

Development of an Augmented Reality Book to Enhance Elementary School Students' Science Literacy

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Abstract

The persistence of minimal scientific literacy among elementary students, coupled with a reliance on traditional instructional media, underscores the necessity for more engaging learning resources. This study designed and evaluated an Augmented Reality Book intended to foster scientific literacy skills in primary school settings. Employing a Research and Development (R&D) design via the Plomp framework, the investigation progressed through the preliminary research, prototyping, and assessment phases. A sample of 30 fourth-grade learners was recruited using purposive sampling. Data collection encompassed observation protocols, teacher/student interviews, perception questionnaires, documentation, and scientific literacy assessments. Analytical methods included descriptive statistics, Normalized Gain (N-Gain) calculations, paired-sample t-tests, and qualitative evaluation. Findings revealed that: 1) expert evaluations yielded a 94.33% mean feasibility score; 2) student feedback averaged 90%, denoting an exceptionally high level of practicality; and 3) the media significantly enhanced learners' scientific literacy, demonstrated by a mean N-Gain of 0.7720 and statistically significant t-test outcomes ($p < 0.05$). Ultimately, the developed Augmented Reality Book stands as a valid, practical, and highly impactful instructional tool for cultivating primary school scientific literacy.

Keywords: *Augmented Reality Book, Scientific Literacy, Science*

Abstrak

Masih terbatasnya tingkat literasi sains murid sekolah dasar serta tingginya ketergantungan pada media pembelajaran konvensional mendorong perlunya inovasi sarana belajar yang interaktif. Penelitian ini berfokus pada pengembangan media *Augmented Reality Book* guna mengoptimalkan kemampuan literasi sains pada tingkat sekolah dasar. Menggunakan pendekatan *Research and Development* (R&D) yang mengacu pada model pengembangan Plomp, proses penelitian meliputi tiga tahapan utama: *preliminary research*, *prototyping stage*, dan *assessment phase*. Subjek penelitian melibatkan 30 siswa kelas IV yang ditentukan melalui *purposive sampling*. Pengumpulan data dilaksanakan lewat teknik observasi, wawancara, penyebaran angket, dokumentasi, serta tes pengukur literasi sains. Data yang diperoleh kemudian diolah menggunakan teknik statistik deskriptif, indeks N-Gain, pengujian *paired sample t-test*, dan analisis kualitatif. Hasil riset mengindikasikan bahwa: 1) produk *Augmented Reality Book* memperoleh skor kelayakan rata-rata sebesar 94,33% dari para ahli; 2) tingkat kepraktisan media mencapai kriteria sangat tinggi berdasarkan respons siswa sebesar 90%; serta 3) media terbukti efektif mendongkrak literasi sains siswa dengan perolehan N-Gain 0,7720 dan nilai signifikansi *t-test* ($p < 0,05$). Berdasarkan hasil tersebut, *Augmented Reality Book* yang dikembangkan teruji valid, praktis, dan efektif sebagai media pendukung literasi sains di sekolah dasar.

Kata kunci: *Augmented Reality Book, Literasi Sains, IPAS*



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INTRODUCTION

The development of science, technology, and information flows in the 21st century has shifted existing educational paradigms. This paradigm, which was originally oriented toward knowledge mastery, has moved toward the development of competencies that enable students to think critically, solve problems, collaborate, and make decisions based on scientific evidence. According to the Programme for International Student Assessment (PISA) framework, "scientific literacy is an individual's capacity to engage with science-related issues as a reflective citizen through three key competencies: explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and scientific evidence". Strengthening scientific literacy at the elementary school level is crucial because it not only contributes to the mastery of scientific concepts but is also closely linked to the development of critical thinking and problem-solving skills, which are core competencies in 21st-century learning (Apriliana & Anggrella, 2024; Daga et al., 2022).

