



Development and Preliminary Evaluation of Augmented Reality Media to Support Fifth-Grade Students' Motivation and Science Learning Outcomes

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Abstract

Interactive learning media can help elementary students visualize abstract science concepts, yet the feasibility of augmented reality (AR) media and associated changes in students' motivation and learning outcomes warrant further investigation. This study aims to develop and preliminarily evaluate AR-based interactive media for teaching the human respiratory system in fifth-grade science. The study employed a research and development approach guided by the ADDIE model, involving 53 students from two elementary schools in Indonesia. Data were collected through observations, interviews, expert validation, teacher and student evaluations, motivation questionnaires, and science learning outcome tests. Product feasibility was assessed descriptively, while pretest–posttest differences were analyzed using paired-samples t-tests. The findings revealed favorable expert evaluations, with mean media and material validation scores of 3.4 and 3.6, respectively, both classified as very good. Following implementation, motivation scores increased by an average of 14.36 points, $t(52) = -18.590$, $p < .001$, while science learning outcome scores increased by 15.72 points, $t(52) = -11.691$, $p < .001$. However, the absence of a reported comparison group prevents attributing these improvements solely to AR media. The study contributes preliminary evidence of AR media feasibility and observed within-group improvements, with implications for interactive elementary science instruction and future controlled evaluations.

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1. Introduction

In the Merdeka Curriculum, Natural Sciences (IPA) and Social Sciences (IPS) are integrated into Natural and Social Sciences (IPAS) (Allutfia & Setyaningsih, 2023). This integration differs from previous approaches that combined subjects through thematic learning (Waseso et al., 2024; Cholilah et al., 2023). IPAS aims to develop students' understanding of natural and social phenomena and their relationships. Some science topics, particularly the structures and functions of internal human organs, are difficult for elementary students to observe directly. The challenges students experience in learning



IPAS have also been discussed by Alfatonah et al. (2023). Appropriate learning media are therefore needed to help students visualize concepts that cannot readily be experienced through direct observation.

The presentation of science material needs to be organized through appropriate learning media so that learning becomes more interesting and meaningful. Educational resources can help teachers explain abstract concepts and encourage participation in classroom activities (Agustira & Rahmi, 2022; Abdullah et al., 2024). Students' learning achievement may be influenced by internal factors, including interest, attitudes, and motivation, as well as external factors, such as teaching practices and available educational resources (Zannah, 2022). Therefore, teachers need to develop learning activities that support students' motivation and engagement (Arianti, 2019). The relevance of interactive learning technologies also depends on their integration with teaching practices rather than the technology alone (Depita, 2024).

Preliminary observations conducted in Grade V at MI Al-Huda Karangnongko and SDN Nanggulan indicated that students' science learning outcomes had not fully met the expected achievement standards. Mid-Semester Assessment (PTS) results showed average scores of 59.5 at MI Al-Huda Karangnongko and 73.48 at SDN Nanggulan, both below the Learning Objective Achievement Criteria (KKTP) score of 75. The reported proportions of students below the achievement criterion were 80.77% and 62.96%, respectively. A preliminary motivation questionnaire completed by 53 Grade V students indicated that 70% did not consider science learning enjoyable, 85% reported frequently feeling bored during lessons, and 74% stated that they did not consistently pay attention to teachers' explanations. These findings indicate a need to improve learning experiences and provide more engaging instructional support.

Observations and interviews with Grade V teachers at both schools further indicated that the use of interactive learning media had not been optimized. Teachers frequently relied on whiteboards, textbooks, static presentation materials, and occasional learning videos displayed through LCD projectors. Teachers reported challenges related to preparation time, knowledge of technological media, and school facilities. Such difficulties are relevant to broader discussions of teachers' roles in developing learning resources (Mukarromah & Andriana, 2022). These local conditions suggest a practical need for media that are appropriate to the curriculum, students' characteristics, and the resources available in each school.

One technological approach that may address these needs is augmented reality (AR). AR integrates virtual two-dimensional or three-dimensional elements with the user's real environment (Ismayani, 2020; Wijaya, 2022). For the human respiratory system, such representations may help students examine the shapes and relationships of structures that cannot be observed directly. This possibility

is consistent with constructivist perspectives emphasizing learners' active participation in constructing understanding (Tohari & Rahman, 2024). Research on AR in elementary science has also highlighted the value of visualization and interaction for conceptual learning (Purwanti et al., 2024; Rohmani et al., 2024). However, reviews have identified challenges relating to usability, implementation, and the appropriateness of instructional design (Basumatary & Maity, 2023; Tarmidzi et al., 2025).

