65	Good
S11	65	Good
S12	50	Enough
S13	65	Good
S14	65	Good
S15	70	Good
S16	50	cukup
S17	65	Good
S18	75	Good
S19	75	Good
S20	65	Good
S21	45	Enough
S22	50	Enough
S23	65	Good
S24	70	Good
S25	70	Good
S26	65	Good
S27	65	Good
S28	75	Good
S29	70	Good

	Average Percentage (%)	65,00	Good

Based on Table 6, the average critical thinking skills score obtained was 65.00, which is in the Good category.

Table 7. Respondents' Assessment Results

Respondens	Student Response Score (%)	Keterangan
S1	85	Very good
S2	80	Very good
S3	78	Good
S4	100	Very good
S5	90	Very good
S6	87	Very good
S7	70	Good
S8	73	Good
S9	78	Good
S10	90	Very good
S11	88	Very good
S12	100	Very good
S13	88	Very good
S14	75	Good
S15	87	Very good
S16	90	Very good
S17	90	Very good
S18	80	Very good
S19	92	Very good
S20	93	Very good
S21	72	Good
S22	80	Very good
S23	82	Very good
S24	78	Good
S25	100	Very good
S26	73	Good
S27	72	Good
S28	73	Good
S29	88	Good
Average Percentage (%)	83,86	Very good

Based on table 7, it shows that the student response to the augmented reality-assisted teaching module is 83.86% in the very good category.

DISCUSSION

Based on the results of the validation of media and material experts on the integrated local wisdom-based biodiversity teaching module assisted by augmented reality, the average validation result was 92.50%. This shows that the integrated local wisdom biodiversity teaching module assisted by augmented reality media is categorized as very valid. The validation results for critical thinking skills questions were 91.11% (very valid).

Validation was carried out by 2 experts, namely material experts and media experts. Material experts checked the content and truth of the content of the material presented, especially biodiversity material. Meanwhile, media experts checked the suitability of the learning media used. Is the media used suitable for teaching biodiversity material so that it can be understood by students. This is in line with research conducted by Sholikha et al., (2024) on the Development of Augmented Reality Learning Media shows that this AR product is very suitable for use in learning. This is also in line with research conducted oleh Iwan et al., (2024) shows that the development of teaching modules assisted by Augmented Reality media is very feasible to be used in learning. The development of interactive e-modules on protista material is very feasible to be used to improve students' biology learning outcomes (Iwan et al., 2024).

Several studies on the development of teaching modules integrated with Augmented Reality meet the criteria of valid, practical and effective in improving critical thinking skills. Augmented Reality technology will produce an interesting product and help students in conducting experiments that can make learning really run according to the goal, namely more critical and innovative thinking (Nawawi & Wijayanti, 2022 ; Destiara, 2020; (Ariandani, 2022) (Arianto et al., 2023). One of the applications of technology that is starting to be applied in the world of education is AR, a technological innovation that combines two-dimensional or three-dimensional virtual objects into the real environment and then projects these virtual objects at the same time (Rahma Sari et al., 2023) (Yusma Hasna Lathifah & Sulistiyawati, 2021). (Qadariah, 2022) (Zalukhu et al., 2023).

The practicality of the biodiversity teaching module based on local wisdom oriented problem based learning assisted by Augmented reality can be seen from the results of student responses to learning using the student module. The results of student responses showed an average value of 83.86% with a very practical category. This is in line with what was conveyed by (Sartika, 2024) that the Development of E Modules based on PBL can be valid, practical, and can improve critical thinking skills. One of the learning models that can be applied by teachers is problem-based learning. PBL is a learning model that challenges students to think critically in solving existing problems. PBL is a learning model that trains students to solve problems that are truly student-centered, with the aim of building their own knowledge, developing thinking skills, solving problems, and developing self-control and self-confidence.

The results of the students' critical thinking skills test obtained an average score of 65.00 indicating that students' critical thinking skills are in the Good category. The application of the PBL learning model integrated with local wisdom and AR technology is effective in improving students' critical thinking skills. The use of PBL provides a more interactive, relevant, and contextual learning experience, which encourages students to think critically and understand the importance of preserving biodiversity (Ardoin et al., 2020). Through PBL integration, critical thinking of low-ability students in biology learning can be improved. (Muhfahroyin et al., 2023). The problem based learning model has a significant influence on students' critical thinking skills (Iwan, Sumitro, Ibrohim, & Rohman, 2024).