Ideally, science learning in elementary schools should not only focus on conceptual mastery, but also facilitate students in developing the ability to explain phenomena scientifically, evaluate and design inquiries, and interpret data and scientific evidence in various everyday contexts (OECD, 2023). In line with this, the Educational Process Standards in Indonesia emphasize that learning must be student-centered, consider student characteristics, and be designed to develop competencies optimally through effective, contextual, and meaningful learning processes (Permendikbudristek, 2022). Therefore, Natural and Social Sciences (IPAS) learning in elementary schools is expected to foster students who possess scientific and critical thinking skills and are capable of applying scientific knowledge to solve various real-world problems (Habsari et al., 2026; Nur Janah et al., 2024).

Although strengthening scientific literacy has become a focal point in 21st-century education, various studies indicate that the scientific literacy skills of elementary school students in Indonesia remain low. The research findings by Utami et al. (2022), show that most students are not yet able to connect scientific concepts with everyday phenomena, particularly regarding scientific process and context aspects. Similarly, Ulumiyah et al. (2022) state that elementary students' scientific literacy skills are still dominated by nominal and functional literacy levels, whereas conceptual and multidimensional literacy levels remain relatively low. Furthermore, Yasa et al. (2022), reported that the implementation of the Scientific Literacy Movement (*Gerakan Literasi Sains*) in elementary schools has not functioned optimally due to limitations in utilizing learning resources, instructional media, and learning activities that train students' scientific thinking skills. These findings demonstrate that low scientific literacy is not merely caused by a lack of conceptual mastery, but is also tied to learning processes that do not fully enable students to actively and contextually develop scientific thinking skills.

This condition of low scientific literacy aligns with field observations. Based on observations and interviews with elementary school classroom teachers, current IPAS learning processes are still dominated by conventional media, namely two-dimensional (2D) printed textbooks and chalkboards. Existing media are unable to dynamically and visually represent abstract science concepts, making it difficult for students to grasp topics that require spatial visualization or complex process flows. Additionally, interviews revealed that instruction remains centered on lectures and reading summaries, lacking interactive inquiry activities that stimulate reasoning skills. The limitations of available learning resources prior to this development cause students to be passive, easily bored, and prone to rote memorization of terms without understanding the meaning behind scientific phenomena.

As an effort to overcome the limitations of conventional instructional media, the utilization of digital technology in education continues to grow, one of which is through the application of Augmented Reality (AR). Augmented Reality in science learning is capable of visualizing abstract concepts into representations that are more concrete, interactive, and easily understood by students. The results of a systematic literature review conducted by show that the utilization of AR in science learning provides a positive impact on conceptual understanding, learning motivation, student engagement, and scientific thinking skills because it is able to present more authentic and interactive visualizations (Rohmani et al., 2024; Zufahmi et al., 2025). One form of Augmented Reality implementation that fits the characteristics of elementary school learning is the Augmented Reality Book. According to Ibrahim et al. (2025), AR-integrated pop-up books substantially boost elementary students' understanding of ecosystem concepts due to their engaging and interactive nature. Thus, AR Books offer substantial utility not merely for concept acquisition, but also for cultivating primary learners' scientific literacy.

Based on these research findings, it can be concluded that incorporating Augmented Reality into science learning delivers a proven positive impact on student learning outcomes. Nevertheless, research specifically developing an Augmented Reality Book designed to facilitate the three PISA 2022 scientific literacy competencies—explaining phenomena scientifically, evaluating and designing scientific inquiry, and interpreting data and scientific evidence—remains relatively limited (Maisarah et al., 2024). Furthermore, most prior studies focused primarily on testing media effectiveness regarding learning outcomes or conceptual understanding, while product development fully integrated with scientific literacy indicators within Phase B IPAS learning under the *Kurikulum Merdeka* has not been comprehensively explored (Ibrahim et al., 2025; Zufahmi et al., 2025). Thus, this study offers novelty through the development of an Augmented Reality Book pedagogically designed around PISA 2022 scientific literacy indicators and tailored to the characteristics of Phase B IPAS learning in the *Kurikulum Merdeka*.