International reviews provide a more differentiated rationale for introducing AR in school science. Reviewing 117 studies of virtual- and augmented-reality-supported K–12 STEM learning, Jiang et al. (2025) observed that science and elementary education were prominent areas of application and that mobile devices were commonly used. Their synthesis also identified challenges related to teacher preparation, classroom management, technical operation, and access to infrastructure. These findings are relevant to the present schools, where teachers reported limited familiarity with AR and constraints involving available facilities. They indicate that an AR resource should be evaluated not merely by the attractiveness of its visual display but also by the usability of the product, suitability of its content, and conditions under which teachers and pupils are expected to use it. The present research, therefore, considers teacher and pupil evaluation alongside expert judgment and learner outcome measures.

Previous studies have developed AR learning media in several elementary school subjects. Wibowo et al. (2022) examined animal classification in Grade V, Sukma et al. (2023) developed Android-based AR media for the solar system in Grade VI, and Faiza et al. (2022) examined AR in social studies. Sari et al. (2023) and Samsiyanawati et al. (2023) addressed other applications of AR, including geometric shapes and interest in learning the digestive system. More directly relevant studies have already developed AR media for the Grade V human respiratory system. Umam et al. (2024) evaluated the feasibility and user responses to such media, while Ridho and Setyasto (2024) developed Android-based AR media and reported changes in science outcomes. These studies establish that neither AR nor its application to the human respiratory system is new. However, their development approaches and assessed outcomes differ from the combined focus on motivation, science learning outcomes, and feasibility in the two school settings adopted here.

Related research published in the *Journal of Integrated Elementary Education* reinforces both the promise and the established nature of technology-supported learning in primary schools. Rosita et al. (2025) investigated AR-supported representations of the human sensory system with 52 fourth-grade pupils at two Islamic primary schools and reported an improvement in retention-related scores in a one-group pretest–posttest study. That study is particularly relevant because it concerns a human biological system, but it examined

retention rather than the combined motivation and science outcome measures used here. Marwah et al. (2025) applied ADDIE to develop and assess interactive digital media for Arabic vocabulary learning in Madrasah Ibtidaiyah, demonstrating the relevance of staged development, expert evaluation, and classroom trials in an elementary setting. Although the media and disciplinary content differ, this work helps position ADDIE as a methodological structure for evaluating an instructional product rather than as an independent claim of novelty. Together, these studies make it necessary to locate the contribution of the present article in its specific design, context, and assessment combination.

Evidence syntheses indicate that AR learning outcomes vary by instructional design and implementation. Abdullah et al. (2022) examined achievement, satisfaction, and interest in science education. Chang et al. (2022) reported positive effects across types of educational outcomes but noted that treatment duration and design features warrant attention. Na and Yun (2024) found positive motivation effects across K–12 studies, with differences associated with AR type and collaborative learning. These findings support a cautious approach: positive responses and improved scores cannot be assumed to arise from the technology itself, and context-specific design and evaluation remain important. Therefore, the present study responds to the identified classroom needs by developing and evaluating an AR-based resource for respiratory-system learning rather than claiming to introduce an unprecedented instructional technology.

A further distinction concerns whether research assesses initial enthusiasm for digital media, students' conceptual learning, teachers' acceptance of a technology, or sustained retention. These are related but not interchangeable constructs. Nikou (2024), for example, investigated the intentions of 89 prospective primary teachers to use mobile AR for science instruction and found that perceived educational value and immersion were associated with intended adoption through perceived usefulness. Such evidence addresses teachers' readiness to employ AR, not children's learning gains. In the present investigation, teacher and student assessments of a developed product are therefore interpreted separately from questionnaire-based motivation scores and achievement-test results. This distinction also permits a more precise comparison with earlier Grade V respiratory-system applications, rather than treating every favorable product rating as direct evidence of improved learning.

The resulting research gap is consequently modest but precise. Prior respiratory-system AR development and closely related JIEEd studies establish feasibility-oriented and before-and-after evaluation traditions, whereas international research shows that outcomes vary with pedagogical and implementation conditions. The participating schools' documented need warrants examination of an AR product within their own constraints, using separate

evidence about expert validation, user judgment, motivation, and learning outcomes. This is an empirical and contextual contribution; it should not be construed as the first use of AR for respiratory-system instruction or as definitive evidence that the technology causes higher scores.

