



Augmented Reality-Based Student Book Using Project-Based Learning: Enhancing Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking

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ABSTRACT

Purpose - This research aims to develop an Augmented Reality-based student book using Project-Based Learning (PjBL) for science learning to enhance the 6C competencies.

Methodology - This study is a research and development (R&D) study using the ADDIE model. The implementation involved 22 fifth-grade students at SD Negeri 95/IV Jambi City, Indonesia. The effectiveness test was conducted over three classroom action research cycles, each consisting of six meetings. The research instruments consisted of: 1) interview and observation guidelines, 2) validation questionnaires, 3) teacher and student response questionnaires, 4) 6C observation sheets, and 5) pretest and posttest. Data analysis included validity, practicality, 6C competencies, and critical thinking using N-Gain analysis.

Findings - The study's results indicate that the developed Augmented Reality (AR) student book based on Project-Based Learning (PjBL) is valid, practical, and effective for fifth-grade science learning. Validation scores were 4.37 for media, 4.67 for material, and 4.53 for language, all categorized as very valid. Practicality scores were 4.67 from teachers and 4.35 from students, both of which were categorized as very practical. The 6C competency scores increased from 38.26% in Cycle I to 52.90% in Cycle II and 75.46% in Cycle III. Students' critical thinking skills also improved, with N-Gain scores increasing from 0.46 to 0.51 and 0.55 across the three cycles.

Contribution - The practical product of this research supports teachers in implementing interactive learning to develop students' 6C competencies and critical-thinking skills.

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INTRODUCTION

Education plays an essential role in developing students' knowledge, attitudes, skills, and character (Sihombing, A., et.al, 2024). In the 21st century, educational demands have become increasingly complex, as students are expected to possess competencies in technology, information, learning, innovation, and life and career skills. (Goulart, V. G., et.al, 2022). Therefore, learning needs to be oriented not only toward the acquisition of academic knowledge but also toward the development of comprehensive competencies that prepare students to respond to contemporary challenges (George, 2023). In Indonesia, the Merdeka Curriculum emphasizes holistic student development, including critical thinking, creativity, collaboration, communication, character, and citizenship (Zen, 2026). These competencies are commonly referred to as the 6C competencies: character, citizenship, critical thinking, creativity, collaboration, and communication. The integration of 6C competencies into learning is considered relevant for developing students who are academically capable while also demonstrating strong character, critical thinking, creativity, collaboration, and effective communication (Palinussa, A. L., et.al, 2025).

Science learning at the elementary school level provides an important context for developing these competencies, as students are expected to understand scientific concepts and apply knowledge to real-life situations. Learning that actively engages students in investigation, problem-solving, collaboration, and communication can provide opportunities to develop 6C competencies simultaneously (Amelia et al., 2026). However, science concepts that involve abstract structures and processes may be difficult for elementary students to understand when presented only through conventional explanations (Erwis et al., 2024). Learning media can therefore support students by making abstract concepts more concrete and meaningful. (Tegeh et al., 2020). Previous research has also demonstrated that Project-Based Learning (PjBL) can improve students' thinking skills by involving them in investigation, collaboration, and problem-solving activities (Elfira & Santosa, 2023). PjBL also encourages students' motivation, participation, and creativity, which can contribute to improved learning outcomes (Setiawan & Arip, 2023).

One topic that requires appropriate learning support is the human organ system. The concepts in this topic involve internal structures and processes that cannot be directly observed by students. Consequently, students may struggle to develop a meaningful understanding of the material when learning is dominated by teacher-centered instruction. Augmented Reality (AR) provides an opportunity to overcome this limitation by presenting digital objects in three-dimensional form within the real environment (Xiong et al., 2021). Through smartphones or tablets, AR can visualize objects that are otherwise difficult to observe directly, potentially making abstract scientific concepts more concrete, interactive, and engaging (Mansour et al., 2025). The use of AR as a learning medium is therefore relevant to elementary science learning because it can provide students with more immersive experiences and support conceptual understanding (Lampropoulos, 2024).

However, the use of technology alone does not necessarily guarantee the development of comprehensive 6C competencies (Wijayati et al., 2025). AR needs to be integrated into an appropriate learning model that provides students with opportunities to investigate, create, collaborate, communicate, and solve problems (Villanueva, A., et.al, 2020). PjBL is relevant in this context because it engages students in authentic projects through stages of planning, designing, implementing, and presenting products (Al-qoyyim & Kurniawan, 2025). These activities provide opportunities for students to practice communication when presenting ideas, collaboration when working in groups, character through responsibility for project completion, and creativity and critical thinking when developing solutions to problems (Lindra et al., 2025). Thus, the integration of AR with PjBL has the potential to create a learning environment that combines interactive visualization with active and student-centered learning.

Despite the potential of AR and PjBL, learning practices at the elementary school level still face challenges in implementing innovative and integrated learning media. Based on observations conducted on February 27, 2026, at SD Negeri 95/IV Jambi City, only 33.3% of Grade V students achieved mastery on the initial cognitive diagnostic assessment of the 6C competencies. Classroom learning was still predominantly teacher-centered and relied on conventional lecture methods. Students had difficulty understanding the human organ system,

while their critical thinking, problem-solving, creativity, collaboration, and communication skills remained limited. Citizenship-related attitudes, such as social awareness and responsibility, as well as character aspects such as discipline, responsibility, and honesty, also required further development. Although supporting facilities were available at the school, the utilization of innovative learning media remained limited.