Addressing the decline in scientific literacy among Indonesia's young generation is critical. If this decline persists, students will remain trapped in rote-memorization patterns lacking reasoning capacity, leaving them cognitively unprepared to understand and respond to natural phenomena or surrounding environmental crises. Moreover, elementary science/IPAS classrooms will lag behind global demands for technological adaptation, widening the digital divide and impeding the achievement of national literacy targets mandated by the government.

Based on this background, this study aims to:

1. Analyze the development needs of an Augmented Reality Book to enhance students' scientific literacy in Phase B IPAS learning.
2. Evaluate the validity and feasibility of the Augmented Reality Book based on expert assessments (content, media, and language) as well as practitioner evaluations.
3. Test the effectiveness of using the Augmented Reality Book in enhancing elementary school students' scientific literacy.

METHOD

This research utilizes a Research and Development (R&D) method following the Plomp & Nienke (2013) model, which comprises three phases: preliminary research, prototyping stage, and assessment phase. In the initial phase, an analysis of needs, curriculum, learning media, and students' baseline scientific literacy condition was conducted. During the prototyping phase, an Assemblr Edu-powered Augmented Reality (AR) Book was designed and refined, undergoing evaluation by experts in content, media, and language alongside a small-scale trial. The assessment phase followed, where the developed product was implemented in the classroom to measure its practical

utility and educational efficacy. A purposive sample of 30 fourth-graders from SDN Karundang 1 Serang City participated in the study. Data collection employed observational methods, interviews, documental reviews, surveys, and pre-/post-intervention scientific literacy assessments. Qualitative insights were processed through Miles and Huberman (2014) framework involving data reduction, visual display, and conclusion formulation. Concurrently, quantitative metrics were evaluated using descriptive summary measures, Normalized Gain (N-gain) scores, Shapiro-Wilk normality testing, Levene's test for variance homogeneity, and a paired-sample t-test to evaluate changes in student performance pre- and post-AR Book deployment.

RESULT AND DISCUSSION

Preliminary Research

Preliminary Research aims to identify fundamental problems in the field through the analysis of curriculum, student characteristics, media needs, learning materials, and learning objectives. Based on interview results with fourth-grade teachers, the school has implemented the Kurikulum Merdeka, which emphasizes a student-centered approach. However, in practice, Natural and Social Sciences (IPAS) instruction remains conventional. Learning is dominated by one-way classical methods (teacher-centered). Teachers rely on static 2D textbooks due to time constraints in creating manual teaching aids. Consequently, fourth-grade students tend to be passive, bored, sleepy, and struggle to understand abstract concepts. This is reflected in an interview with a student who stated,

"Sometimes I get bored and dizzy when forced to read textbooks continuously. There are only a few pictures, and they are static. Sometimes I feel confused imagining what the pictures mean when the material is difficult."



Figure 1. Classical IPAS Learning Condition in Grade IV

Factual conditions in the field demonstrate a gap between the implementation of the *Kurikulum Merdeka*—which emphasizes student-centered learning—and actual IPAS learning practices that are still dominated by conventional approaches. Teacher-centered instruction causes students to remain passive and encounter difficulties in understanding abstract concepts. These findings align with Piaget's cognitive development theory, which explains that elementary school students are in the concrete operational stage, thereby requiring learning experiences that involve real objects or concrete visual representations to build conceptual understanding (Wardani, 2022).

Based on observations, the presence of a Smart TV in the classroom has not been utilized optimally as it is only used as a video player, resulting in limited student interaction. Additionally, the limited variety of instructional media causes students to become easily bored and less engaged during the learning process. According to Adhiah (2023), concrete and interactive learning media can help students construct concepts through direct learning experiences, thereby increasing engagement and conceptual understanding. The utilization of digital technology in learning should not

merely focus on device usage, but also on the media's capacity to facilitate students in actively constructing knowledge. These conditions indicate that technology utilization has not fully supported IPAS learning characteristics—which demand observing, exploring, and discovering concepts independently—and that learning needs lie not only in providing digital technology, but also in developing media capable of integrating printed learning resources with interactive digital visualizations.