Accordingly, this research aimed to develop AR-based interactive learning media for Grade V science using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model. Specifically, it sought to identify learning needs, develop and validate the AR media, examine expert and user evaluations of product feasibility, and compare students' motivation and science learning outcomes before and after implementation. The study offers context-specific evidence from MI Al-Huda Karangnongko and SDN Nanggulan on the feasibility and potential instructional value of AR-supported IPAS learning. Because the reported assessment design does not include a comparison group, the pretest–posttest differences are treated as observed changes rather than conclusive causal effects.

2. Methods

This study employed a research and development (R&D) approach to develop and evaluate augmented reality (AR)-based interactive learning media for Grade V science. The development followed the ADDIE model: Analysis, Design, Development, Implementation, and Evaluation (Branch, 2009). During the analysis, the researchers identified learning difficulties, student motivation, and media needs. Design involved planning learning content and the product structure according to curriculum requirements and student characteristics. During Development, the AR media were created and evaluated by experts. Implementation involved using the developed media with Grade V students, while Evaluation examined product assessments and changes in student scores after implementation.

The study involved instrument experts, media and material experts, three science teachers who evaluated the product, and students and class teachers in two schools. The three teacher evaluators were drawn from MI Al-Huda Karangnongko, SDN Nanggulan, and MI Ma'arif Bego. Classroom implementation involved 26 Grade V students at MI Al-Huda Karangnongko and 27 at SDN Nanggulan, for a reported total of 53 students. The developed learning resource addressed the human respiratory system.

The available product documentation identifies a human-respiratory-system learning resource constructed with Assemblr Edu and organized around a main interface, user guidance, information about the media, curriculum learning outcomes and objectives (CP and TP), and visualized instructional content. These features were retained as the principal product components during

reporting of the Design and Development stages. The source manuscript does not specify the duration of classroom implementation, the number of teaching sessions, or access arrangements for pupils, so no uniform exposure schedule can be established from the available records. Accordingly, this report describes the order of documented activities but does not imply a particular intervention dose or standardized fidelity protocol.

Data were collected through classroom observations, teacher interviews, documentation, expert validation sheets, teacher and student assessment questionnaires, learning motivation questionnaires, and science learning outcome tests. Observations and interviews were used for preliminary needs identification. Expert validation and user questionnaires provided product evaluation data. Motivation questionnaires and learning outcome tests were administered before and after the AR-based learning activities.

Product and learner assessments addressed different questions. The media specialist assessed five technical aspects—ease of use, display quality, design alignment, quality of use, and program management—while the subject-material assessment considered depth, suitability for pupils, organization, content, and alignment with the instructional topic. Each of the three teacher evaluators completed ten product-assessment items. For the pupil feasibility assessments, 26 students at MI Al-Huda Karangnongko and 27 at SDN Nanggulan provided ten responses each on a four-category rating scale. These evaluations concern perceptions of the developed resource and should not be conflated with measures of motivation or achievement. The original report does not supply complete evidence of questionnaire reliability, achievement-test item quality, or the cutoff criteria for the verbal classification 'Very Good'; these remain necessary for final methodological verification.

Qualitative information from observations, interviews, and documentation was organized through reduction, presentation, and conclusion drawing and verification. Quantitative product assessments were summarized using means and percentages. Differences between pretest and posttest motivation and learning outcome scores were examined using paired-samples t-tests in SPSS version 22. The manuscript reported Kolmogorov–Smirnov normality tests for separate pretest and posttest distributions and Levene's variance tests. These diagnostics are reproduced in Results for transparency, but normality of the paired differences—the relevant assumption for a paired-samples t-test—has not been documented. The analysis was reported for 53 paired observations, although the normality tables list 26 students for SDN Nanggulan rather than the 27 described in the sample. The available design supports descriptive changes following the intervention, rather than attribution of causal effects.

For the outcome evaluation, the reported inferential analysis combined the two school samples into 53 paired pretest–posttest observations for each

variable. The descriptive quantities available for reporting include the signed mean paired differences, standard deviations of the differences, standard errors, t statistics, degrees of freedom, and confidence intervals. Negative differences arise because the source software output defines each difference as the pretest score minus the posttest score. Although these summaries establish the direction of the reported change, the source records do not include a control condition or a documented assessment of the normality of the paired differences. Therefore, the analysis cannot distinguish the effects of the developed medium from repeated testing, instructional time, or other accompanying classroom experiences.

3. Results

The findings are organized according to the analysis, design, development, implementation, and evaluation stages of the ADDIE process. The results draw on observations and interviews, need questionnaires, expert and user evaluations, and pretest–posttest assessments.

