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Development of Augmented Reality Media on the Material of *Pteridophyta* Plant Classification on the Slopes of Mount Gumitir as a Biology Teaching Material for Class X

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Abstract: This study aims to develop augmented reality (AR) media on the classification of Pteridophyta for Grade X students. The development followed the 4-D model, including the define, design, develop, and disseminate stages. Visual objects in the form of images and videos of Pteridophyta were obtained from their natural habitat on the slopes of Mount Gumitir and developed into web-based media accessible via smartphones, allowing students to interact directly with the material. Media feasibility validation was conducted by a language expert (90%), a material expert (96%), and a media expert (89%), categorized as highly feasible. A limited trial was conducted in two schools with a total of 88 students in experimental and control classes. Post-test results showed an increase in the average scores of the experimental class (85–86) compared to the control class (40–42). The Mann-Whitney test results ($U = 22.50$; $Z = 7.950$; $p < 0.001$) indicated that the increase was statistically significant. This AR media provides 3D visualizations of real plants, enhancing students' understanding, motivation, and interest in learning. Further development should focus on increasing interactive features and infrastructure support so that this media can be optimally implemented in biology learning.

Keywords: Augmented reality; Learning media; Mount Gumitir; Pteridophyta.

Introduction

The advancement of information and communication technology has a significant impact on education (Zuhara et al., 2019), especially in the use of interactive and engaging learning media (Romadhon et al., 2023). One of the technological innovations that is increasingly being used in the learning process is augmented reality (AR), which is a technology that combines virtual elements and real objects in 2D to 3D displays (Amrina et al., 2023). AR is currently evolving into pervasive AR that is contextual and integrated into daily life, supporting continuous real and virtual interactions in learning (Pantidi, 2024). AR-based learning media can create interactive experiences (Atmajaya, 2017) so that it can make it easier for teachers and students to understand the material in a more interesting way (Juwita et al., 2021).

Augmented reality (AR) technology has also been shown to enhance engagement and understanding of abstract concepts in bioscience learning (Cannizzaro et al., 2022; Reeves et al., 2021). Widiasih et al., (2023) also demonstrated that AR media is effective in assisting the understanding of abstract eye optics material in physics learning, thus the use of AR in biology material such as the classification of pteridophyta plants also has the potential to enhance the understanding of concepts that are difficult to visualize. In addition, AR also allows the real integration of 3D objects for visualizing morphological and anatomical details, thus supporting

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the understanding of complex concepts in biology (Cooper, 2023; Schmidthaler et al., 2023).

In the subject of biology, particularly the material on the classification of pteridophyta plants, the use of augmented reality (AR) based media is still minimal (Fransyaigu et al., 2024). This is due to the fact that learning in schools is still conventional, tends to be monotonous, and does not actively involve students. This situation affects the low motivation for learning and the understanding of students regarding the material being taught (Ramdani et al., 2019). However, the limited access of teachers to design interactive AR media also poses a barrier to its widespread implementation in schools, as there are still few AR toolkits that are easy for teachers to use to support interactive learning.

Along with the development of the digital era, the utilization of technology in learning has a positive impact and supports the Merdeka Curriculum which focuses on strengthening digitalization in education or digital technology. Therefore, augmented reality (AR) media is highly relevant as a learning medium (Prabowo & Wakhudin, 2024). Oktavianda et al. (2024); Rahmawati et al. (2023) also emphasize that the use of interactive digital media in the 4.0 era is effective in enhancing student engagement and learning outcomes, making the application of AR as a learning medium in line with the demands of modern education.

