



Development of Augmented Reality-Integrated Booklets and Flash Cards to Enhance Students' Scientific Literacy and Motivation on Biodiversity Topics at SMA Negeri 2 Marang Kayu

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Abstract: This study was motivated by the low levels of students' scientific literacy and learning motivation in biodiversity topics, as well as the limited availability of learning media capable of visualizing abstract concepts contextually at SMA Negeri 2 Marang Kayu. This study aimed to describe the validity, practicality, and effectiveness of Augmented Reality (AR)-integrated Booklet and Flash Card media in improving students' scientific literacy and learning motivation. The study employed a Research and Development (R&D) method using the 4D model, which consists of define, design, develop, and disseminate stages. The research subjects included material experts, media experts, language experts, and tenth-grade students of SMA Negeri 2 Marang Kayu as the trial participants. The research instruments consisted of validation sheets, student response questionnaires, scientific literacy tests, and learning motivation questionnaires. The data were analyzed descriptively, while the effectiveness of the media was tested using a paired sample t-test and N-gain score analysis. The results showed that the developed media were categorized as highly valid, with validation scores of 96% from language experts, 90% from material experts, and 87% from media experts. The media were also considered highly practical based on students' responses. Furthermore, the media proved to be significantly effective ($p < 0.05$) in improving students' scientific literacy and learning motivation. Students' scientific literacy scores increased from 57.63 to 79.63, while learning motivation scores increased from 61.05 to 75.59.

Keywords: Augmented reality; Booklet; Flash card; Learning motivation; Scientific literacy

Introduction

The 21st century is often recognized as an era of knowledge, information-based economy, globalization, digital technology, and the Industrial Revolution 4.0. These rapid developments provide various opportunities when utilized optimally, including in the field of education. Advances in information technology

offer enormous potential to support the learning process (Maulida & Rahmatan, 2025). The increasingly rapid development of digital technology has also significantly influenced various aspects of life, particularly the educational sector. This condition encourages the education sector to continuously innovate in the

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learning process in order to adapt to the demands of contemporary developments (Yuwafi et al., 2025).

Technology is currently utilized not only as a means of communication and entertainment, but also as an important medium in supporting learning activities. The presence of digital technology enables learning to become more flexible, interactive, and accessible anytime and anywhere. The implementation of technology in learning makes the learning process more practical and easier for students to understand (Ulfa & Fadilah, 2025). In addition, the integration of technology in education has become one of the major demands of 21st-century learning, which emphasizes critical thinking, creativity, collaboration, and digital literacy skills. Therefore, the utilization of technology as a learning medium needs to be innovatively developed in order to improve both the quality of the learning process and students' learning outcomes. In line with this, learning media constitute one of the essential components that support the success of the teaching and learning process (Fadilah et al., 2025).

In the field of education, the use of learning technology provides opportunities for teachers to create a more engaging and student-centered learning environment. The utilization of digital media can help students understand learning materials more concretely through visualization, simulation, and interactive animations. Furthermore, students in the digital era tend to be more interested in using technology and electronic devices to support their literacy and learning activities (Hamidi & Widiani, 2023). Technology is also capable of increasing student engagement in the learning process, as students not only receive information passively but can also interact directly with the learning materials. One of the technologies that has increasingly been implemented in education is Augmented Reality (AR). AR technology enables two-dimensional and three-dimensional virtual objects to be displayed in real-world environments in real time, thereby providing students with a more engaging and meaningful learning experience.

Although the development of educational technology continues to advance, the learning process in schools still faces various challenges, particularly in Biology education. Biology is a branch of natural science that studies living organisms and complex life phenomena. In Biology learning, many topics are abstract in nature, requiring learning media that can assist students in understanding concepts visually and contextually. One topic that is often considered difficult by students is Biodiversity. This topic encompasses concepts related to the diversity of living organisms, organism classification, and the relationships between living organisms and their environments. However, learning processes that are still dominated by lecture

methods and the use of textbooks make it difficult for students to visualize the studied objects concretely. As a result, learning becomes less engaging, and students tend to become bored quickly.