3.1 Preliminary analysis of learning needs and instructional media

Classroom observations at MI Al-Huda Karangnongko and SDN Nanggulan showed frequent use of textbooks, static presentations, and LCD projectors. Students often remained passive during instructional discussions. Teachers described limited preparation time and technological familiarity as obstacles to producing interactive materials. These observations provide the context for developing a learning resource intended to support visualization and engagement.

The preliminary motivation questionnaire involved 53 Grade V students. In the reported responses, 70% did not find science enjoyable, 85% often felt bored during lessons, and 74% did not always attend to teacher explanations. Only 34% responded that teachers motivated them before lessons. In addition, the four questionnaire items do not measure identical aspects of student experience. The first addresses the enjoyment of the science subject, the second the frequency of boredom, the third perceived teacher encouragement before class, and the fourth attention to explanations. Accordingly, the percentages should be read as responses to these particular statements rather than as an overall validated motivation index. Their consistent pattern nevertheless supplied a practical justification for examining a learning resource that might offer a different form of access to scientific content. The available study does not demonstrate that these responses were caused by a particular teaching medium.

Table 1.

Preliminary student motivation questionnaire (reported percentages)

Statement	Yes (%)	No (%)
Is science fun?	30	70
Do you often get bored with learning at school?	85	15
Does the teacher provide motivation before starting the lesson?	34	66
Do you always pay attention to the teacher's explanation?	26	74

Mid-Semester Assessment results further indicated that reported averages at both schools fell below the KKTP criterion of 75. The percentages and class sizes are presented in Table 2.

Table 2.

Preliminary science assessment (PTS) results

School	Grade	Mean	Passing Grade	Above Passing Grade (%)	Below Passing Grade (%)	Students
MI Al-Huda Karangnongko	V	59.50	75	19.23	80.77	26
SDN Nanggulan	V	73.48	75	37.04	62.96	27

Needs-analysis interviews indicated that both Grade V teachers supported the development of AR-based media despite limited prior experience with the technology. Student responses likewise suggested a need for visual learning resources: 66% reported difficulty understanding current explanations, 81% indicated that existing media did not facilitate their understanding, and 94% expressed support for using AR.

The needs questionnaire similarly distinguished difficulty understanding teacher explanations, perceived helpfulness of existing instructional media, prior awareness of AR, and willingness to use it. The reported 94% agreement with proposed AR use signals receptiveness, whereas the 87% who had not heard of AR indicates that familiarity with the technology was limited. These responses are not contradictory: favorable expectations can exist despite little previous experience. They also indicate that students' initial willingness should not be used as evidence of the product's subsequent feasibility or learning impact, which were considered at later ADDIE stages.

Table 3.

Student needs questionnaire (reported percentages)

Statement	Yes (%)	No (%)
Do you understand the material presented by the teacher?	34	66
Does the teacher use media that help you understand science?	19	81
Have you heard of augmented reality media?	13	87
Do you agree with using AR media in learning?	94	6

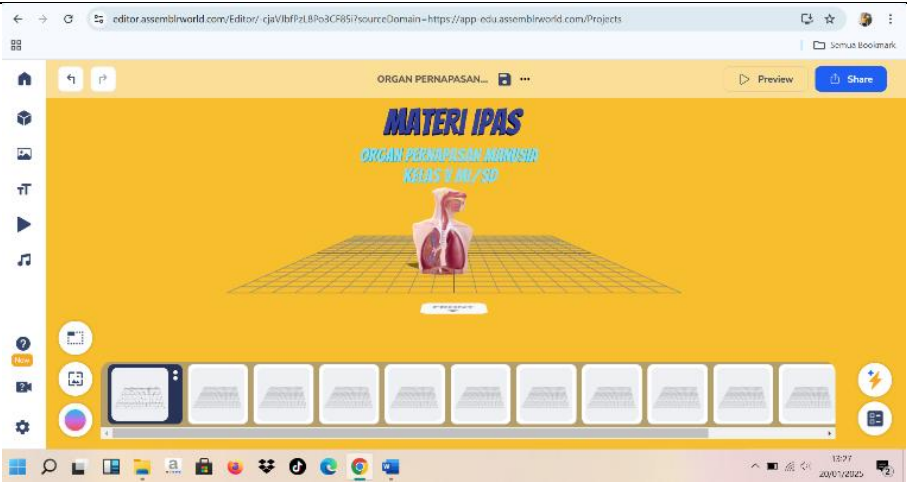
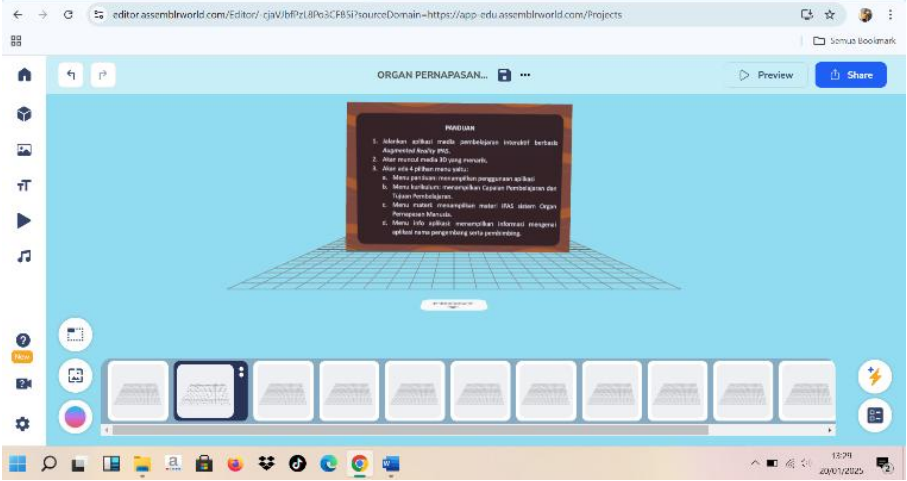
3.2 Design of AR learning media