These conditions indicate a gap between the demands of 21st-century learning and the learning practices implemented in the classroom. Previous studies have discussed PjBL as a strategy for developing students' thinking skills and AR as a medium for presenting abstract concepts; however, studies that integrate AR into PjBL specifically to develop the comprehensive 6C competencies of elementary students in science learning remain limited. Furthermore, there is a need for learning materials that integrate AR into structured student activities rather than merely using it as an additional visualization tool. This gap highlights the importance of developing learning materials that combine technological visualization with project-based activities and explicit opportunities to develop 6C competencies.

The novelty of this study lies in the development of an AR-based student book integrated with PjBL to support the development of six competencies: character, citizenship, collaboration, communication, creativity, and critical thinking in elementary science learning on the human organ system. The integration of AR enables students to visualize abstract scientific concepts interactively. At the same time, PjBL provides structured opportunities to investigate problems, develop project products, collaborate, communicate scientific ideas, and demonstrate responsible behavior. Using the ADDIE model within a Research and Development (R&D) framework, this study aims to develop an AR-based PjBL student book for Grade V elementary science learning and examine its feasibility and effectiveness in improving students' 6C competencies.

METHODOLOGY

Research Design

This research employed an R&D approach using the ADDIE development model, which consists of five stages: Analysis, Design, Development, Implementation, and Evaluation (Sugiyono, 2023). The ADDIE model was selected because it provides a systematic framework for developing educational products through needs analysis, product design, development, implementation, and evaluation. The developed product was an AR-based student book integrated with PjBL to provide interactive learning experiences and to support the development of the 6C (Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking) competencies.

The first stage was Analysis. This stage aimed to identify the actual conditions, learning needs, student characteristics, 6C competencies, and technological conditions relevant to the development of the AR student book. Curriculum analysis was conducted by examining the learning curriculum implemented at SD Negeri 95/IV Jambi City. The school uses the Merdeka Curriculum. Needs analysis was conducted through teacher interviews and observations to identify problems encountered in science learning, the use of learning media, and the need for interactive and contextual learning materials. Student analysis included students' cognitive abilities, interests, motivation, attitudes, and 6C competencies. The technology analysis examined the availability of digital devices and internet access, as well as students' and teachers' ability to use technology for learning.

The second stage was Design. At this stage, the researcher designed the structure and content of the AR-based student book in line with the learning objectives and outcomes. The design included selecting and organizing learning materials, learning activities, project activities, evaluation questions, and AR components. A storyboard was prepared to determine the layout, colors, typography, illustrations, and sequence of the book. The product structure included the cover, preface, table of contents, learning outcomes, learning objectives, learning materials, illustrations, AR features, project activities, and evaluation. The PjBL syntax was integrated into the learning activities through fundamental questions, project planning, scheduling, project implementation and monitoring, testing project results, and evaluation of learning experiences.

The third stage was Development. The product design was developed into an AR-based student book using Assemblr EDU. The AR features were integrated into selected learning materials to provide three-dimensional and interactive visualizations. The AR content could be accessed via links or by scanning barcodes with Google Lens on smartphones, tablets, or computers equipped with a webcam. The initial product was then evaluated by three experts: a media expert, a materials expert, and a language expert. The experts assessed the product's quality and suitability and provided comments and suggestions for revision. The product was revised based on the results of expert validation before implementation.

The fourth stage was Implementation. The revised AR student book was implemented in fifth-grade science learning at SD Negeri 95/IV Jambi City. The implementation involved 22 fifth-grade students and was conducted over three classroom action research cycles, each consisting of six meetings. Each cycle consisted of planning, action, observation, and reflection. During the learning activities, students worked individually and in groups using the AR student book and completed project-based activities following the PjBL syntax. The teacher acted as a facilitator, while students actively observed, discussed, divided tasks, completed projects, and presented their results. Students' 6C competencies were observed during the learning process. Pretests and posttests were also administered to measure students' critical thinking skills. Teacher and student responses were collected to determine the practicality of the developed product.

The fifth stage was Evaluation. Evaluation was conducted throughout the ADDIE process via formative evaluation and at the end of implementation to assess the quality of the developed product. The final evaluation considered the validity, practicality, development of 6C competencies, and improvement of students' critical thinking skills. Reflection results from each classroom action research cycle were used to identify weaknesses in the learning process and determine improvements for the subsequent cycle.

Participant

The study involved 22 fifth-grade students at SD Negeri 95/IV Jambi City, Indonesia. The students participated in implementing the AR-based student book across three classroom action research cycles. Three experts were also involved in the development stage to validate the product: one media expert, one materials expert, and one language expert. The students participated in learning activities, completed pretests and posttests, 6C competency observations, and student response questionnaires. At the same time, the teacher provided practitioner responses regarding the practicality of the developed product.

Data Collection

Data were collected using interviews, observations, questionnaires, tests, and documentation. During the analysis stage, interviews and observations were conducted to identify curriculum conditions, learning needs, student characteristics, existing learning media, and the use of technology in science learning. The results of this stage were used as the basis for designing the AR-based student book. During the development stage, data were collected through validation questionnaires completed by media, material, and language experts. The validation results were used to assess the product's validity and identify areas requiring revision.

During the implementation stage, observations were conducted to record students' 6C competencies during learning activities. Teacher and student response questionnaires were administered after the AR student book was used to assess its practicality. Pretests were administered before the learning activities, and posttests after them, to measure changes in students' critical thinking skills. Documentation was also collected to support the research process and implementation data.

The classroom implementation followed three cycles. Each cycle consisted of planning, action, observation, and reflection. Reflection at the end of each cycle was used to identify problems and improvements needed for the following cycle. Thus, the implementation consisted of six meetings.