Figure 2. Passive Smart TV Usage in the Classroom

Consequently, an Augmented Reality Book was chosen as the primary intervention, blending physical books with AR technology that generates interactive 3D objects upon page scanning. This dual format helps transform abstract knowledge into tangible visual forms, driving student engagement and supporting IPAS curriculum targets. This concept is validated by Alfarizi et al. (2024), who confirmed the role of AR media in strengthening conceptual understanding through interactive visual features, and Malihah (2024), who stressed that AR utilization in IPAS learning enhances student motivation, participation, and mastery of abstract topics.

The researcher also conducted a material analysis to formulate the learning competencies to be achieved and to facilitate the instructional design for implementing the Augmented Reality Book. The researcher conducted observations by analyzing Grade IV IPAS learning materials, selecting Chapter 1 regarding plants as the source of life on earth as the content for developing the Augmented Reality Book. Based on curriculum analysis, material analysis, and several formulated learning objectives, the researcher formulated one primary learning objective to be used in developing the Augmented Reality Book. The learning objective to be achieved is: through group discussion activities, students can correctly relate the structure of main plant body parts (roots, stems, leaves, flowers, fruits, and seeds) with their functions for survival. This objective serves as a behavioral change target and a directional guide for student learning.

Prototyping Stage

In the prototyping stage, an initial prototype of the Augmented Reality Book was developed as instructional media to enhance elementary school students' scientific literacy. Product development began with creating a storyboard as a media development reference. The Augmented Reality Book was structured systematically starting from the cover page, book identity, user guidelines, learning achievements, learning objectives, instructional materials, summary, reflection, student worksheets (LKPD), glossary, to author profile. Each material was equipped with illustrations, QR codes, and three-dimensional (3D) objects accessible via the Assemblr Edu application, allowing students to interact directly with the learned content. This aligns with Rosidah et al. (2025) who state that developing Augmented Reality-based media needs to begin with storyboard preparation and an iterative design process so that the resulting product aligns with user needs and is easier to refine during the validation stage.



Figure 3. Augmented Reality Book

After the initial prototype was developed, the product was validated by two media expert validators, two material expert validators, and two language expert validators. Validation was conducted to determine media feasibility prior to limited trial implementation. Media expert evaluation covered layout appearance, media presentation, and content compatibility. Based on validation results, the first validator provided a feasibility score of 95%, while the second validator provided 93%. Based on both expert evaluations, an average percentage of 94% was obtained, falling into the "Very Feasible" category. This finding aligns with research by Rahmah & Maarif (2025), suggesting that Augmented Reality-based learning media obtaining validation in the very feasible category indicates that the media has met design, functional, and content aspects, making it suitable for implementation.

Validation was also conducted on material aspects. Evaluated aspects included relevance, accuracy, and communicativeness of the developed AR Book media. Validation results showed that the first validator gave a score of 94%, while the second validator gave 96%, resulting in an average percentage of 95% categorized as "Very Feasible." This result supports research by Agusta (2022), indicating that material expert validation is a critical stage to ensure alignment between media content and learning objectives so that the media can effectively support the enhancement of students' scientific literacy.

Furthermore, language aspect validation was conducted to evaluate conciseness, communicativeness, and adherence to updated spelling rules (EYD) in the developed AR Book. Results showed that both validators provided a percentage of 94%, obtaining an average of 94% ("Very Feasible"). According to Setiawan et al. (2025), using communicative and easily understandable language is an essential component in developing Augmented Reality-based media because it directly affects media readability and students' conceptual understanding.