Augmented reality (AR) media can support learning in the classification of pteridophyta plants. Pteridophyta plants are a group of plants that belong to the kingdom plant. Pteridophyta also has a wide distribution in various areas with humid conditions, including in mountainous and sloped areas, as also found in sedimentary layers in Antarctica (Trevisan et al., 2022). This plant has a cormus and a bundle of transport vessels or xylem and phloem (Puspa et al., 2023). Pteridophyta plants are grouped into four classes including Lycopsida, Psilopsida, Equisetopsida, and Filicinae. Pteridophyta plants have a variety of habitats in addition to growing in moist places (Hydrophytes), pteridophyta plants are also often found on tree trunks, also attached to rocks or Epiphytes (Yunita et al., 2022). Pteridophyta is also included in the Cormophyta plant because it has a clearly visible morphological structure (Janna, 2020). Pteridophyta plants are plants that reproduce through spores. The morphological structure of pteridophyta plants includes roots, rhizomes, leaves, indiciums and sporangiums, so it requires visual aids to help students understand the shape and function in detail, especially in the sporangium and indisum more clearly (Pradipta et al., 2020). In line with this, palinology research using SEM on Polystichum spores shows that the detailed visualization of spore ornamentation is very important in the classification and understanding of pteridophyta structures, so the use of interactive media such as AR in learning can be an effective means of helping students understand morphology more deeply (Liu et al., 2024).

Morphological visualization, especially in the reproductive process of pteridophyta, is important for deep understanding and therefore requires interactive learning media (Yang et al., 2022). The use of AR in this material allows students to understand the structure, function, and life cycle of pteridophyta plants in real and contextual terms (Bai, 2017). Research by Khotimah et al., (2023) analyzing the diversity of ferns in Palak Siring Waterfall shows the potential of ferns to be used as an environmental science learning resource in schools, so that the use of AR for Pteridophyta plant classification materials can help students understand the diversity and ecology of pteridophyta plants contextually.

Aisyah & Triyanto, (2020) also emphasized the importance of using teaching materials that are in accordance with the characteristics of learning, namely active, innovative, and technology-based learning. Therefore, (Wibowo et al., 2022) said that augmented reality (AR) media is suitable for use because it is not only visually attractive but also relevant to real conditions.

Based on this background, this study aims to design and develop Augmented Reality (AR)-based learning media on Pteridophyta classification materials for grade X high school/MA students. The novelty of this research lies in the use of real objects taken directly from the Mount Gumitir Slope Plantation area. The AR media developed allows students to learn contextually, by presenting visualizations of Pteridophyta plants as if they were in their natural habitat.

Method

Researchers use the 4-D development model in the Research and Development (R&D) approach. This model includes four stages, namely Define, Design, Develop, and Disseminate, which are used by (Thiagarajan, 1974). This model is considered relevant for designing technologybased learning media as a whole. This is in line with Dengel et al. (2022) who stated that the integration of AR in learning requires the development of media that is accessible, GUI-based, and supports interactivity without requiring advanced programming skills from teachers so that it can be applied in the classroom optimally. Sukmayanti et al., 2024) said that the use of 4D development models in the development of edutourism media on Pteridophyta material has been proven to be valid and effective, supporting the relevance of the use of this model in research on the development of Pteridophyta AR media.

The steps or procedures for research development are described as follows.

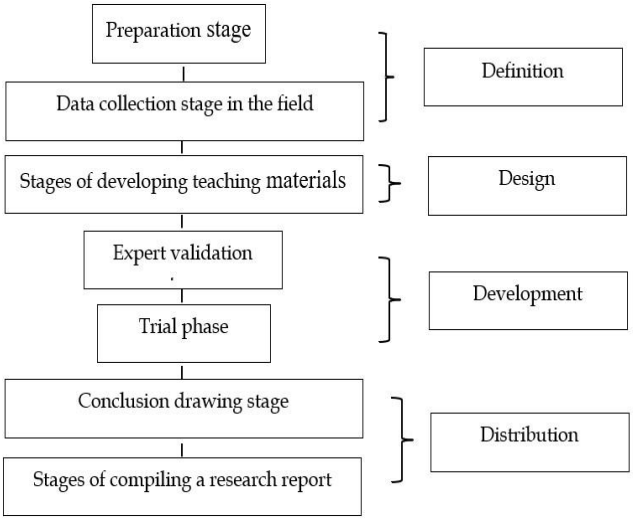


Figure 1. 4-D development model (Source: Nerita et al., 2018)

Research Development Procedures

Define

The initial step is carried out with a needs analysis through interviews and observations of teachers and students to identify the problems faced in learning the Pteridophyta material. In addition, a direct exploration was conducted to the native habitat of fern plants in the slopes of Mount Gumitir to collect species data through documentation and recording of morphological characteristics. At this stage, the researchers collect data in the form of images and videos of Pteridophyta plants, and record detailed information regarding the discovery location, soil pH, environmental temperature, and the morphological characteristics of each species found.