The PBL model is a learning model that is delivered by presenting a problem, asking questions, facilitating investigations, and finding solutions. The problems studied should be contextual problems found by students in everyday life. Learning tools can improve critical thinking skills (Asminah et al., 2022) The results of the study show that the developed PBL module meets the criteria of being valid, practical and effective in improving critical thinking skills (Hanida et al., 2023). Activities in the PBL model, such as identifying problems in everyday life, are also useful for training students' critical thinking skills (Iwan et al., 2023).

In the learning process, teachers as sources of information need to process various information so that students can receive information correctly and clearly, therefore there needs to be an aid in the form of AR learning media (Fitrianingsih et al., 2023; ;Law & Heintz, 2021; Aslan, 2021). AR technology in education is a useful tool to make teaching and learning effective (Arulanand et al., 2020). Research result (Suharti et al., 2024) through educational games integrated with augmented reality affects students' critical thinking skills. Augmented Reality has the ability to add new forms and methods and the ability of Augmented Reality technology will make the class more interactive (Garzón et al., 2020). It is necessary to update learning to be able to provide digital skills to students through the application of technology, one of which is the application of augmented reality (Tamam & Qomaria, 2023). The application of AR encourages students to be interactive,

so that it can represent all student learning styles, both those that are dominant in visual and audio, because it can integrate all aspects of cognition that students need (Kharchenko et al., 2021). New technologies used in Augmented Reality and its role in education are very important (Sharma et al., 2022). The development of AR-assisted biology learning media can make it easier for students to understand the material (Andriyanto & Josi, 2022).

Integration of local wisdom in learning, especially biodiversity material, is very important to improve students' critical thinking skills. This is in line with research conducted by (Ramadani, 2025) Local wisdom-based education is considered capable of bridging science and culture, as well as supporting critical thinking skills that are relevant to facing challenges in the era of globalization. Likewise by (Rosidi et al., 2023) conclude that the PBL-based e-module containing local wisdom in the form of the use of plants as medicinal plants and their conservation efforts meets the criteria of valid, practical, and effective in improving students' critical thinking skills, problem solving, and environmental attitudes. Teachers need the development of an electronic learning module for environmental change based on integrated ethnoecology PjBL that is easy to understand and effective in improving critical and creative thinking skills (I. Fitriani & Hidayat, 2024).

Research by (Alshehri, 2024) shows that the knowledge gained from formal environmental education can produce an attitude of caring for nature or the environment. Preschool environmental awareness attitudes there is a significant difference between the average pretest and posttest environmental values of the experimental group (Güvenir & Türkmen, 2024). Integration of local culture in understanding science concepts so that it can improve community science literacy and science learning in schools (Suprapto et al., 2024). Integration of Local Culture in learning can improve students' understanding of objects in everyday life (Rahmat et al., 2024; Fitriani & Hidayat, 2024). Research result (H. Fitriani et al., 2024) shows that plant anatomy textbooks can improve the critical analysis skills of prospective biology teachers. The results of the study (Iwan et al., 2020) development of PBL-based teaching materials integrated with local wisdom of Tifa in Papua and the influence of local wisdom integration in problem-based learning to improve students' problem solving (Iwan et al., 2024a).

The results of this study indicate that local wisdom-based learning can increase student engagement and understanding. In the context of biodiversity learning, the integration of local wisdom and AR technology can provide a more realistic and in-depth learning experience. The teaching module can display AR models of various plant and animal species typical of a particular region, providing a more visual and interactive understanding to students. The use of AR in biodiversity learning can be an effective tool to increase awareness of environmental conservation, critical thinking and understanding of the concept of biodiversity. By addressing existing challenges and taking advantage of available opportunities, technology-based and culture-based education can be an effective strategy in preparing learners for a more dynamic future rooted in their cultural identity.

CONCLUSION

Based on the results of the research on the development of a biodiversity teaching module oriented to problem-based learning integrated with local wisdom assisted by augmented reality, it meets the criteria of valid, practical and effective. The results of the students' critical thinking skills test obtained an average score of 65.00. This shows that the students' critical thinking skills are in the good category. The teaching module oriented to problem-based learning integrated with local wisdom assisted by augmented reality on biodiversity material can empower students' critical thinking skills. It is hoped that the results of this study can be used as recommendations for the development and use of a problem-based learning model integrated with local wisdom assisted by augmented reality to empower critical thinking skills on other biological materials in order to foster an attitude of protecting and caring for natural resources for sustainable development.

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