Table 1. Summary of Expert Validation Averages

Expert Validation	Average Feasibility Percentage	Feasibility Criteria
Media Expert	94%	Very Feasible
Material Expert	95%	Very Feasible
Language Expert	94%	Very Feasible

Overall, validation results indicate that the Augmented Reality Book met the criteria of being very feasible for use as learning media. Nevertheless, the validation process aimed not only to measure product feasibility, but also served as part of a formative evaluation to refine media quality prior to student implementation. This is supported by Rosidah et al. (2025), who explain that formative evaluation through expert

validation and prototype revision is an essential stage to produce media that is fully ready for classroom learning. However, unlike several studies focusing solely on media validity levels, Rohmah & Handayani (2022) emphasize that successful Augmented Reality media implementation is also influenced by teacher readiness, supporting devices, and learning environment conditions. Therefore, all feedback from validators served as the basis for revising Prototype I to produce a more optimal Prototype II.

Assessment Phase

To evaluate product efficacy in advancing students' scientific literacy according to the three primary PISA benchmarks, the assessment phase implemented a pretest-posttest research design alongside user feedback questionnaires to gauge media practicality. PISA's scientific literacy framework centers on three main competency domains (OECD, 2023). Analytical procedures in this stage integrated both descriptive and inferential statistical techniques carried out across sequential testing phases. Pretest and posttest results were analyzed descriptively and underwent prerequisite testing first to describe score distribution by calculating the mean, median, mode, standard deviation categorization, and Normalized Gain (N-Gain) calculation to measure the exact magnitude of students' scientific literacy increase. Based on testing across 30 respondents, the descriptive statistical analysis results for scientific literacy data are presented below.

Table 2. Descriptive Analysis Results

Statistical Parameter	Pre-test	Post-test
Mean	51.83	89.17
Median	52.00	90.00
Modus	52.00	91.00
Standar Deviasi	3.94	4.25
Minimum Score	44.00	79.00
Maximum Score	58.00	97.00

These data show that the mean score increased sharply from 51.83 (pretest) to 89.17 (posttest). The small standard deviation values (3.94 and 4.25) reflect that skill improvement occurred evenly across students. To facilitate observing the surge in student performance and comparing mean scores more concretely, the descriptive statistics above are also presented visually. The bar chart below illustrates the contrast between students' average pre-test and post-test achievements.

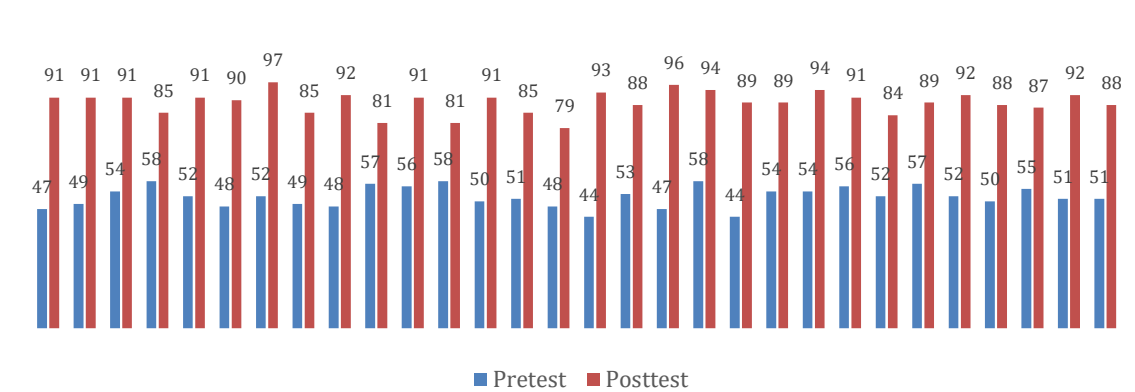


Figure 4. Pretest-Posttest Results

Based on the bar chart above, a clear visual contrast is observed regarding students' mean achievements before and after receiving learning treatment. Visually, the height difference in each bar provides direct, clear confirmation of a massive group performance improvement, demonstrating that the learning method or treatment applied in class was effective in significantly boosting students' Scientific Literacy skills. To determine the specific distribution of student capability levels, scores were categorized into three tiers (High, Medium, and Low) using a normal distribution reference based on Standard Deviation (SD). The summary table of student frequency distribution based on these categories is presented below.