Another issue encountered in Biology learning is the low level of students' scientific literacy. Scientific literacy refers to the ability to apply scientific knowledge, identify problems, and draw conclusions based on scientific evidence (Putri, 2020). In Indonesia, scientific literacy has become an essential component of science education; however, the results of the PISA survey indicate that Indonesian students' scientific literacy remains below the international average (Azkia et al., 2023; Pujiyanti et al., 2025; Sumarah et al., 2025). Indonesian students' scientific literacy scores are categorized at Level 1 out of four levels of scientific literacy, indicating that their scientific literacy skills are still relatively low (Rahardhian, 2023). This condition demonstrates that the level of scientific literacy among students in Indonesia remains concerning. Despite nearly 20 years of participation in scientific literacy assessments, Indonesia has consistently ranked among the ten countries with the lowest levels of scientific literacy (Makhrus & Hidayatullah, 2025; Sulastri et al., 2025).

The development of scientific literacy in Indonesia has actually been promoted through curricula that emphasize the understanding of scientific concepts, process skills, and problem-solving abilities. In addition, efforts to improve scientific literacy are also supported through school literacy movements (Saputro, 2022). Scientific literacy skills are essential for students in order to face future developments in science and technology. However, in practice, students still tend to memorize concepts without fully understanding the application of scientific knowledge in everyday life. In biodiversity topics, students continue to experience difficulties in identifying organism species, explaining biodiversity phenomena, and analyzing the relationships between living organisms and their environments. One of the factors contributing to the low level of scientific literacy is the limited use of learning media capable of connecting abstract concepts with real-life conditions surrounding students.

In addition to the low level of scientific literacy, students' learning motivation is also an important issue in Biology education. Learning motivation refers to the internal and external drives that influence students' enthusiasm and willingness to learn. Motivation plays a crucial role in determining students' level of understanding. Students with high learning motivation tend to be more active in exploring learning materials, whereas students with low motivation often experience difficulties in understanding the concepts being studied (Hidayatullah et al., 2025). Motivation is also essential in

the learning process because students with low motivation tend to engage in learning activities less optimally (Musfirah et al., 2025; Yanti et al., 2020). Based on preliminary observations conducted at SMA Negeri 2 Marang Kayu, it was found that some students showed low interest in participating in Biology learning, particularly on biodiversity topics. Learning activities that were monotonous and lacked the use of innovative learning media caused students to be less motivated to explore the material more deeply. This condition had an impact on students' low engagement and the less optimal learning outcomes achieved.

To address these various issues, innovative learning media are needed to improve both students' scientific literacy and learning motivation. One potential solution is the development of Augmented Reality (AR)-integrated booklets and flash cards. AR technology enables learning materials to be presented in three-dimensional (3D) forms, thereby helping students understand difficult concepts more clearly (Febriany & Bektiningsih, 2025). In addition, AR is capable of providing interactive learning experiences and creating more authentic learning activities (Ruswanti et al., 2025; Tarigan et al., 2023).

Booklets are learning media in the form of small books that present materials concisely, systematically, and attractively, thereby enabling students to understand the material independently more easily. This medium is expected to help students comprehend abstract concepts through interactive three-dimensional visual displays (Amalina et al., 2025). Learning activities using such media also become more enjoyable and effective, which can enhance students' understanding and retention of learning materials (Putra et al., 2025). On the other hand, flash cards can assist students in recognizing concepts through images and brief information that are easy to understand. Flash cards are among the most popular and effective media for learning factual knowledge and improving students' memory retention (Sharmin & Chow, 2020). Furthermore, the use of Augmented Reality Flash Cards can increase students' learning motivation and facilitate learning activities through marker-based features capable of displaying three-dimensional objects when directed toward a smartphone camera (Chakim et al., 2025; Siregar et al., 2025).

The integration of AR technology into booklets and flash cards enables students to observe three-dimensional visualizations of biodiversity objects through smartphones. Consequently, students can gain a more interactive, engaging, and contextual learning experience. The use of AR-based booklets and flash cards is expected to help students understand biodiversity concepts more concretely through realistic digital visualizations. In addition, these media can also

increase students' interest and participation because the learning process becomes more innovative and less monotonous. The integration of AR allows students to explore learning materials independently, thereby improving their scientific literacy skills, particularly in explaining scientific phenomena, evaluating information, and interpreting data. Attractive and interactive visual displays can also enhance students' learning motivation, as students become more interested and enthusiastic during the learning process.

Based on the aforementioned explanation, the development of Augmented Reality-integrated booklets and flash cards is considered important as an innovative learning medium for biodiversity topics at SMA Negeri 2 Marang Kayu. The developed media are expected to provide a solution to the low levels of students' scientific literacy and learning motivation, while also supporting the creation of Biology learning that is more effective, interactive, and aligned with technological advancements in the digital era. Therefore, this study is entitled "Development of Augmented Reality-Integrated Booklets and Flash Cards to Improve Students' Scientific Literacy and Learning Motivation on Biodiversity Topics at SMA Negeri 2 Marang Kayu."