Design

At this stage, the media is designed using the Assemblr Edu platform which supports the development of visual content in 3D form so that it can be used via Android devices. The design is adapted to the grade X curriculum, including basic competencies and learning indicators, and takes into account student characteristics. The steps in creating augmented reality media include:1. Collecting data on the morphological characteristics of pteridophyte plants and materials2. Account creation. 3. Design of pteridophyte plants. 4. Creating visual objects by editing pteridophyte plants to match the marker.5. Developing media using Unity available in 2D or 3D. 6. Internal testing or preview to ensure the media functions as intended. 7. Revising the project if there are any mistakes. 8. Finalizing the media by packaging it in the form of a QR code.

Develop

The developed media was then validated by three experts consisting of a media expert, a content expert, and a language expert in accordance with the assessment indicators in tables 3, 4, and 5. After validation, the media was tested on a limited basis at two educational institutions.

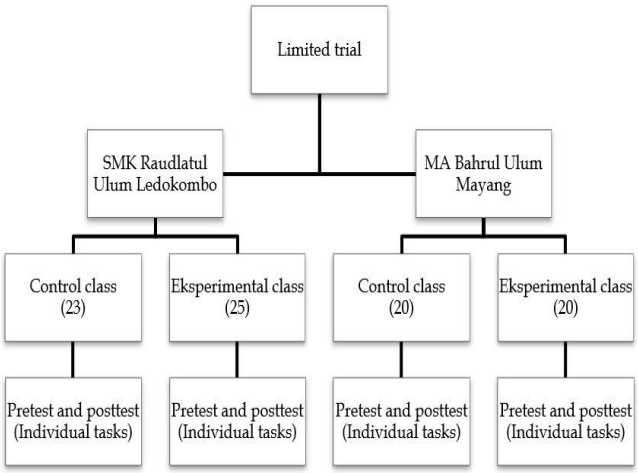


Figure 2. Limited trial flowchart.

Disseminate

The media that has been developed is then applied in learning at school and presented to biology teachers as an alternative teaching material. Apart from being used in formal learning, media is also used by students independently and in small groups.

Research Subjects and Instruments

This study involved 88 grade X students from two educational institutions, namely SMK Raudlatul Ulum, Ledokombo District and SMK Bahrul Ulum, Mayang District. Each school consists of a control class and an experimental class. The research instruments include data collection instruments, expert assessment instruments and student learning outcome instruments.

Data Collection Instruments

Table 1. Observation tool instruments

Instrument Tool	Utility
Camera	Documentation tools
Stationery	Recording data
Soil tester	Measuring pH

Table 2. Observation material instruments

Instrument Tool	Utility
Pteridophyta plants	Research subjects

Table 3. Validation by language experts (Saputra et al., 2022)

Assessment Indicators	Number of Questions
Compliance with Language Rules	5
Dialogic and interactive	5
Compliance with student development	5
Straightforward	5
Commutative	5

Table 4. Expert validation of material (Hotimah & Novitasari, 2024)

Assessment Indicators	Number of Questions
Timeliness of material	5
Feasibility of material	5
Accuracy of material	5
Feasibility of material presentation	5
Encourage curiosity	5

Table 5. Media expert validation (Harefa et al., 2023)

Assessment Indicators	Number of Questions
Material quality	10
Product usage	5
Technical quality aspects	5
Creativity and innovation aspects	5

The questionnaire data from the three experts was then analyzed using the Formula 1.

$$NP = \frac{R}{SM} \times 100\% \quad (1)$$

Information:
NP = Expected percentage value
R = Total scores obtained
SM = Maximum score (Rumansyah & Soeprianto, 2016).

The data resulting from the media feasibility is then developed into a qualification level with criteria in the form of the following table.