Instrument

The research instruments consisted of interview guidelines, observation sheets, validation questionnaires, teacher and student response questionnaires, 6C observation sheets, and pretest-posttest questions. The validation questionnaires were used by media, material, and language experts to assess the quality of the developed AR student book. The validation used a five-point scale ranging from 1 to 5. The media validation assessed the presentation and technical aspects of the AR student book, the material validation assessed the accuracy and suitability of the learning content, and the language validation assessed the clarity and appropriateness of the language used.

The teacher and student response questionnaires were used to assess the product's practicality. The questionnaires used a five-point Likert scale consisting of Strongly Agree (5), Agree (4), Moderately Agree (3), Disagree (2), and Strongly Disagree (1).

The 6C observation sheet was used to assess Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking during the learning process. Character included responsibility, honesty, discipline, respect, and caring. Citizenship included environmental concern, social responsibility, respect for others' opinions, and active participation. Collaboration included individual responsibility, group interaction, social skills, and group evaluation. Creativity was assessed through fluency, flexibility, originality, and elaboration in students' project products. Communication included the ability to express ideas clearly, listen actively, respond appropriately, and use communication media. Critical thinking was assessed through interpretation, analysis, evaluation, inference, explanation, and self-regulation.

The pretest and posttest were used to measure students' critical thinking skills before and after the implementation of the AR-based student book. The assessment was based on critical-thinking indicators: interpretation, analysis, evaluation, inference, explanation, and self-regulation.

Data Analysis

The data were analyzed using quantitative and qualitative approaches. Quantitative analysis was used to assess product validity, practicality, achievement of 6C competencies, and improvement in critical thinking skills. Qualitative analysis was used to analyze expert comments, suggestions, interview results, observation notes, and responses obtained during the development and implementation processes.

Validity Analysis

The validity of the AR-based student book was determined by assessments from media, material, and language experts using a five-point scale. The average scores were interpreted according to the following criteria.

Table 1. Validity Criteria

Average Score	Category
4.22–5.00	Very Valid
3.41–4.21	Valid
2.61–3.40	Fairly Valid
1.80–2.60	Less Valid
0–1.79	Very Little Valid

Practicality Analysis

Product practicality was determined based on teacher and student responses after using the AR-based student book. Responses were scored using a five-point Likert scale.

Table 2. Practicality Criteria

Average Score	Category
4.22–5.00	Very Practical
3.41–4.21	Practical
2.61–3.40	Fairly Practical
1.80–2.60	Less Practical
0–1.79	Very Little Practical

6C Competency Analysis

Students' 6C competencies were analyzed using percentage scores obtained from observation sheets. The percentage was calculated by dividing the total score obtained by the maximum possible score, then multiplying by 100%. The interpretation criteria are presented in Table 3.

Table 3. 6C Competency Criteria

Percentage	Category
81.25–100%	Very High
62.50–81.24%	High
43.75–62.49%	Moderate
25.00–43.74%	Low

The development of 6C competencies was examined across three cycles. The success criterion was achieved when students' 6C competencies increased in each cycle and reached at least the high category (62.50–81.24%).

Critical Thinking Analysis

Students' critical thinking skills were analyzed using N-Gain based on pretest and posttest scores. N-Gain was calculated using the following formula:

$$N\text{-Gain} = \frac{\text{Skor Posttest} - \text{Skor Pretest}}{\text{Skor Maksimal} - \text{Skor Pretest}}$$

The interpretation of N-Gain scores is presented in Table 4.

Table 4. N-Gain Criteria

N-Gain Score	Category
≥ 0.70	High
$0.30 < 0.70$	Medium
< 0.30	Low

The effectiveness criterion was achieved when the average N-Gain score reached at least the medium category.

Qualitative Data Analysis

Qualitative data obtained from interviews, observations, expert comments, suggestions, and documentation were analyzed through three stages: data reduction, data presentation, and conclusion drawing. The analysis was conducted throughout the research process to identify product weaknesses, implementation problems, and necessary improvements.

Data Triangulation

Data triangulation was conducted to strengthen the credibility of the research findings. Source triangulation involved teachers, students, and validators, while technique triangulation involved interviews, observations, questionnaires, tests, and documentation. Time triangulation was conducted across three implementation cycles consisting of six meetings.

Table 5. Data Triangulation

Type of Triangulation	Sources/Techniques	Purpose
Source	Teachers, students, validators	Compare information from different sources
Technique	Interviews, observations, questionnaires, tests, documentation	Verify findings using different data collection techniques
Time	Cycle I, Cycle II, Cycle III	Examine changes across implementation cycles

FINDINGS

This development research was conducted using the ADDIE development model, which consists of Analysis, Design, Development, Implementation, and Evaluation. The product developed is an Augmented Reality (AR)-based student textbook integrated with Project-Based Learning (PjBL) for Grade V elementary science learning. The textbook is designed to provide interactive learning experiences through AR technology while fostering students' development of the 6C (Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking) competencies.

Analysis

The analysis stage aimed to identify learning needs, curriculum requirements, student characteristics, technological readiness, and the initial condition of students' 6C competencies. The analysis included curriculum analysis, needs analysis, student characteristics, learning materials, 6C competencies, and educational technology. Based on curriculum analysis, the school has implemented the Merdeka Curriculum for Phase C. The developed textbook aligns with the learning outcomes of Grade V science, covering four main topics: human organ systems, ecosystems, energy, and the solar system. AR was selected to visualize scientific concepts that are difficult to observe directly, while PjBL was integrated to facilitate project-based learning experiences. Classroom observation revealed that science learning was still dominated by teacher explanations, discussions, and assignments. Existing teaching materials consisted mainly of text and static images, offering limited opportunities for students to observe, analyze, collaborate, and solve problems actively. The school already had supporting facilities such as Chromebooks, smartboards, and Wi-Fi; however, these technologies had not been used optimally in science instruction. Interviews with teachers confirmed that interactive digital teaching materials and AR had never been implemented in classroom learning. Teachers expressed the need for a learning resource that combines attractive visualizations, project activities, and technology integration to improve students' engagement and 6C competencies.