Method

This study employed a Research and Development (R&D) approach aimed at developing and evaluating the feasibility of Augmented Reality (AR)-integrated Booklet and Flash Card learning media on biodiversity topics. This approach was chosen because the study not only focused on the effect of media implementation on learning outcomes, but also on the process of product development to ensure that the media met the criteria of validity, practicality, and effectiveness for use in Biology learning at SMA Negeri 2 Marang Kayu. The development model applied in this study was the 4D model developed by Sivasailam Thiagarajan, which consists of four stages: define, design, develop, and disseminate (Figure 1).

This model was selected because it provides systematic stages and allows continuous product evaluation and revision, enabling the developed product to align with students' needs and the characteristics of Biology learning. At the define stage, an initial and final analysis was conducted through the identification of learning problems, curriculum analysis, student characteristic analysis, concept analysis, and the formulation of learning objectives. The analysis focused on the low levels of students' scientific literacy and learning motivation in biodiversity topics, as well as the need for contextual learning media based on the local potential of East Kalimantan. At the design stage, a prototype of the AR-integrated Booklet and Flash Card

media was developed, including the preparation of learning materials, visual designs, three-dimensional objects of endemic flora and fauna, and the development of research instruments such as scientific literacy tests, learning motivation questionnaires, validation sheets, and student response questionnaires. Furthermore, at the develop stage, the product was validated by material experts, media experts, and language experts to determine the feasibility level of the media. The revised product was then tested through limited trials and field trials using a lesson study approach based on the plan, do, and see cycles. Finally, the disseminate stage was conducted through limited implementation and the distribution of the product to Biology teachers at the research school as a supporting learning medium.

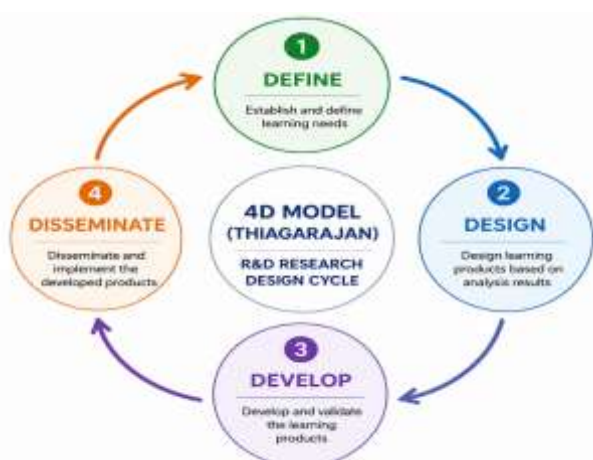


Figure 1. 4D method R&D cycle

The study was conducted from December 2025 to February 2026 at SMA Negeri 2 Marang Kayu as the location for product development and limited trials, while the effectiveness testing was carried out at SMA Negeri 1 Marang Kayu and SMA Negeri 3 Marang Kayu. The research population consisted of all tenth-grade students in the 2025/2026 academic year. The research sample was determined using a purposive sampling technique by considering the equivalence of academic ability, teaching teachers, and class characteristics. The sample consisted of four classes with a total of 48 students, divided into experimental and control classes. The experimental class utilized the AR-integrated Booklet and Flash Card media, whereas the control class employed conventional learning methods.

The research instruments included expert validation sheets, scientific literacy tests in the form of essay questions, learning motivation questionnaires, observation sheets, semi-structured interviews, and student response questionnaires using a Likert scale. Prior to implementation, all instruments were tested for content validity and reliability. Quantitative data were analyzed descriptively to determine the validity and

practicality levels of the media, while the effectiveness of the media was analyzed using normality tests, homogeneity tests, independent sample t-tests, and normalized gain (N-gain) calculations assisted by IBM SPSS Statistics. Meanwhile, qualitative data obtained through observations and interviews were analyzed using the interactive model developed by Matthew B. Miles, A. Michael Huberman, and Johnny Saldaña, which consists of data reduction, data display, and conclusion drawing.

Result and Discussion

The results of the needs analysis conducted at SMA Negeri 2 Marang Kayu revealed several issues in Biology learning, particularly on biodiversity topics. Students still experienced limitations in scientific literacy, especially in recognizing and identifying endemic flora and fauna of East Kalimantan related to their surrounding environment. In addition, students' learning motivation was relatively low because the learning process was still dominated by conventional methods that were less interactive and had not been able to provide engaging learning experiences.