Table 6. Eligibility criteria (Ernawati, 2017)

Score in percent (%)	Eligibility categories
81 – 100	Very worthy
61 – 81	Worthy
41 – 60	Quite worthy
21 – 40	Not worthy

Learning Outcome Instruments

The learning outcome instrument used 25 pretest and posttest questions in essay form. Data were analyzed using a quantitative descriptive approach to evaluate the effectiveness of the media on learning outcomes.

Results and Discussion

The study was conducted in two schools, namely SMK Raudlatul Ulum, Ledokombo District and SMK Bahrul Ulum, Mayang District. Each school involved a control class and an experimental class. This study focuses on the material on the classification of pteridophyta plants for class X based on augmented reality (AR) in the Merdeka curriculum.

This study uses four stages that include Define, Design, Develop, and Disseminate. The definition stage in this development includes three main steps, namely initial preparation, data collection in the field and the process of identifying pteridophyta plant species taken from the slopes of Mount Gumitir plantation. Some preparations include a digital camera or mobile phone, stationery and a laptop as a data processor. To collect data, exploration is also carried out at several locations. The location taken at that point is to find the presence of pteridophyta plant species. Observations include documentation, morphology, habitat growth, and environmental conditions such as soil pH, temperature, humidity, and coordinate points.

Based on the research results, the types of pteridophyta plants found in the plantations on the slopes of Mount Gumitir consist of 17 species, 15 genera, 6 families, 3 orders, classified into 3 classes and 2 divisions. Of the 17 species of pteridophyta plants found in several places, one of which is attached to tree trunks and rocks.

Table 7. Types of pteridophyte plants found.

Classification	Figure
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family:Polypodiaceae Genus: Pecluma Species: Pecluma plumula	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family: Polypodiaceae Genus: Dryopteris Species: Dryopteris expansa	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family: Polypodiaceae Genus: Pyrrosia Species: Pyrrosia platyphylla	

Classification	Figure
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family: Polypodiaceae Genus: Phymatosorus Species:Phymatosorus scolopendia	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family: Polypodiaceae Genus: Platycerum Species: Platycerum bifurcatum	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family: Aspleniaceae Genus: Pelazaneuron Species: Pelazoneuron kunthii	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family:Aspleniaceae Genus: Asplenium Species: Asplenium nidus	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family:Aspleniaceae Genus: Pteris Species: Pteris multifidapoir	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family: Pteridaceae Genus: Pteris Species: Pteris vittata	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family: Pteridaceae Genus: Pteris Species: Pteris ensiformis burm	
Division: Pteridophyta Class: Pteridosida Order: Polypodiales Family: Pteridaceae Genus: Pityrogramma Species: Pityrogramma calomelanus	
Division: Pteridophyta	

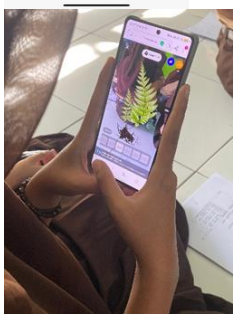
Classification	Figure
Class: Pteridosida Order: Polypodiales Family: Pteridaceae Genus: Andiantum Species: Adiantum trapeziforme	
Division: Pteridophyta Class: Pteridosida Ordo: Polypodiales Family: Pteridaceae Genus: Antrophylum Species: Antrophylum reticulatum	
Division: Pteridophyta Class: Pteridosida Ordo: Polypodiales Family: Pteridaceae Genus: Nephrolepis Spesies: Nephrolepis exaltata	
Division: Pteridophyta Class: Pteridosida Ordo: Polypodiales Family: Nephrolepidaceae Genus: Nephrolepida Species: Nephrolepis cordifolia	
Division: Pteridophyta Class: Equisetopsida Order: Equisetales Family: Equisetaceae Genus: Equisetum Species: Equisetum hymal	
Division: Magnoliophyta Class: Liliopsida Order: Asparagales Family: Asparagaceae Genus: Asparagus Species: Asparagus setaceus	

Figure 2. QR Code

The second step is the design stage, where researchers create learning media using augmented reality (AR) technology for the material on class X pteridophyta plant classification. This media is designed using Unity 3D software with the final result being an application that can be used on Android devices. So that the camera is directed at the marker image, the application will display a 3D model of the pteridophyta plant complete with additional information such as text and sound. The flow of use is made simple so that it is easy for students to understand, starting from the initial display, scanning the marker, to the appearance of objects and explanations. The material presented is arranged based on the Biology teaching module for class X on the material of pteridophyta plant classification using the Merdeka Curriculum, covering the characteristics, structure and classification of pteridophyta plants. This initial design was validated by experts before entering the further development stage.