Student interviews indicated that many students had difficulty understanding abstract concepts, drawing conclusions, explaining ideas, and providing logical reasons. Students were more motivated when learning involved pictures, videos, practical activities, and collaborative projects rather than text-based instruction. These findings demonstrated the need for an interactive AR-based textbook integrated with PjBL. The initial analysis of 6C competencies showed that responsibility and collaboration had begun to develop, but communication, creativity, citizenship awareness, and critical thinking remained limited. Students rarely expressed opinions, created independent products, or analyzed problems critically, making these competencies important targets of the developed textbook.

Table 6. Needs Analysis from Classroom Observation

Observed Aspect	Summary of Findings
Learning implementation	Teacher-centered through explanation, discussion, and assignments
Student activity	Active participation is still uneven.
Teaching materials	Dominated by text and pictures
Project activities	Not implemented regularly
Technology	Chromebook, Smartboard, and Wi-Fi are available but underutilized.
Learning need	Interactive AR-based textbook integrated with PjBL

Design

The design stage focused on preparing the initial prototype of the AR-based textbook according to the findings from the analysis phase. The textbook was structured into introductory, core, and closing sections, including learning outcomes, objectives, user instructions, AR guides, learning activities, project tasks, exercises, reflections, glossary, and references.

Four science chapters were designed: Human Organ Systems, Ecosystems, Energy Conservation and Alternative Energy, and the Solar System. Each chapter integrates AR visualizations, contextual problems, collaborative discussions, project activities, and competency-based assessments to encourage meaningful learning experiences.

The Project-Based Learning syntax was systematically embedded throughout the textbook. Students begin by identifying contextual problems, planning projects, organizing schedules, conducting AR-based investigations, presenting project outcomes, and finally evaluating and reflecting on their learning process. Learning activities were intentionally designed to develop the six competencies of Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking through both individual and group-based tasks, allowing students to observe, discuss, design products, communicate ideas, and solve authentic scientific problems.

Table 7. Integration of PjBL syntax

PjBL Phase	Student Activity
Driving Question	Observe contextual problems and answer guiding questions.
Project Planning	Design project ideas and divide group responsibilities
Scheduling	Arrange project timeline
Project Implementation	Use AR features and complete the project.
Presentation	Present and demonstrate project results
Reflection	Evaluate learning outcomes and project performance.

The learning activities were designed to systematically develop the competencies in Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking.

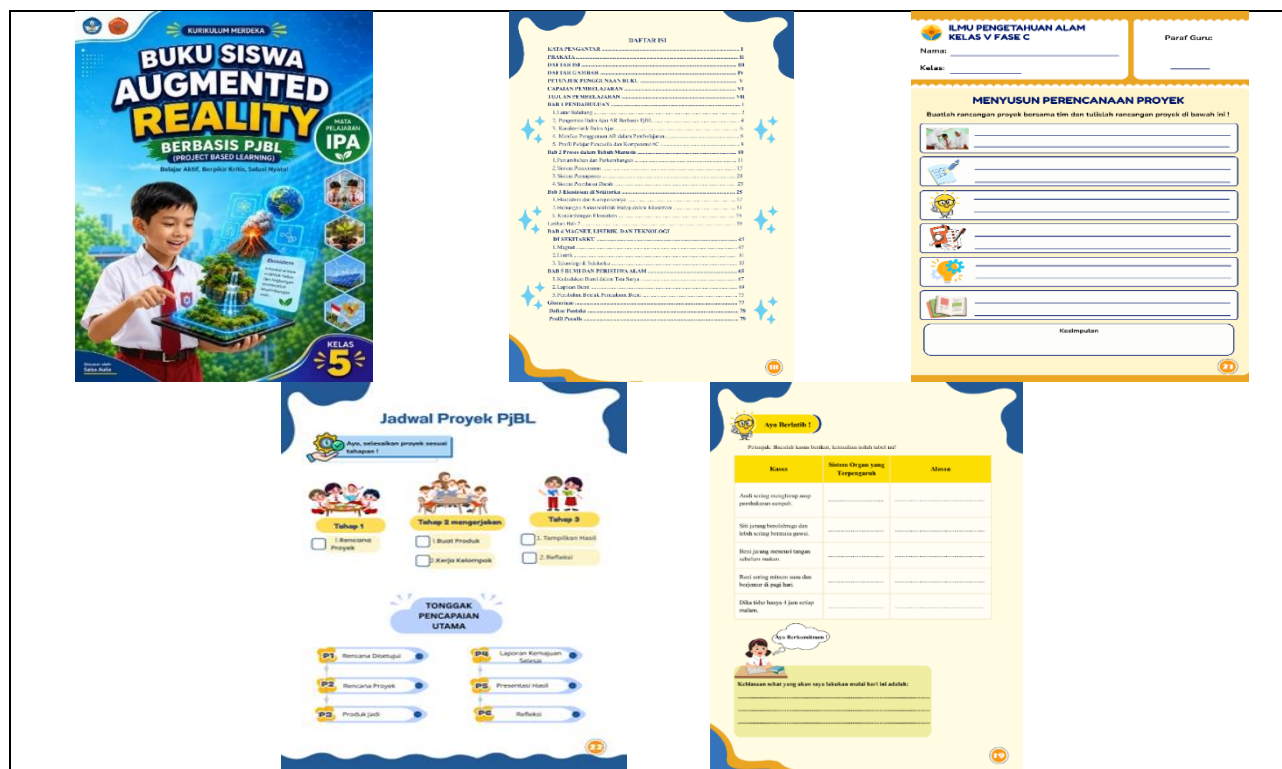


Figure 1. Augmented Reality-Based Student Book Using Project-Based Learning Process