Nevertheless, the school possessed supporting potential in the form of available technological infrastructure and students' high interest in the use of digital media for learning. These conditions became the basis for developing Augmented Reality (AR)-integrated Booklet and Flash Card media as a more innovative and contextual alternative learning medium. Before being implemented in the learning process, the developed product underwent a validation stage by experts to assess the feasibility of its conceptual, technical, and pedagogical aspects. The recapitulation of the media validation results is presented as follows.

The validation results indicated that the product was categorized as Highly Valid by all three experts, with percentages of 90.90% from the material expert, 86.90% from the media expert, and 91.07% from the language expert. The material expert validation emphasized the accuracy of the biodiversity content and its relevance to endangered endemic flora and fauna of East Kalimantan, while also confirming the suitability of the material with the curriculum. The media expert provided suggestions regarding navigation, interactivity, and the suitability of the design with the cognitive level of senior high school students, while also confirming the technical strengths of the product, such as accessibility and stability. Meanwhile, the language expert reinforced the contextualization of local issues and the integration of scientific literacy values that were easily understood by students, using communicative language appropriate for the senior high school level.

Table 1. Results of Validation by Language, Material, and Media Experts

Validator	Maximum Score/Achievement Score	Validity Percentage (%)	Category	Comments and feedback
Linguist	51/56	91.07	Very Valid	The title's appeal, the questionnaire's instructions clear
Material and Teaching Equipment Expert	120/132	90.90	Very Valid	The depth of the quantitative data analysis activities
Media Expert	73/84	86.90	Very Valid	The Augmented Reality design in Flash Cards is still simple, and the layout and visual design are consistent

Based on the feedback obtained, substantial revisions were made to the product draft, particularly in the presentation of supporting data, the complexity of investigative tasks, and the addition of critical thinking skill assessment rubrics. These revisions specifically improved aspects that received lower scores during the validation process, such as optimizing media loading speed, clarifying work instructions, and strengthening quantitative data analysis activities. The revisions aimed to ensure that the product was not only scientifically accurate, but also pedagogically effective and relevant to students' daily lives, while being ready for further testing. This revision process was also accompanied by limited consultations with teachers to ensure that improvements in technical and pedagogical aspects were implemented in alignment with classroom learning needs.

One of the objectives of this study was to develop Augmented Reality-integrated Booklet and Flash Card media by incorporating issues related to the endemic flora and fauna of East Kalimantan in order to improve students' scientific literacy and learning motivation on biodiversity topics. One of the aspects evaluated in this study was the practicality of the Booklet and Flash Card media, which was measured through student response questionnaires using a 1–4 rating scale (Strongly Disagree to Strongly Agree). The questionnaire data were analyzed quantitatively and categorized based on predetermined criteria. The questionnaire data were collected from several trial stages, including limited trials (small-group classes) and dissemination stages conducted in several tenth-grade classes at SMAN 2 Marang Kayu. The average scores obtained at each stage are presented in the following table.

Table 2. Results of Analysis of Student Responses to Practicality

Trial Phase	Class	Number of Students	Average Score	Category
Trial 1	Experiment 1	20	2.9	Less Practical
Trial 2	Experiment 2	26	3.7	Very Practical
Trial 3	Experiment 3	32	3.5	Very Practical

Based on the table above, it can be seen that most trial stages were categorized as Highly Practical, with the highest average score reaching 3.7. However, during the initial trial stage (Product Trial 1), which involved one limited class, the Booklet and Flash Card media were still categorized as Less Practical, with an average score of 2.9. Based on the descriptive analysis of the questionnaire and observation data, the main obstacles identified at this stage included students' confusion in using the flash cards and scanning the barcodes provided on the flash cards, technical issues such as slow loading times, as well as students' perceptions that the level of task difficulty and the complexity of the instructional language were still relatively high. Based on the descriptive analysis of the questionnaire item data, the practicality assessment of the Booklet and Flash Card media was examined through three main dimensions: ease of use, utility and relevance to learning objectives, and overall practicality. In general, the majority of students provided positive responses in the

Agree to Strongly Agree categories toward the various aspects being measured.