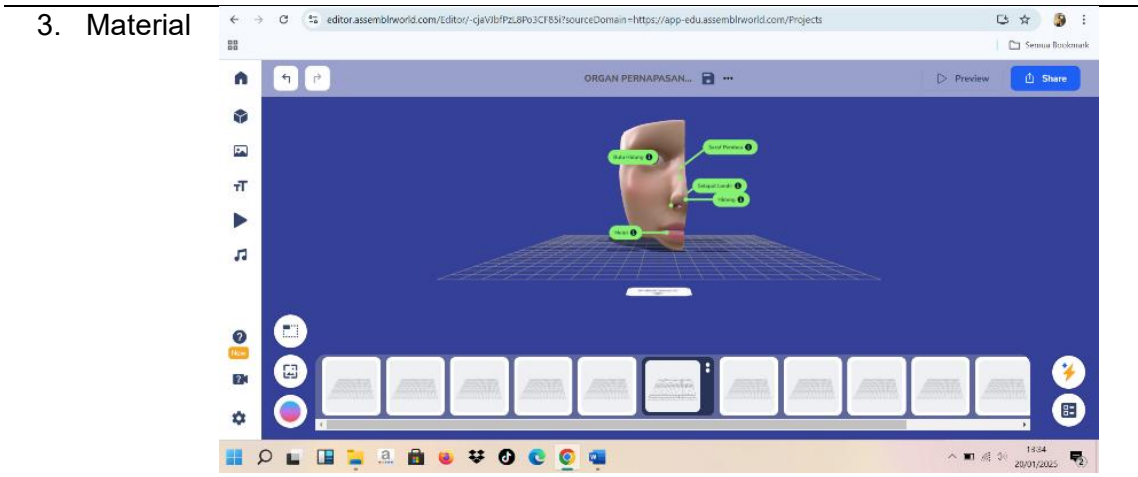
The design was based on the reported learning needs, student characteristics, and relevant IPAS learning outcomes (CP) and objectives (TP). The product was planned as an interactive resource focused on structures and functions of the human respiratory system. A storyboard organized the main interface, usage guidance, media information, curriculum objectives, and instructional content.

The prototype was created using Assemlr Edu. Screenshots documenting the developed product are presented in Table 4. The prototype included a main page, user guide, media information, curriculum objectives, and instructional materials.

Table 4.

Sample page of AR media prototype

No	Page	Visual Display
1.	Main	
2.	Guide	



3.3 Development of AR Media

The expert review covered technical properties of the media and the appropriateness of curricular and instructional content. The media assessment totaled 17 points across five indicators (mean 3.4), while the material assessment totaled 18 points across five indicators (mean 3.6). Both were reported as “Very Good” based on the authors’ categorization.

The expert assessments represent distinct dimensions of product appraisal. Technical evaluation addressed whether the interface and program elements were judged suitable for use, whereas material evaluation concerned the learning content and curriculum alignment. The five recorded ratings on each expert form permit verification of the arithmetic mean, but the number of independent validators within each expert category and the decision thresholds for the verbal ratings require confirmation. These limits matter because favorable average judgments establish only preliminary content and technical acceptability to the extent they are supported by the reported validation procedure.