Development

The development stage involved producing the AR-based textbook prototype and integrating Augmented Reality features into selected science materials. The product combined printed learning materials with digital AR content, enabling students to access three-dimensional visualizations of scientific objects and processes using supported devices. The developed textbook emphasizes interactive learning through contextual illustrations, AR visualization, project worksheets, reflective questions, and competency-based evaluation. Each project was designed to encourage collaborative problem-solving while connecting science concepts with students' daily experiences. Before implementation, the prototype underwent expert validation and revision to ensure its alignment with curriculum requirements, scientific content, AR functionality, PjBL activities, and the targeted development of 6C competencies. Suggestions from validators were incorporated into the revised version before classroom use.

The development stage involved producing the complete AR-based textbook by integrating printed learning materials with Augmented Reality technology. The prototype was subsequently validated by materials and media experts to assess its feasibility before classroom implementation. The validation instrument used a 4-point Likert scale covering content, language, presentation, AR integration, and technical quality.

Material Expert Validation

The materials expert evaluated eight aspects of the assessment. The overall validation yielded an average score of 3.69 and a feasibility percentage of 92.2%, indicating that the AR-based textbook is Highly Feasible.

Table 8. Results of Material Expert Validation

No.	Assessment Aspect	Mean	Percentage	Category
1	Curriculum suitability	4.00	100%	Highly Feasible
2	Depth of material	3.00	75%	Feasible
3	Scientific accuracy	4.00	100%	Highly Feasible
4	Integration with STEAM/6C concepts	3.00	75%	Feasible
5	Language and terminology	4.00	100%	Highly Feasible
6	Ease of understanding	3.50	87.5%	Highly Feasible
7	Relevance to daily life	4.00	100%	Highly Feasible
8	Creativity and innovation	4.00	100%	Highly Feasible
	Overall average	3.69	92.2%	Highly Feasible

The results indicate that the textbook has excellent curriculum alignment, scientific accuracy, language quality, and relevance to students' daily lives. The aspects requiring improvement were the depth of material and the integration of interdisciplinary concepts, which were revised before implementation.

Media Expert Validation

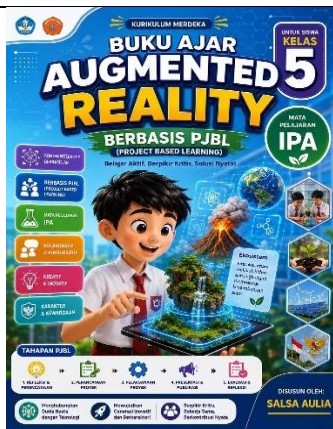
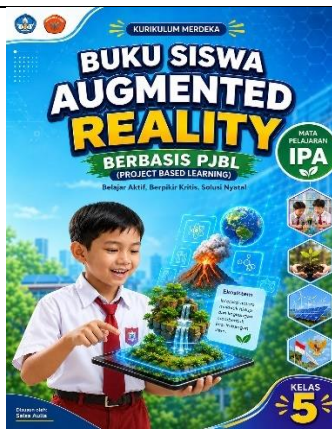
The media expert assessed the visual appearance, navigation, interactivity, technical quality, and suitability for digital learning. The overall result achieved an average score of 3.00 with a feasibility percentage of 75%, categorized as Feasible.

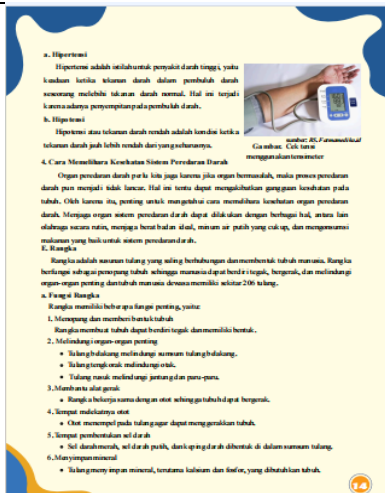
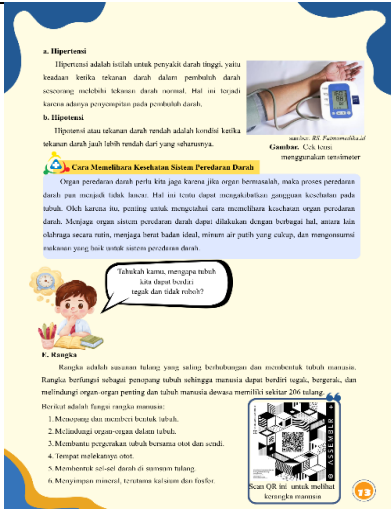
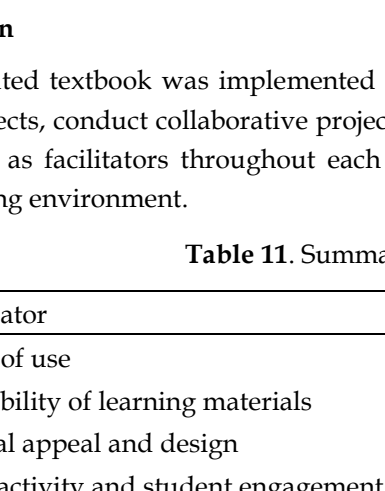
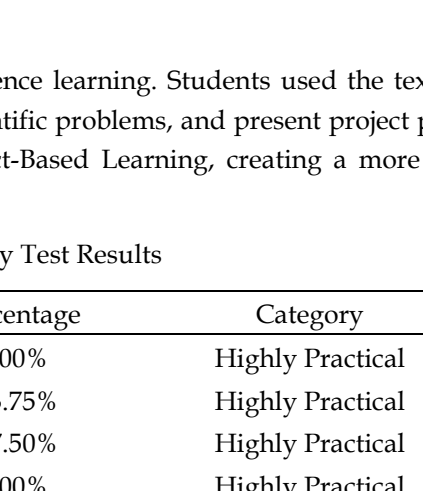
Table 9. Results of Media Expert Validation