These positive responses were primarily directed toward the attractiveness of the booklet and flash card displays, the clarity of the provided instructions, the ease of identifying flora and fauna, and the engaging visuals that aligned with students' learning styles in the digital era. However, during the initial trial stage, several significant obstacles were still identified. These challenges included students' confusion in using the flash cards, particularly among those who were not yet familiar with digital learning barcodes, technical issues such as slow access or error links, as well as some students' perceptions that the level of difficulty of the tasks in the student worksheets (LKPD) was still relatively high. Furthermore, trials were conducted to determine the effectiveness of the developed product in improving students' scientific literacy and learning motivation. The results of the effectiveness testing are presented in the following tables.

Table 3. Descriptive Statistics

Test	N	Minimum	Maximum	Mean	Std. Deviation	Variance
Scientific Literacy Pretest	78	33	80	57.63	10.37	107.61
Scientific Literacy Posttest	78	62	96	79.63	7.48	55.95
Learning Motivation Pretest	78	38	83	61.05	10.99	120.70
Learning Motivation Posttest	78	56	95	75.59	9.59	91.93

Based on Table 3, it was found that the total number of respondents involved in this study was 78 students. The descriptive statistical results indicated an improvement in students' scientific literacy and learning motivation after the implementation of Augmented Reality (AR)-integrated booklet and flash card media on biodiversity topics at SMA Negeri 2 Marang Kayu. For the scientific literacy variable, the pretest scores showed a minimum score of 33 and a maximum score of 80, with an average score of 57.63. The standard deviation value of 10.37 indicated that students' initial scientific literacy abilities were relatively varied. After learning using the developed media, the posttest scores increased, with a minimum score of 62 and a maximum score of 96, while the average score increased to 79.63. In addition, the standard deviation decreased to 7.48, indicating that students' scientific literacy abilities became more evenly distributed after the treatment was implemented. The decrease in variance from 107.61 to 55.95 also demonstrated that the differences in students' abilities became smaller after the learning process.

For the learning motivation variable, the pretest scores showed a minimum score of 38 and a maximum score of 83, with an average score of 61.05. The standard deviation value of 10.99 indicated that students' initial motivation levels were still varied. After the implementation of the AR-based booklet and flash card media, the posttest motivation scores increased, with the average score reaching 75.59, a minimum score of 56, and a maximum score of 95. The decrease in standard deviation to 9.59 and the variance value of 91.93 indicated that students' learning motivation not only improved but also became more homogeneous. Overall, the descriptive statistical results indicated that the AR-integrated booklet and flash card media had a positive impact on improving students' scientific literacy and learning motivation. The increase in posttest average scores for both variables demonstrated that the learning process became more effective, interactive, and engaging. The integration of AR technology into the learning media helped students understand biodiversity concepts more concretely and visually, thereby increasing student engagement in the learning process.

Table 4. Tests of Normality

Test	Kolmogorov-Smirnov ^a			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Science Literacy Pretest	0.09	78	0.18	0.99	78	0.48
Science Literacy Posttest	0.06	78	0.20*	0.99	78	0.73
Learning Motivation Pretest	0.09	78	0.19	0.98	78	0.29
Learning Motivation Posttest	0.05	78	0.20*	0.99	78	0.51

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

The normality test was conducted to determine whether the research data were normally distributed as a prerequisite for the use of parametric statistical analysis. In this study, the normality test was performed using the Kolmogorov-Smirnov test and supported by the Shapiro-Wilk test. Based on Table 5, the results of the normality test for the scientific literacy variable indicated that the pretest data obtained a Kolmogorov-Smirnov significance value of 0.18 and a Shapiro-Wilk significance value of 0.48. Therefore, the scientific literacy pretest data were considered normally distributed. Furthermore, the scientific literacy posttest data obtained a Kolmogorov-Smirnov significance value of 0.20 and a Shapiro-Wilk significance value of 0.73. These values were also greater than 0.05, indicating

that the scientific literacy posttest data were normally distributed.

For the learning motivation variable, the pretest data showed a Kolmogorov-Smirnov significance value of 0.19 and a Shapiro-Wilk significance value of 0.29. Since both values were greater than 0.05, the motivation pretest data were considered normally distributed. Meanwhile, the motivation posttest data obtained a Kolmogorov-Smirnov significance value of 0.20 and a Shapiro-Wilk significance value of 0.51. These results indicated that the motivation posttest data were also normally distributed because they met the significance criterion of greater than 0.05.

Overall, the results of the normality test indicated that all research data, both for the scientific literacy and learning motivation variables, were normally

distributed. This finding demonstrates that the research data met the normality assumption and were therefore appropriate for further parametric statistical analysis to determine the effectiveness of the use of Augmented

Reality (AR)-integrated booklet and flash card media in improving students' scientific literacy and learning motivation on biodiversity topics at SMA Negeri 2 Marang Kayu.