Table 3. Summary of Categorization Results

Category (SD)	Number of Students (Pre-test)	Percentage (Pre-test)	Number of Students (Post-test)	Percentage (Post-test)
High	7 students	23,3%	5 students	16,7%
Medium	19 students	63,3%	21 students	70,0%
Low	4 students	13,3%	4 students	13,3%
Total	30 students	100%	30 students	100%

Based on the categorization summary table above, a shift in students' Scientific Literacy skill distribution is observed based on standard deviation benchmarks. At the pre-test stage, the majority of students were in the "Medium" category with 19 students (63.3%), followed by the "High" category with 7 students (23.3%), and the "Low" category with 4 students (13.3%). Although Standard Deviation (SD)-based categorization indicated a performance shift, this analysis does not reveal the magnitude of effectiveness or gain efficiency from pre-test to post-test for individual students. Therefore, to measure treatment effectiveness more accurately, further analysis was conducted using the Normalized Gain (N-Gain) test. The N-Gain analysis results are detailed below.

Table 4. N-Gain Results

Gain Index Indicator	Average Score	Effectiveness Classification
Average N-Gain Score	0.7720	High (Score Threshold ≥ 0.70)
Average N-Gain Percentage (%)	77.20%	Effective (Percentage Threshold $> 76\%$)

Based on the N-Gain calculation formula, an average N-Gain Score index of 0.7720 was obtained. Referring to classification criteria, this score falls into the High scale gain category (≥ 0.70). Furthermore, converting this value into percentage format yielded an average N-Gain Percentage of 77.20%. Referring to effectiveness interpretation criteria, a percentage exceeding 76% proves that the developed Augmented Reality Book learning media is categorized as highly Effective in increasing fourth-grade elementary students' scientific literacy.

Prior to hypothesis testing, prerequisite testing was conducted via normality tests to determine data distribution and Levene's homogeneity test to check variance equality, followed by a parametric paired-sample t-test to determine the statistical significance of differences in students' scientific literacy scores before and after using the Augmented Reality Book. The Shapiro-Wilk method was used for normality testing, yielding the following data.

Table 5. Normality Test Results

Data Group	Test Statistic	p-value (Sig.)	Analysis Conclusion
Pretest Science Literacy	0.9617	0.3419	Normally Distributed ($p > 0,05$)
Posttest Science Literacy	0.9525	0.1976	Normally Distributed ($p > 0,05$)

Statistical outputs from the Shapiro-Wilk test indicated p -values of 0.3419 and 0.1976 for pretest and posttest scores, respectively. Based on statistical decision criteria, because these values were consistently higher than 0.05, both datasets were confirmed to follow a normal distribution. Variance homogeneity was then evaluated, producing the data detailed below.

Table 6. Homogeneity Test Results

Variance Test Method	F-statistic Value	p-value (Sig.)	Analysis Conclusion
Levene's Test (Pretest vs Posttest)	0.0092	0.9241	Homogeneous Variance ($p > 0,05$)

Based on the Levene's Test output in the table above, an F-statistic value of 0.0092 was obtained with a significance value (p-value) reaching 0.9241. Referring to statistical decision-making criteria, because the significance value far exceeded the minimum threshold ($0,9241 > 0,05$), it is concluded that pretest and posttest variances of student scientific literacy were homogeneous. With normality and homogeneity tests satisfied, primary prerequisites for parametric statistical analysis were fully met. The subsequent step was hypothesis testing, conducted to determine whether observed mean differences were statistically significant or occurred merely by chance. Therefore, to empirically prove the research hypothesis regarding treatment effectiveness, a Paired Sample t-Test was conducted as detailed below.

Table 7. T-Test Results

Group Analysis	Calculate d t-value	df	p-value (2-tailed)	Hypothesis Conclusion
Pretest - Posttest Science Literacy	-31.5438	29	0.0000	H1 Accepted (Significant)

The paired-sample t-test yielded a t -value of -31.5438 ($p = 0.0000$). Given that the resulting p-value was significantly lower than the critical alpha level of 0.05, H_0 was rejected and H_1 was accepted. This statistical outcome confirms empirically that the integration of the Augmented Reality Book drives a marked improvement in fourth-graders' scientific literacy skills.