Table 5.
Media and material expert evaluation (reported values)

Evaluator	Assessment dimension	Item scores	Total	Mean
Media expert	Usability, display, design, use, management	4, 4, 3, 3, 3	17	3.4
Material expert	Depth, student suitability, structure, content, title	4, 3, 3, 4, 4	18	3.6

The three participating teachers gave product evaluation means of 4.0, 3.8, and 3.4 across 10 items, respectively. These assessments were also described as “Very Good” in the original manuscript.

Table 6.

Teacher evaluation of AR media (reported scores)

Teacher evaluator	Items	Total score	Mean
Teacher 1	10	40	4.0
Teacher 2	10	38	3.8
Teacher 3	10	34	3.4

Student evaluations involved 26 pupils at MI Al-Huda Karangnongko and 27 at SDN Nanggulan, each completing ten items. Most ratings were in categories 3 and 4. The detailed response records are presented in Appendices A and B. The discrepancies between reported total scores and average scores require verification.

The student response distributions nevertheless offer a useful descriptive result independent of the disputed means: at both schools, no response was recorded in rating category 1, and the large majority of responses fell in categories 3 and 4. Because each student answered ten items, these counts refer to questionnaire responses rather than to unique pupils endorsing each category. Therefore, the distribution describes overall favorable item-level judgments, but it cannot identify which interface features pupils most valued, whether assessments differed by item, or how individual ratings related to the achievement measures. Those more detailed questions would require the item-level questionnaire documentation.

Table 7.

Distribution of students' media evaluation responses

School	Rating 1	Rating 2	Rating 3	Rating 4	Total responses
MI Al-Huda Karangnongko	0	3	83	174	260
SDN Nanggulan	0	2	152	116	270

3.4 Implementation and Evaluation of AR Media

AR-based media were used for Grade V learning activities on the human respiratory system at the two participating schools. The students first completed pretests, received instruction using the developed media, and then completed posttests and motivation questionnaires. Kolmogorov–Smirnov and Shapiro–Wilk tests were performed for the separate pretest and posttest distributions. Several p-values were below .05, indicating that not all of those distributions met the normality criterion. As presented in Table 10, paired-samples t-tests were reported for 53 pairs of observations. The mean difference, calculated as pretest minus posttest, was -14.36 for motivation and -15.72 for science learning outcomes. Both comparisons were reported as statistically significant, and negative mean differences indicate higher posttest scores.

Table 10.
Reported paired-samples tests of pretest–posttest differences

Outcome	Mean diff.	SD diff.	SE	t	df	p
Motivation	–14.35849	5.62308	.77239	–18.590	52	< .001
Science outcomes	–15.71698	9.78692	1.34434	–11.691	52	< .001

4. Discussion

4.1 Limited Classroom Interactivity and Teacher Constraints Create a Need for New Learning Media

The needs analysis showed that science instruction in MI Al-Huda Karangnongko and SDN Nanggulan frequently relied on textbooks and static presentations, while students reported limited engagement. This is compatible with earlier discussion of the relationship between instructional resources and science learning outcomes (Zannah, 2022; Agustira & Rahmi, 2022). Mukarromah and Andriana (2022) emphasize teachers' roles in preparing learning resources, while Abdullah et al. (2024) discuss the continuing importance of media in contemporary education. However, the preliminary observations do not establish that conventional media were the sole cause of students' difficulties, because motivation and achievement may reflect multiple learner and school factors.

Teachers also identified constraints involving preparation time, administrative commitments, technology familiarity, and available facilities. These conditions suggest that the feasibility of AR depends not only on its appearance but also on how it can be implemented in normal teaching. Depita (2024) associates digital resources with the possibilities of active learning, while Tarmidzi et al. (2025) identify implementation opportunities and challenges for AR in elementary education. The practical implication is that media development should be accompanied by clear learning objectives and teacher guidance rather than simply introducing a novel digital interface.

This distinction between technical availability and effective adoption is supported by international evidence on teacher readiness. Nikou (2024) investigated prospective teachers' intentions to use mobile AR in primary science and identified perceived usefulness as a pathway through which immersion and educational value related to adoption intentions. The present teachers were not assessed using that model, so their findings cannot be transferred as an observed mechanism. Nevertheless, the comparison underscores why a favorable product rating is insufficient to establish routine implementation: preparation, teacher confidence, instructional fit, and perceived value remain separate educational questions. For the participating schools, a realistic

application of the findings is therefore to consider the teacher support and practical resources necessary to use the existing AR product meaningfully, rather than assuming that the product alone will alter instruction.