Table 5. Test of Homogeneity of Variances

Variable	Class	Levene Statistic	df1	df2	Sig.
Scientific Literacy Pretest	Class X-1 and X-4	0.00	1	44	0.97
	Class X-2 and X-4	0.15	1	50	0.70
	Class X-3 and X-4	2.44	1	56	0.12
Scientific Literacy Posttest	Class X-1 and X-4	1.01	1	44	0.32
	Class X-2 and X-4	0.02	1	50	0.89
	Class X-3 and X-4	1.58	1	56	0.21
Learning Motivation Pretest	Class X-1 and X-4	1.11	1	44	0.30
	Class X-2 and X-4	0.11	1	50	0.74
	Class X-3 and X-4	0.54	1	56	0.47
Learning Motivation Posttest	Class X-1 and X-4	3.89	1	44	0.06
	Class X-2 and X-4	3.45	1	50	0.07
	Class X-3 and X-4	0.07	1	56	0.79

The homogeneity test was conducted to determine whether the variance of data among the classes involved in the study was equal or homogeneous. This test employed Levene's test, with the criterion that the data are considered homogeneous if the significance value (Sig.) is greater than 0.05. Data homogeneity is important to ensure that any differences in the obtained results are caused by the treatment provided, namely the use of Augmented Reality (AR)-integrated booklet and flash card media, rather than differences in the initial characteristics among the groups. Based on Table 6, the results of the homogeneity test for the scientific literacy pretest variable showed that the comparison between classes X-1 and X-4 obtained a significance value of 0.97, classes X-2 and X-4 obtained 0.70, and classes X-3 and X-4 obtained 0.12. All of these significance values were greater than 0.05, indicating that the scientific literacy pretest data were homogeneous. This result demonstrates that the students' initial scientific literacy abilities across the classes were relatively similar before the treatment was administered.

For the scientific literacy posttest variable, the homogeneity test results showed a significance value of 0.32 for classes X-1 and X-4, 0.89 for classes X-2 and X-4, and 0.21 for classes X-3 and X-4. All significance values were greater than 0.05, indicating that the scientific literacy posttest data were also homogeneous. Thus, the improvement in students' scientific literacy outcomes after the learning process occurred under conditions of equal variance among the classes. Furthermore, for the learning motivation pretest variable, the significance values obtained were 0.30 for classes X-1 and X-4, 0.74 for classes X-2 and X-4, and 0.47 for classes X-3 and X-4. These values indicate that all learning motivation pretest data were homogeneous because the significance values were greater than 0.05. This finding suggests that the

students' initial motivation levels across the classes were relatively similar before the implementation of the AR-based learning media.

For the learning motivation posttest variable, the significance values obtained were 0.06 for classes X-1 and X-4, 0.07 for classes X-2 and X-4, and 0.79 for classes X-3 and X-4. All of these values were also greater than 0.05, indicating that the learning motivation posttest data were homogeneous. Therefore, it can be concluded that all research data had homogeneous variances and thus fulfilled the requirements for further parametric statistical analysis. These results strengthen the conclusion that the use of Augmented Reality (AR)-integrated booklet and flash card media can be objectively analyzed in improving students' scientific literacy and learning motivation on biodiversity topics at SMA Negeri 2 Marang Kayu.

The Independent Samples t-test was conducted to determine whether there were significant differences between the experimental class and the control class after the implementation of Augmented Reality (AR)-integrated booklet and flash card media on biodiversity topics at SMA Negeri 2 Marang Kayu. The test was performed on the variables of scientific literacy and learning motivation, with the criterion that if the significance value (Sig. 2-tailed) was less than 0.05, a significant difference existed between the two groups.

Based on Table 6, the results for the scientific literacy variable showed that the comparison between classes X-1 and X-4 obtained a significance value of 0.00 with a t-value of 5.19. Since the significance value was smaller than 0.05, this result indicated a significant difference between the two classes. The mean difference value of 12.95 demonstrated that the experimental class achieved higher scientific literacy outcomes than the control class.