The following are the results of the development of augmented reality (AR) media in the form of QR Codes.

Table 8. Some of the results of making augmented reality (AR) media

Figure	Information
	When first opened, the Assembler Edu application displays a login page that asks users to enter a username and password to access the learning features.
	The cover of the augmented reality (*AR*) learning media for the classification of pteridophyt*a* plants is designed to be attractive and educational, displaying titles, logos, and visual elements to attract students' interest in learning. This cover functions as an opening page before users access the material.
	The main image displays plants from their natural habitat in 3D, allowing students to zoom in and rotate the objects for clearer observation.
	The Pyrrosia platyphylla plant comes from its natural habitat and is displayed in 3D with visual markers on morphological parts such as rhizomes, roots, and leaves. The augmented reality (*AR*) feature makes it easier for students to understand plant structures in a real and interactive way.
	The 3D model of Phymatosorus scolopendria displays spores in detail and is equipped with interactive symbols that display additional information, making it easier for students to understand plant morphology in real time through augmented reality (*AR*).
	This interactive animated video explains the life cycle of pteridophytes from the sporophyte to gametophyte stages, complete with narration and supporting text to facilitate user understanding.
	In a school learning trial, augmented reality (*AR*) technology allows students to point the device's camera at a marker to display a 3D object of a pteridophyte plant. This object can be observed from various angles, helping students understand the structure of ferns in a more focused and interactive way.

The third stage in this research is the development stage, which includes the validation process by linguists of augmented reality (AR) media on the material on pteridophyta plant classification. Validation was carried out by Mr. Luf Iskandar, S.Pd., with the aim of ensuring that the use of language in the media is appropriate to the level of student understanding, clear, and easy to understand. The assessment includes dialogic and interactive language rules, as well as the clarity of delivery. The validation process was carried out twice

and resulted in a final score of 90% of the maximum total, so that the media was declared very linguistically feasible and effective to support learning.

The next validation stage was carried out by a material expert, namely Mr. Sarwo Danuji, M.P. The aim is to ensure that the content presented in augmented reality (AR) media is in accordance with the curriculum and supports the achievement of basic competencies. The aspects assessed include suitability in learning. Assessment by material experts includes several important aspects, including the suitability of the material to the learning topic, the appropriateness of the material content, the accuracy of the information conveyed, the appropriateness of the presentation, and the ability of the media to encourage students' curiosity.

Validation was conducted three times to obtain comprehensive feedback and refine the media according to the validator's suggestions. The final result obtained a score of 96% of the maximum total, so it was categorized as very feasible and had met the standards of material eligibility for use in learning.

The final validation stage involved media expert, Mr. Ferdy Sugianto, M.Pd., who assessed augmented reality (AR) based learning media for the pteridophyta plant classification material for class X Biology. This validation aims to ensure that aspects of visual design, interface, and media interactivity are able to support effective, interesting, and easy-to-use learning. The assessment includes overall media quality, ease of use, technical quality, and elements of creativity and innovation. The validation process was carried out two times to perfect the product based on input at each stage. The final results showed a score of 89% of the total maximum value, so that the media is categorized as very feasible and meets the standards of good learning design.

The following is a bar chart showing the results of media validation by three experts, language experts (90%), material experts (96%), and media experts (89%). This graph can be used to clarify the suitability of the media from various aspects of the assessment.