4.2 Visualizing Abstract Respiratory Structures Supports the Pedagogical Value of Augmented Reality

The developed product provided visual representations of respiratory organs that are difficult to examine directly in the classroom. Its design is consistent with constructivist accounts of learning in which students actively construct meaning through engagement with representations and experiences (Tohari & Rahman, 2024). AR offers one possible way to relate descriptions of internal structures to their visible forms and spatial relationships (Purwanti et al., 2024). Nonetheless, a visual display does not automatically produce understanding; the nature of interaction, instructional explanation, and learning tasks remains important.

The product received positive evaluations from media and material experts and three teachers, together with predominantly high-category student ratings. These findings support a favorable perception of product features but should be interpreted cautiously until the student assessment means, validation categories, and instrument quality are confirmed. Positive usability and feasibility ratings are analytically distinct from measured changes in motivation and achievement.

The present study is related to earlier development work on AR media in elementary science and other subjects. Wibowo et al. (2022) examined AR media for animal classification, Sukma et al. (2023) developed media for the solar system, and Faiza et al. (2022) addressed social studies learning. Applications in geometry and animal recognition also demonstrate the variety of AR learning contexts (Sari et al., 2023; Wijaya, 2022). Importantly, the Grade V respiratory system has already been the subject of AR development research: Umam et al. (2024) focused on interactive media and user responses, while Ridho and Setyasto (2024) examined an Android-based product and science outcomes. Thus, the current study's defensible contribution is not the novelty of AR or respiratory-system content itself. Its context-specific contribution is the combination of media development and evaluation of both learning motivation and science outcomes across two schools.

In addition, Rosita et al. (2025) examined AR-supported learning of the human sensory system in Grade IV and reported improved retention-related performance following implementation; their research used a one-group pretest–posttest design involving two Islamic elementary schools. Similarity in topic area and design makes their study a useful comparator while also drawing attention to the limitations of before–and–after evidence. Marwah et al. (2025), by contrast, developed interactive digital materials through ADDIE for Grade II Arabic learning and documented expert, practitioner, and learner assessments. The first study

speaks more directly to AR visualization of human biology, whereas the second supports the rationale for systematically evaluating a digital instructional product. Together, they indicate that the contribution of the present work should be defined by its respiratory-system product, two learning-related outcome variables, and local deployment context, rather than the presence of either AR or ADDIE as such.

This cautious interpretation is supported by broader evidence. Chang et al. (2022) found benefits from AR across learning outcomes but also identified heterogeneity associated with intervention duration and design. Basumatary and Maity (2023) described benefits and implementation challenges in early and primary education, and Rohmani et al. (2024) synthesized evidence concerning AR in elementary science. These reviews indicate why media quality, pedagogy, and context should be considered together when interpreting findings from a single product implementation.

The larger K–12 STEM evidence base provides an additional counterweight to purely optimistic accounts. Jiang et al. (2025) synthesized 117 VR/AR studies and found both possible educational advantages and implementation difficulties concerning distraction, technical operation, teacher readiness, and school infrastructure. Those challenges matter for interpreting results from classrooms where conventional presentations had been prevalent, and teachers reported limited technological expertise. Moreover, Chang et al. (2022), in a meta-analysis of 134 experimental and quasi-experimental studies, identified variation across learning outcomes and noted the relevance of intervention duration and three-dimensional visualization design. These findings do not predict the present study's effect size; rather, they indicate that the observed score increases should be interpreted in relation to content, learning tasks, teacher guidance, and the unreported length of exposure.

4.3 Interactive Visualization May Explain Higher Motivation and Science Learning Scores

The reported paired comparisons indicated that students' motivation and science outcome scores were higher after AR-based learning activities, with mean differences of 14.36 and 15.72 points, respectively. One possible explanation is that interactive representations encouraged attention and made relationships among respiratory organs easier to visualize. This interpretation is consistent with work on student interest in AR-supported science activities (Samsiyanawati et al., 2023) and with discussions of AR applications for motivation (Zulfahmi & Wibawa, 2020). Ayundari and Manalu (2024) also investigated AR-supported biology education in a different school context. However, these comparisons should be treated as contextual parallels rather than direct replications.

The broader evidence base supports a qualified expectation of motivational benefits. Na and Yun (2024) synthesized K–12 experimental studies and found that AR interventions were associated with positive motivational outcomes, with design and collaborative learning identified as relevant moderators. Chang et al. (2022) likewise emphasized that gains differ across outcomes and implementations. In the present study, the motivational or cognitive mechanisms that produced the score changes were not independently measured. Claims about increased engagement or better visualization as mechanisms should therefore be understood as plausible explanations, not demonstrated mediating effects.