Table 6. Independent Samples Test

Posttest	Levene's Test					t-test for Equality of Means			
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Science Literacy in Grades X-1 and X-4	1.01	0.32	5.19	44	0.00	12.95	2.50	7.93	17.98
Scientific Literacy in Grades X-2 and X-4	0.02	0.89	7.99	50	0.00	17.46	2.18	13.07	21.85
Scientific Literacy in Grades X-3 and X-4	1.58	0.21	10.17	56	0.00	18.62	1.83	14.96	22.29
Learning Motivation in Grades X-1 and X-4	3.89	0.06	3.95	44	0.00	10.99	2.79	5.37	16.60
Learning Motivation in Grades X-2 and X-4	3.45	0.07	4.46	50	0.00	11.04	2.48	6.06	16.01
Learning Motivation in Grades X-3 and X-4	0.07	0.79	7.72	56	0.00	15.79	2.05	11.70	19.89

In the comparison between classes X-2 and X-4, the significance value obtained was 0.00 with a t-value of 7.99 and a mean difference of 17.46. These findings indicated that the use of AR-based learning media had a significant effect on improving students' scientific literacy. Similarly, in the comparison between classes X-3 and X-4, the significance value obtained was 0.00 with a t-value of 10.17 and a mean difference of 18.62. These values indicated that the experimental class had significantly better scientific literacy abilities than the control class after the treatment was administered.

For the learning motivation variable, the test results between classes X-1 and X-4 showed a significance value of 0.00 with a t-value of 3.95 and a mean difference of 10.99. These results indicated a significant difference in learning motivation between the two classes. Furthermore, the comparison between classes X-2 and X-4 obtained a significance value of 0.00 with a t-value of 4.46 and a mean difference of 11.04, while the

comparison between classes X-3 and X-4 obtained a significance value of 0.00 with a t-value of 7.72 and a mean difference of 15.79. All results demonstrated that the experimental classes had higher levels of learning motivation compared to the control class.

Overall, the results of the Independent Samples t-test indicated significant differences between the experimental and control classes in both scientific literacy and learning motivation variables. These findings suggest that the use of Augmented Reality (AR)-integrated booklet and flash card media was effective in improving students' scientific literacy and learning motivation on biodiversity topics. The integration of AR technology was able to create a more interactive, engaging, and contextual learning experience, enabling students to understand the material more easily and become more motivated to participate in the learning process.

Table 7. N-Gain Values of Environmental Literacy and Critical Thinking Indicators

Variable	Indicators	Class X-1	Class X-2	Class X-3	Class X-4
Scientific Literacy	Explaining Phenomena	0.8	0.6	0.7	0.8
	Evaluating	0.8	0.5	0.6	0.7
	Interpreting Data	0.8	0.4	0.7	0.6
Scientific Literacy	Persistence	0.8	0.7	0.5	0.5
	Activity	0.9	0.8	0.6	0.5
	Interest	1.0	0.5	0.6	0.6

Based on Table 8, the N-gain values for each indicator showed that the use of Augmented Reality (AR)-integrated booklets and flash cards resulted in positive improvements in students' scientific literacy and learning motivation on biodiversity topics at SMA Negeri 2 Marang Kayu. Overall, most indicators were categorized as moderate to high, indicating that the developed learning media provided students with a more interactive and meaningful learning experience.

For the scientific literacy variable, the "Explaining Phenomena" indicator showed the highest and most consistent improvement across all classes. Classes X-1 and X-4 achieved N-gain values of 0.8, which were categorized as high, while classes X-2 and X-3 obtained scores of 0.6 and 0.7, respectively. These results indicate that the integration of three-dimensional visualization through AR technology significantly helped students understand and explain biodiversity phenomena more

concretely. Interactive visual media enabled students to observe learning objects more realistically, thereby facilitating the understanding of abstract biological concepts.

For the "Evaluating" indicator, the N-gain values ranged from 0.5 to 0.8. Class X-1 achieved the highest score of 0.8, while the other classes were categorized within the moderate to high range. These findings suggest that the use of AR-based booklets and flash cards improved students' abilities to analyze information, compare concepts, and evaluate issues related to biodiversity. Furthermore, the presentation of materials connected to the surrounding environmental context made it easier for students to understand the application of scientific concepts in everyday life. Meanwhile, for the "Interpreting Data" indicator, the N-gain values ranged from 0.4 to 0.8. Class X-1 obtained the highest score of 0.8, while class X-2 achieved the lowest score of 0.4, which still fell within the moderate category. Nevertheless, overall, these results indicate that the developed learning media were able to help students read, understand, and interpret scientific data. The integration of contextual information and AR visualization encouraged students to become more active in processing information and enhanced their critical thinking skills.