No.	Assessment Aspect	Mean	Percentage	Category
1	Visual design	3.00	75%	Feasible
2	Suitability for target users	3.50	87.5%	Highly Feasible
3	Integration of media and content	3.00	75%	Feasible

No.	Assessment Aspect	Mean	Percentage	Category
4	Ease of navigation	4.00	100%	Highly Feasible
5	Interactivity	2.00	50%	Quite Feasible
6	Creativity and innovation	2.50	62.5%	Feasible
7	Technical quality	3.00	75%	Feasible
8	Conformity with digital learning	3.00	75%	Feasible
	Overall average	3.00	75%	Feasible

The AR-based textbook, integrated with Project-Based Learning (PjBL), was revised based on recommendations from the material expert, media expert, and practitioner during the validation process. The revisions focused on improving the learning content, visual design, navigation, illustrations, and the clarity of learning activities to enhance the textbook's quality and feasibility. The results of the product revisions are presented in Table 10.

No.	Before Revision	After Revision
1	 The cover section still uses an illustrated cover image.	 The cover has been revised using an authentic/real image.
2	 Before the revision, the syntax of Project-Based Learning (PjBL) was not clearly presented.	 After the revision, the PjBL syntax was organized into six stages: a driving question at the beginning of the chapter, followed by project planning, schedule development, project implementation and monitoring, testing the results, and evaluating the experience.

No.	Before Revision	After Revision
3		
	The text layout was not proportional, making the pages appear overcrowded, and there was no AR QR code in the skeletal system material section.	The layout has been improved to make it look neater, and the QR code has been added to the learning material.
4		
	The book's user guide did not yet include instructions for using the QR code.	The instructions for students on using the QR code have been revised.

Implementation

The validated textbook was implemented in Grade V science learning. Students used the textbook to explore AR objects, conduct collaborative projects, discuss scientific problems, and present project products. Teachers acted as facilitators throughout each stage of Project-Based Learning, creating a more student-centered learning environment.

Table 11. Summary of Practicality Test Results

No.	Indicator	Mean	Percentage	Category
1	Ease of use	4.00	100%	Highly Practical
2	Suitability of learning materials	3.75	93.75%	Highly Practical
3	Visual appeal and design	3.50	87.50%	Highly Practical
4	Interactivity and student engagement	4.00	100%	Highly Practical
5	Efficiency in learning	3.75	93.75%	Highly Practical
Overall Average		3.80	95%	Highly Practical

Based on Table 11, the practicality test showed that the AR-based textbook integrated with Project-Based Learning (PjBL) achieved an overall average score of 3.80 and a 95% level of practicality, placing it in the Highly Practical category. The highest scores were obtained for ease of use, interactivity, and student engagement (100%), indicating that the textbook is easy to use and effectively engages students in the learning process. Meanwhile, the suitability of learning materials and learning efficiency each achieved 93.75%, while visual appeal and design achieved 87.50%. These findings indicate that the developed textbook is highly practical for supporting Grade V science learning.

Evaluation

The evaluation stage assessed the suitability of the developed textbook as a learning resource and its contribution to students' learning experiences. The findings indicate that integrating Augmented Reality with Project-Based Learning provides a more interactive, contextual, and meaningful science-learning process while supporting the development of the Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking competencies.

Table 12. Recapitulation of the Improvement of 6C Competencies Across Learning Cycles

6C Competency	Cycle I	Category	Cycle II	Category	Cycle III	Category
Citizenship	39.55%	Poor	53.00%	Fair	71.91%	Good
Character	37.89%	Poor	53.93%	Fair	78.19%	Good
Communication	37.23%	Poor	52.75%	Fair	73.30%	Good
Collaboration	40.34%	Poor	52.80%	Fair	72.84%	Good
Creativity	38.59%	Poor	52.64%	Fair	72.82%	Good
Critical Thinking	35.96%	Poor	52.30%	Fair	83.73%	Very Good
Average 6C	38.26%	Poor	52.90%	Fair	75.46%	Good

Among the six competencies, Critical Thinking demonstrated the greatest improvement, reaching 83.73% and the Very Good category in Cycle III. Overall, these findings indicate that the implementation of the Augmented Reality-based textbook, integrated with Project-Based Learning (PjBL), effectively supported the development of students' Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking (6C) competencies.

Table 13. Pretest, Posttest, and N-Gain Test Results of Students' Critical Thinking Skills

Cycle	Number of Participants	Mean Pretest	Mean Posttest	Difference	N-Gain	Category
I	22	59.43	78.41	18.98	0.46	Moderate
II	22	57.50	79.32	21.82	0.51	Moderate
III	22	60.11	82.05	21.94	0.55	Moderate

Based on Table 13, students' critical thinking skills improved consistently across the three learning cycles. In Cycle I, the mean pretest score increased from 59.43 to 78.41 in the posttest, with an N-Gain value of 0.46, indicating a moderate level of improvement. In Cycle II, the mean posttest score increased to 79.32, producing an N-Gain of 0.51, which also fell within the moderate category. The highest learning outcome was achieved in Cycle III, with a mean posttest score of 82.05 and an N-Gain of 0.55, both remaining in the moderate category. Overall, the progressive increase in posttest scores and N-Gain values demonstrates that implementing the Augmented Reality-based textbook integrated with Project-Based Learning (PBL) effectively enhanced students' critical thinking skills throughout the learning process.