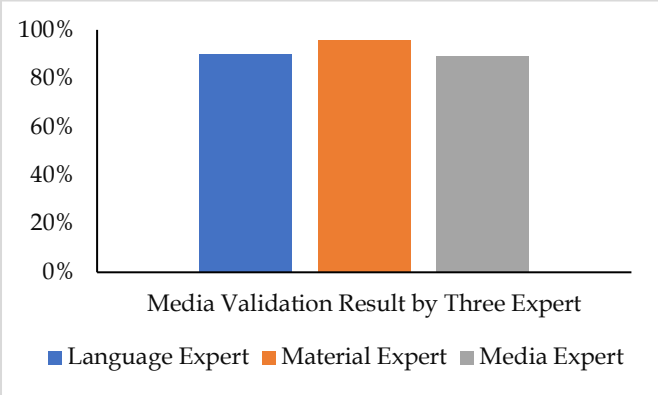


Figure 3. Media Validation Result by Three Expert

In the trial stage, the learning media that had previously been declared feasible by expert validators including aspects of media, materials, and language were then implemented to students. The trial was carried out in two educational units, namely SMK Raudlatul Ulum, Ledokombo District and SMK Bahrul Ulum, Mayang District with a total number of 88 students. The trial was carried out on two groups, namely the experimental class using augmented reality (AR) media, and the control class using conventional teaching materials. augmented reality (AR) media displays 17 species of ferns from the slopes of Mount Gumitir in the form of interactive 3D models that can be rotated and enlarged via smartphone.

The effectiveness of the media is assessed by giving an essay test of 25 questions which is done before (pretest) and after (posttest) the learning activity. This instrument is used to measure the increase in students' understanding of the material on the classification of ferns (Pteridophyta) after using the developed media.

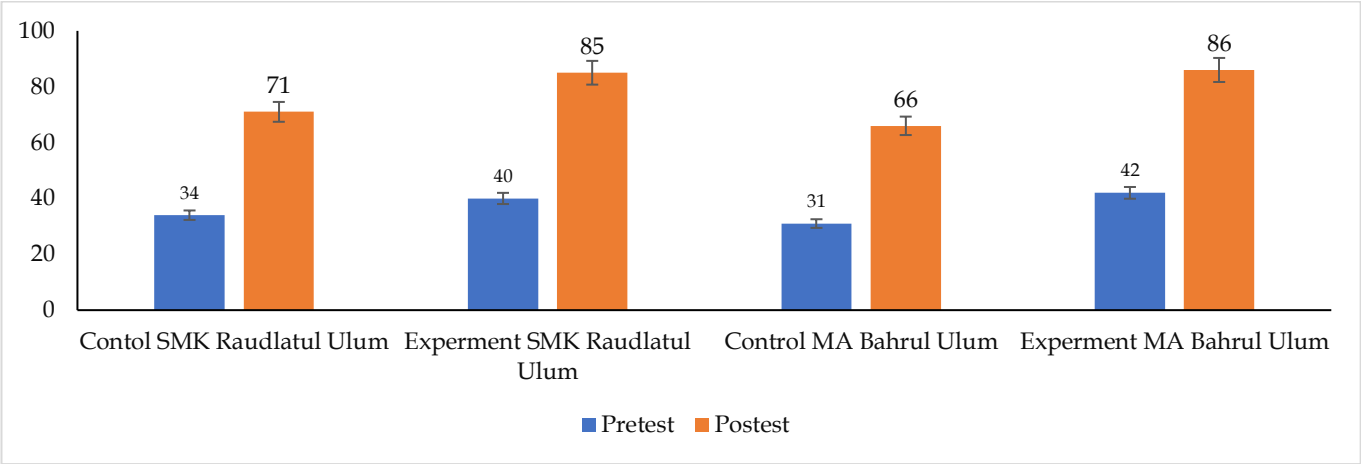


Figure 4. Comparison of average value

Based on Figure 4, all classes experienced an improvement in learning outcomes. However, a more significant improvement occurred in the experimental class, both at SMK Raudlatul Ulum from an average of 40 to 85 and at SMK Bahrul Ulum from an average of 42 to 86. Meanwhile, the control class in the two schools also experienced improvement, but not as much as the experimental class. The significant improvement in learning outcomes in the experimental class shows that the use of augmented reality (AR) media has a positive effect in helping students understand the concepts of pteridophyta plants.