For the learning motivation variable, the "Interest" indicator showed significant improvement, particularly in class X-1, which achieved an N-gain score of 1.0 categorized as high. These results indicate that the use of AR technology provided a unique appeal to students, making learning more enjoyable and less monotonous. The use of interactive media increased students' curiosity and enthusiasm in learning biodiversity topics.

The "Activity" indicator also showed substantial improvement, with scores ranging from 0.5 to 0.9. Class X-1 achieved the highest score of 0.9, while class X-2 obtained 0.8. These findings indicate that the use of flash cards and AR technology created more active learning interactions between students and teachers. Students became more engaged in discussions, observations, and exploration activities during the learning process. For the "Persistence" indicator, the N-gain scores ranged from 0.5 to 0.8, which were categorized as moderate to high. This indicates that the developed learning media helped students maintain focus and consistency in participating in learning activities and completing assigned tasks. Overall, the results presented in Table 8 confirm that AR-integrated booklets and flash cards were not only effective in improving student learning outcomes, but also in developing important indicators of scientific literacy and learning motivation. The use of AR-based media provided a more innovative, contextual, and interactive learning experience, making

it highly relevant for Biology instruction, particularly on biodiversity topics at SMA Negeri 2 Marang Kayu.

The findings of this study demonstrate that the integration of Augmented Reality technology into booklets and flash cards can create more engaging and student-centered learning experiences. AR media provide visual and interactive experiences that help students understand abstract concepts more concretely. In biodiversity topics, three-dimensional visualizations of flora and fauna objects enable students to observe the characteristics of organisms and the relationships among ecosystem components more easily. Augmented Reality is known as an effective learning medium because it can harmoniously integrate the real world with the virtual world. AR-based learning is an active learning method that facilitates the transfer of acquired information into long-term memory. Furthermore, AR is recognized as a rapidly developing technology with significant potential for application across various levels of education and diverse fields of study (Faria & Miranda, 2024). This supports the improvement of students' scientific literacy skills, particularly in explaining phenomena, evaluating information, and interpreting scientific data. In addition to improving cognitive aspects, the use of AR-based media also had a positive impact on students' affective aspects. Learning activities that combined digital technology with exploratory experiences increased students' interest, attention, and active participation during the learning process. Students became more motivated because the learning process felt more modern, enjoyable, and aligned with current technological developments. Direct interaction through flash cards and AR displays also helped create a collaborative learning atmosphere, enabling students to participate more actively in discussions and ask questions. AR technology can provide highly interactive experiences, thereby creating more authentic learning activities and interactions (Tarigan et al., 2023).

The findings of this study are consistent with various previous studies stating that the use of AR-based learning media can improve students' conceptual understanding, critical thinking skills, and learning motivation. AR technology is capable of integrating real and virtual environments simultaneously, thereby making the learning process more contextual and meaningful. Therefore, AR-integrated booklets and flash cards can serve as an effective and innovative alternative learning medium to support Biology instruction at the senior high school level, particularly for topics requiring high levels of visualization, such as Biodiversity.

Conclusion

Based on the development process, validation, trials, and data analysis conducted at SMA Negeri 2 Marang Kayu, it can be concluded that the Augmented Reality (AR)-integrated Booklet and Flash Card media possessed a very high level of validity and were feasible for use in Biology learning, particularly on biodiversity topics. This was demonstrated by the expert validation results, which included scores of 96% from the language expert, 90% from the material expert, and 87% from the media expert. These findings indicate that the product was conceptually and technically feasible and capable of presenting accurate 3D object visualizations in the learning process. In addition, the developed media were categorized as highly practical based on students' responses in the experimental classes X-2, X-3, and X-4. This practicality was reflected in the ease of media use, clear AR navigation, and learning instructions that were easy to understand both independently and during group activities. The results of the study also demonstrated that the use of AR-integrated Booklet and Flash Card media was significantly effective in improving students' scientific literacy and learning motivation. This was evidenced by the t-test results, which showed a significance value of 0.000 (< 0.05), accompanied by an increase in the average scientific literacy score from 57.63 to 79.63 and an increase in learning motivation from 61.05 to 75.59. The N-Gain improvement scores were categorized as moderate to high, with several learning interest indicators even achieving perfect scores in certain classes.

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Author Contributions

Umi Khusna conceptualized the research idea, designed of methodology, management and coordination responsibility; Makrina Tindangen, and Taufan P Daru, H.M Amir M, Sukartiningsih, Sonja Verra Tinneka L analyzed data, conducted a research and investigation process; conducted literature review and provided critical feedback on the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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