DISCUSSION

The development of the Augmented Reality (AR)-based Student Book, integrated with Project-Based Learning (PjBL), employed the ADDIE model, consisting of Analysis, Design, Development, Implementation, and Evaluation. The selection of this model was based on its systematic framework that enables instructional products to be developed according to learner needs, validated through expert review, implemented in authentic classroom settings, and continuously improved through evaluation. In this study, the ADDIE model produced a student book that integrates AR technology, project-based learning activities, and the development of six 21st-century competencies (6C), namely Character, Citizenship, Collaboration, Communication, Creativity, and Critical Thinking.

The analysis stage included curriculum analysis, learner needs analysis, learner characteristics, 6C competency analysis, and educational technology analysis. The findings revealed that Grade V IPAS learning at SD Negeri 95/IV Kota Jambi still relied primarily on conventional printed textbooks and teacher-centered instruction. At the same time, several topics, particularly the human organ system, were abstract and difficult for students to visualize. Consequently, students required more interactive learning resources that could transform abstract scientific concepts into concrete learning experiences. This finding supports the Cognitive Theory of Multimedia Learning, which posits that combining verbal and visual representations improves conceptual understanding by enabling learners to process information through dual cognitive channels (Mayer, 2021). The decision to integrate Augmented Reality into the student book, therefore, addressed the need for concrete visualization. At the same time, Project-Based Learning was selected to provide authentic learning experiences that encourage students to solve problems collaboratively. Similar findings were reported by Amalia et al. (2023), who demonstrated that AR improves elementary students' conceptual understanding and critical thinking, while Arianda et al. (2024) concluded that PjBL effectively promotes the development of 6C competencies through collaborative and inquiry-based activities.

The design stage involved planning the structure of the AR-based student book, determining learning objectives based on the IPAS Learning Outcomes, organizing instructional content, designing AR visualizations, integrating the six phases of Project-Based Learning, and embedding activities that explicitly facilitate 6C competencies. Unlike conventional textbooks that primarily present information, the developed student book functions simultaneously as a learning guide, project handbook, and interactive digital resource. Students begin learning through contextual problems, observe scientific objects using AR visualization, complete collaborative projects, present their findings, and reflect on their learning experiences. The integration of AR and PjBL reflects the principle of situated learning, which emphasizes that knowledge becomes more meaningful when learned within authentic contexts where it will be applied. (JoronaValona et al., 2025). Furthermore, the project activities were intentionally designed to strengthen communication, collaboration, creativity, and critical thinking rather than merely assessing content mastery. These findings indicate that the design process successfully aligned curriculum requirements with the pedagogical demands of the Merdeka Curriculum, which prioritizes contextual, student-centered, and competency-based learning.

The development stage transformed the instructional design into a complete AR-based student book containing instructional materials, AR QR codes, project worksheets, exercises, summaries, evaluation tasks, and reflection activities. Expert validation was subsequently conducted by material, media, and language experts to determine the product's feasibility. The material validation score increased from 2.80 to 4.67, media validation improved from 3.50 to 4.37, and language validation rose from 3.13 to 4.53, indicating that all aspects reached the very valid category after revision. The substantial improvement demonstrates that iterative revision based on expert feedback enhanced both the pedagogical and technical quality of the product. Material revisions focused on aligning learning outcomes, enriching instructional content, integrating 6C competencies, and improving evaluation according to learning objectives. Media revisions emphasized authentic visual design, clearer PjBL syntax, balanced page layout, and QR usage instructions. In contrast, language revisions simplified instructional sentences and made learning activities more dialogic for elementary learners. These findings reinforce Kamilah (2026) The argument is that formative evaluation is

essential in instructional product development because expert feedback substantially improves product quality before implementation. Similarly, Wahyudianto et al. (2025) reported that systematic revision following expert validation increases the instructional validity and usability of digital learning materials.

An important finding emerging from the validation process is that improvements were not limited to aesthetic presentation but also strengthened the instructional capacity of the student book to facilitate 6C competencies. Several indicators of communication, creativity, and citizenship showed higher scores after revision, suggesting that expert feedback directly enhanced competency-oriented learning design rather than merely improving appearance. This finding extends previous AR development studies by demonstrating that digital instructional materials should be evaluated simultaneously from technological, pedagogical, and competency-development perspectives.

The implementation stage consisted of a limited classroom trial conducted over three instructional cycles involving six meetings with Grade V students. The AR-based student book functioned as both the primary learning resource and the guide for completing collaborative projects. During implementation, students interacted with AR visualizations to observe scientific structures, discussed problems within groups, planned project completion, produced learning products, and presented their findings. The classroom observations demonstrated that students gradually became more engaged and autonomous as they adapted to project-based learning. This result is consistent with experiential learning theory, which proposes that meaningful knowledge is constructed through concrete experience, reflection, conceptualization, and active experimentation (Kolb, 1984). Similarly, Rahmi (2024) found that integrating AR with PjBL significantly increases learning participation and activity among elementary IPAS students. Therefore, the implementation findings suggest that AR serves primarily as a cognitive support tool for visualization, whereas PjBL provides the pedagogical structure through which higher-order competencies are developed.