To determine the significant increase in the use of augmented reality media, normality and homogeneity tests were carried out as a prerequisite for analysis. The test results showed that the data was abnormal but homogeneous, so the analysis was continued using the mean- Whitney test to determine the effectiveness of augmented reality media on students' learning outcomes.

Table 9. Descriptive statistics of pretest and posttest results.

Test	N	Mix	Max	Mean
Pretest	88	16.00	52.00	36.91
Posttest	88	56.00	98.00	77.25

Based on Table 9, it can be seen that the average posttest score of students has increased compared to the average score of the pretest. The average pretest score was 36.91 with a standard deviation of 8.63, while the average posttest score increased to 77.25 with a standard deviation of 10.27. This increase in value shows a positive influence after the use of Augmented Reality media in learning

Table 10. Results of the mann-Whitney pretest and posttest.

Test	Mann-Whitney U	Z	Sig. (2-tailed)	Note
Pretest	442.000	-4.446	0.000	There is a difference
Posttest	22.500	-7.950	0.000	There is a difference

Based on Table 10, the significance value in the pretest and posttest was 0.000 ($p < 0.05$). This shows a significant difference between the learning outcomes of the control class and the experimental class both before and after treatment. A negative Z value indicates that the average score of the experimental class is higher than that of the control class, so it can be concluded that the use of Augmented Reality media is effective in improving students' learning outcomes in the pteridophyta plant classification material.

The results of this study show that the use of augmented reality (AR) media makes a real contribution to improving student learning outcomes, especially in experimental classes. The average posttest score of the experimental class was higher than that of the control class, indicating that augmented reality was effective in conveying Pteridophyta material in a more interesting and easy-to-understand way.

One of the reasons for the success of AR in learning is its ability to present interactive 3D visualizations, allowing learners to see the morphological structure and classification of plants in real time from various angles. This is supported by research findings Kanti et al., (2022), which state that AR media supports the learning process because it can make learners more active and the material easier to remember.

In addition, AR interactivity also encourages active student engagement, which according to the constructivist approach is very important in the process of meaningful learning. Students not only receive information passively as in the control class, but they are directly involved in the exploration of AR objects, which sparks curiosity and increases motivation to learn (Ningrum et al., 2021). This is supported by research by Thahir & Kamaruddin (2021), who found that AR can improve the understanding of abstract matter in biology.

Augmented reality (AR) media has advantages because it can display objects in a real and interesting way, so that learning materials are easier to understand and remember by students. However, its use also has challenges, such as limited supporting tools and the need for training for teachers so that they can run augmented reality (AR) media optimally (Mustaqim, & Kurniawan , 2017).

The disseminate stage or the spread of this stage is the last stage taken from the 4D model. This study examines the diversity of pteridophyta plants in the Mount Gumitir area and develops augmented reality (AR)-based learning media as pteridophyta plant classification material for grade X students. The results show that the area has many types of pteridophyta plants that have the potential to be used as learning resources. The augmented reality (AR) media that was developed has proven to be effective in increasing students' understanding and interest in learning because its appearance is attractive, easy to use, and in accordance with the curriculum.

This media has also been distributed in two schools and presented directly to teachers teaching Biology as teaching material. However, further development is still needed, such as adding interactive features and adjusting content to suit students' learning

characteristics. The use of augmented reality (AR) based on local potential is considered capable of creating more interesting learning while also fostering concern for the environment.

Conclusion

The use of Augmented Reality (AR) media in pteridophyta plant classification materials is effective in improving student learning outcomes. After being tested on 88 students, the average post-test score of the class using (AR) increased from 40- 42 to 85-86, this result was statistically significant (U = 22.50; Z = -7,950; $p < 0.001$). The media was created based on the documentation of 17 species of pteridophyta plants from their native habitat on the slopes of Mount Gumitir, thus presenting interesting and contextual content. The media also received a "very decent" rating from linguists (90%), material experts (96%), and media experts (89%). The main challenge is the limited equipment and the lack of teacher training. For this reason, infrastructure support and feature improvements are needed so that AR can be used optimally. Overall, this AR media is feasible, effective, and has a real impact on improving learning outcomes, student motivation, and local environmental awareness.

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Conflicts of Interest
The authors declare no conflict of interest.

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