The distinction between motivation and conceptual achievement is particularly important here. A visually novel product may attract attention, while improved achievement requires pupils to relate images to curricular concepts and retain or apply that information. Neither pathway was independently measured in the present report. Its two posttest comparisons, therefore, show that the measured outcomes moved in the same direction but do not establish that motivation mediated learning, or that visualization improved conceptual understanding through a specific process. The comparison with Rosita et al. (2025), which emphasized retention, further highlights why a posttest improvement should not be equated with durable learning. Longer-term follow-up or process evidence would be required to test those interpretations.

Most importantly, the reported implementation did not include an identified comparison group or random assignment. Improvements may also reflect ordinary teaching exposure, repeated testing, or other contextual influences. The use of paired-samples t-tests additionally depends on the distribution of paired-score differences, an assumption not verified in the source analysis. These limitations do not invalidate the descriptive observation that posttest scores exceeded pretest scores, but they constrain claims that AR alone produced the differences.

Measurement and reporting issues place additional boundaries on interpretation. A statistically significant paired mean difference depends on the suitability of the outcome measure and the analytical assumptions, not merely on the size of the t statistic. The source report describes several significant normality tests for the individual score distributions, but it does not report the distribution of within-student differences required for the chosen paired test. In addition, some normality rows show 26 observations for the school, otherwise described as enrolling 27 participants, and the arithmetic of the student feasibility tables requires checking. Until those issues are reconciled, the strongest supported interpretation is that the recorded assessment means increased and that the product was evaluated favorably by participating users, subject to the limits of the reported instruments.

For practice, the findings support consideration of AR as one option for representing the location and relationships of respiratory organs, particularly when a textbook diagram or static presentation provides limited spatial information. Classroom use should nevertheless be connected to explicit IPAS objectives and accompanied by teacher explanation, questions that direct attention to relevant structures, and checks of understanding. These are implications informed by science-education literature and by the product's documented content, not instructional procedures verified as having been implemented during the trial. At the institutional level, the reported constraints point to the value of discussing device access, preparation time, and teacher familiarization before adopting the resource more widely. The teacher-adoption evidence synthesized by Nikou (2024) and the implementation challenges described by Jiang et al. (2025) support treating these conditions as matters for future evaluation rather than as already resolved in the participating schools.

Future research should also distinguish three evaluation targets that are sometimes merged in development articles: whether the product meets technical and content specifications, whether teachers and pupils can use it in an ordinary classroom, and whether it provides learning advantages over realistic alternatives. The present expert and user judgments primarily address the first two questions, whereas the before-and-after outcome scores only partially address the third. A stronger design would compare AR-supported teaching with a sufficiently specified alternative condition, document equivalent instructional exposure, assess reliability and item-level validity, and report separate descriptive results for each school alongside combined estimates when justified. Such a design would make it possible to evaluate when AR adds educational value beyond a more visually attractive mode of presentation.

The study, therefore, contributes context-specific development and preliminary evaluation evidence about AR-supported respiratory-system learning in elementary education. Future research should document the validation and reliability of outcome instruments, use suitably designed comparison groups, report classroom implementation details, and examine longer-term retention and conceptual understanding. These steps would help distinguish the effectiveness of the specific AR resource from other components of instruction.

5. Conclusion

This study developed and evaluated augmented reality-based interactive learning media for Grade V science learning on the human respiratory system through the ADDIE model. The product received favorable evaluations from media and materials experts, with average scores of 3.4 and 3.6, respectively, and was also evaluated positively by participating teachers and students. Reported pretest–posttest comparisons showed higher motivation and science

learning outcome scores following implementation in MI Al-Huda Karangnongko and SDN Nanggulan. These findings suggest that the developed media is a potentially useful instructional resource for visualizing concepts in elementary science.

The contribution of this study lies in the context-specific development and preliminary assessment of AR media together with two student outcome measures. However, the small two-school sample, absence of an identified comparison group, incomplete methodological reporting, and unresolved assessment-score discrepancies limit the strength of causal and generalizable conclusions. Further investigations should verify measurement quality, compare AR-supported instruction with appropriate alternatives, and assess longer-term learning and engagement outcomes.

Declarations

The final manuscript was approved by all authors, who declared no conflicts of interest. The research met ethical requirements, secured informed consent, and maintained participant confidentiality. Grammarly supported academic language refinement and citation consistency. No research data were generated through AI. The authors verified the manuscript and take full responsibility for its accuracy and integrity.

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