The practicality of the developed product was evaluated through teacher and student responses. The teacher's practicality score was 4.67, while student responses averaged 4.35 (95.73%), both of which were categorized as very practical. These findings indicate that the student book is easy to use, visually appealing, understandable, and effective in supporting classroom learning. Students also reported that AR visualization helped them understand scientific concepts more easily because they could directly observe three-dimensional representations of learning objects. The high practicality aligns with Rahmawati et al. (2024), who reported that AR-based instructional media facilitate classroom implementation by reducing students' dependence on verbal explanation alone. Likewise, Najih et al. (2024) concluded that AR media improve learner engagement and motivation because interactive visualization increases students' curiosity during learning (Sattar et al., 2025). Nevertheless, it should be acknowledged that the teacher practicality assessment involved only one classroom teacher, meaning that broader generalizations regarding teacher acceptance require larger-scale implementation involving multiple practitioners.

The evaluation stage examined not only product feasibility but also its effectiveness in improving students' competencies. The most notable outcome was the progressive improvement of 6C competencies across three implementation cycles. Students' overall competency achievement increased from 38.26% in Cycle I (Low) to 52.90% in Cycle II (Moderate), then to 75.46% in Cycle III (Good), representing an overall improvement of 37.20 percentage points. The gradual progression indicates that competency development occurred through repeated participation in collaborative project activities rather than immediate mastery after a single intervention. Character and Citizenship improved as students became more responsible, disciplined, and respectful during project completion; Collaboration and Communication developed through group discussion and presentations; Creativity emerged as students generated project ideas and designed products; and Critical Thinking increased through investigation, analysis, and problem-solving. These findings are consistent with Zhou et al., (2025), who emphasized that PjBL promotes integrated development of 6C competencies by engaging students in authentic collaborative inquiry. Rather than treating 6C as separate instructional objectives, this study embedded them directly into every learning activity, making competency development observable throughout the learning process.

The effectiveness of the AR-based student book was further demonstrated by improvements in critical-thinking ability, as measured using N-Gain analysis. Students' N-Gain increased consistently from 0.46 in Cycle I to 0.51 in Cycle II and 0.55 in Cycle III, all within the moderate category. Although the gain did not reach the high category, the consistent upward trend indicates meaningful improvement in students' ability to analyze information, construct arguments, solve problems, and formulate conclusions. This pattern supports the constructivist perspective of Vygotsky (1978), which argues that higher-order thinking develops through social interaction and guided problem solving. In the present study, AR visualization reduced the abstractness of scientific concepts, while project activities required students to interpret evidence collaboratively before making decisions. Similar findings were reported by Rujiani et al. (2025), who demonstrated that AR-assisted PjBL enhances critical reasoning and communication among elementary students. Likewise, Sulasono et al., (2025) found that project-based learning significantly improves elementary students' critical thinking by having learners actively investigate authentic problems rather than memorizing factual information. The moderate N-Gain observed in this study therefore suggests that AR and PjBL function synergistically: AR supports conceptual visualization, whereas PjBL stimulates analytical reasoning through meaningful learning tasks.

Despite these positive findings, several limitations should be acknowledged. First, the study involved only one Grade V class at a single elementary school, limiting the generalizability of the findings to broader educational contexts. Second, the implementation employed classroom action cycles without a comparison group, so improvements in competencies cannot be attributed exclusively to the AR-based student book, as other instructional factors may also have contributed. Third, the intervention was conducted over only six meetings, preventing investigation of the long-term impact of AR-supported project learning on students' competency retention and independent learning behavior. Future research is therefore recommended to employ quasi-experimental designs involving larger samples, multiple schools, longer intervention periods, and comparative analysis between AR-based and conventional learning materials.

The findings of this study provide both theoretical and practical implications. Theoretically, they strengthen the instructional framework that integrates Augmented Reality and Project-Based Learning within competency-based education by demonstrating that digital visualization and authentic project experiences can jointly facilitate the development of 6C competencies and critical thinking. In practice, the developed student book offers a practical instructional alternative for elementary IPAS teachers implementing the Merdeka Curriculum, particularly in schools equipped with digital facilities such as Chromebooks and internet connectivity. The product was designed to support the gradual digital transformation of elementary classrooms in Indonesia, including schools in Jambi, where integrating digital technology into learning continues to present both opportunities and implementation challenges. By combining printed learning materials with AR-based visualization accessed through QR codes, the student book provides a practical bridge between conventional teaching resources and digital learning experiences. This approach allows teachers to integrate interactive technology into project-based learning without relying entirely on fully digital instructional materials. Therefore, the developed student book has the potential to support technology-enhanced learning at the school level while remaining adaptable to available infrastructure and teachers' instructional needs. More broadly, the study supports the Merdeka Curriculum's emphasis on contextual learning, project-based instruction, digital literacy, and the cultivation of 21st-century competencies required for future learners.

CONCLUSION

The study concluded that the developed Augmented Reality (AR)-based Student Book integrated with Project-Based Learning (PjBL) is valid and practical for Grade V science learning. Developed using the ADDIE model, the student book integrates science materials, AR features, project activities, evaluation, and 6C competency development. The product was categorized as very valid, with validation scores of 4.37 for media, 4.67 for material, and 4.53 for language. It was also very practical, with scores of 4.67 from teachers and 4.35

from students. The implementation showed an increase in 6C competencies from 38.26% in Cycle I to 52.90% in Cycle II and to 75.46% in Cycle III, representing a 37.20 percentage-point increase. Critical thinking also improved, with N-Gain increasing from 0.46 to 0.51 and then to 0.55. These findings indicate that integrating AR and PjBL can provide an interactive and project-based learning experience that supports the development of 6C competencies and critical thinking. The developed student book can therefore serve as an alternative learning resource aligned with the *Kurikulum Merdeka*. However, this study was limited to a single school and a small sample of Grade V students, which may restrict the generalizability of the findings. Future studies should involve larger samples across multiple schools and employ more rigorous experimental designs to examine the long-term effectiveness of the student book and its potential to enhance students' 6C competencies and critical thinking.

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