The enhancement in students' scientific literacy following the use of the Augmented Reality Book indicates that the developed media facilitated students in understanding abstract IPAS concepts through interactive 3D visualizations. These visualizations provided more concrete learning experiences so that students did not merely memorize concepts, but were also able to connect concepts with observed phenomena. This is reflected in the N-Gain score of 0.7720 (categorized as high), indicating that the AR Book was effective in improving students' scientific literacy. This finding aligns with Agusta (2022), who stated that Augmented Reality media positively

influences scientific literacy and metacognitive skills by presenting concepts contextually and interactively. Results are also supported by Agustin et al. (2025), who argued that science literacy-oriented Augmented Reality learning media assists students in understanding abstract concepts via concrete visual delivery, making the learning process more meaningful. Additionally, Rohman et al. (2026), explained that integrating Augmented Reality technology in IPAS learning contributes to scientific literacy enhancement through active, contextual, and student-centered experiences. Therefore, the scientific literacy increase in this study shows that AR Book development serves not only as visual media, but also as a tool supporting students in building deeper scientific understanding. To reinforce quantitative test results, supporting data capturing student perceptions, interest, and operational experiences during learning are presented below.

Table 8. Student Response Questionnaire Results

No	Evaluation Aspect	Percentage	Category
1	Visual Appearance	89.3%	Very Good
2	Material Quality	90.7%	Very Good
3	Utility / Benefits	90.0%	Very Good
Average		90.0%	Very Good

Besides effectively increasing scientific literacy, the developed AR Book demonstrated a very high level of practicality. This is evidenced by student questionnaire responses averaging 90.0%, supported by visual appearance (89.3%), material quality (90.7%), and utility aspects (90.0%), placing the media in the "Very Practical" category. This high practicality level indicates that students could easily operate the media, understand usage instructions, and enjoy a more engaging learning experience compared to conventional textbooks. This finding aligns with Yoga & Tegeh (2024), who stated that 3D visual Augmented Reality media increases student interest and conceptual understanding by delivering interactive learning experiences. These results are further strengthened by Rahmawati et al. (2024), who explained that Augmented Reality media receives positive student responses due to its capacity to enhance student engagement, learning motivation, and material comprehension ease. The high practicality of the AR Book in this study demonstrates that the developed media is not only feasible for IPAS instruction, but also capable of creating effective, engaging learning experiences tailored to elementary school student characteristics (Damanik & Fajari, 2025; Fajari & Meilisa, 2022; Rahmatin et al., 2025).

CONCLUSION

In conclusion, through the application of Plomp's development framework involving preliminary research, prototyping, and assessment phases, this research successfully created an Augmented Reality Book (AR Book) centered on plant ecosystems that was confirmed to be valid, practical, and highly impactful for elevating primary students' scientific literacy. Expert evaluations yielded a mean feasibility score of 94.33%, which falls into the "Very Feasible" classification. Classroom implementation involving 30 fourth-grade pupils revealed a substantial enhancement in scientific literacy skills, evidenced by a mean score rise from 51.83 on the pre-test to 89.17 on the post-test, an N-Gain index of 0.77 in the high category, and paired-sample t-test calculations indicating a statistically significant difference. These outcomes demonstrate that embedding Augmented Reality capabilities into physical textbooks is capable of fostering an IPAS learning environment that is markedly more interactive, contextual, and student-centered. Nevertheless, this investigation is restricted by its application in a single educational institution, a small sample cohort, and a single instruction unit, meaning the findings cannot yet be broadly generalized. Additionally, the study did not evaluate long-

term impacts regarding knowledge retention. Future research should involve larger student samples, span across multiple grade levels, and develop AR Books for alternative IPAS topics while accounting for school infrastructure readiness.

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