

DEVELOPMENT OF AUGMENTED REALITY (AR) LEARNING MEDIA ON HUMAN RESPIRATORY SYSTEM MATERIALS TO IMPROVE SCIENCE PROCESS SKILLS STUDENT V OF SD NEGERI PAKEL YOGYAKARTA

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ABSTRACT

This study developed an Augmented Reality (AR)-based learning medium and examined its potential to enhance fifth-grade students' science process skills in learning the human respiratory system. A Research and Development (R&D) approach was applied using a modified Borg and Gall model comprising ten stages, from potential and problem identification to final product development. The study involved five students in a limited trial and 58 students in the effectiveness test, consisting of 29 students in the experimental group and 29 in the control group. Data were collected through observations, interviews, expert validation, teacher and student response questionnaires, and pretest-posttest instruments. Qualitative data were analyzed descriptively, while quantitative data were examined using percentages, gain and N-Gain scores, normality and homogeneity tests, and an independent samples t-test. The results indicated a high level of media feasibility, with validation scores of 97.5% from the material expert and 95% from the media expert. Student responses reached 97.5% in the limited trial and 97.8% in the wider implementation, while the teacher response was 95%. The experimental group achieved an average N-Gain of 0.7009, categorized as high, compared with 0.2221, categorized as low, in the control group. The pretest difference was not significant ($p = 0.276$), whereas the posttest difference was significant ($p < 0.001$). These findings suggest that AR-based learning media has potential to support science process skills development.

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INTRODUCTION

Natural Science (IPA) learning in elementary school has an important role in building science literacy, critical thinking skills, and understanding of scientific concepts from an early age. Science learning is not only oriented to mastering facts, but also needs to provide opportunities for students to make observations, exploration, reasoning, and scientific communication (Angelia et al., 2022; Muliadi et al., 2022). Consistent with the principles of the Independent Curriculum,

science instruction should emphasize contextual, student-centered learning experiences that enable learners to connect scientific concepts with phenomena encountered in their everyday lives. Learning that provides students with the opportunity to connect science concepts with real experiences is also considered important in building more meaningful conceptual understanding (Bybee, 2018; Krajcik & Merritt, 2018)

One of the science topics in elementary education that involves relatively abstract concepts is human respiration. The material includes the structure and function of organs in the body as well as breathing mechanisms that cannot be directly observed by students (Hokayem & Gotwals, 2016; Ibáñez & Delgado-Kloos, 2018). This condition can cause students to have difficulty in building mental representations of the relationship between organ structure and physiological processes. The predominant use of two-dimensional images and verbal explanations is also not fully able to provide the visual and spatial experience necessary to understand the concept. Limitations in visualizing internal biological structures can lead to the formation of simple or inconsistent understandings of scientific concepts (Heiser & Tversky, 2016; Muslim et al., 2023; Nieveen, 2018).

These problems are also found in science learning at SD Negeri Pakel Yogyakarta. Based on initial observations and interviews with classroom teachers, learning material on the human respiratory system still makes a lot of use of textbooks and static images. Students are relatively able to identify the names of respiratory organs, but still have difficulty when asked to explain the working mechanism and the relationship between components of the respiratory system in sequence. This situation highlights a mismatch between the learning requirements, which emphasize students' ability to comprehend processes and conceptual relationships, and the learning media currently available to support such understanding. For this reason, instructional media should be designed to make biological structures and processes easier to visualize while providing interactive learning experiences that correspond to the developmental and learning characteristics of elementary school students. The use of digital technology, especially augmented reality (AR), has the potential to be an alternative to overcome these problems. AR allows three-dimensional virtual objects to be displayed in a real environment so that students can observe, manipulate, and explore objects that were previously difficult to observe directly (Kucuk et al., 2020; Kurniawati & Widodo, 2020). In science learning, these characteristics allow abstract concepts to be visualized more concretely and provide a more interactive learning experience. A number of studies show that the use of AR can support students' conceptual understanding, learning engagement, and visual-spatial ability in learning abstract objects or phenomena (Garzón & Acevedo, 2019; Ibáñez & Delgado-Kloos, 2018).

The advantages of AR are becoming increasingly relevant in learning the human respiratory system because students can obtain three-dimensional representations of organ structures, intercomponent relationships, and mechanisms of the respiratory process (Nida et al., 2021; Rahmatika et al., 2023). Models that can be observed from various points of view have the potential to help students build relationships between the shapes, positions, functions, and working mechanisms of organs in a more integrated manner. In addition, an interactive learning environment can provide opportunities for students to explore objects independently so that learning is not only centered on the delivery of information by teachers. However, the effectiveness of AR is not only determined by its use of technology, but also by the quality of instructional design, content suitability, visual representation quality, and its relationship to learning objectives (Dunleavy & Dede, 2019; Yuen et al., 2020).

Although research on AR in education continues to grow, its application at the elementary school level still faces a number of challenges. The development of AR media needs to consider the cognitive characteristics of students, ease of use, suitability of the material with the curriculum, and pedagogical aspects that support the achievement of learning goals (Sari & Suyanto, 2019; Setiawan & Haq, 2020). Media that only displays three-dimensional objects without a clear design of learning activities risks making AR just a visual technology, not a learning medium that can improve the quality of the learning process. Therefore, the development of AR media needs to be carried out through a systematic research and development process, including needs analysis, product design, validation, practicality tests, and effectiveness testing (Anggraeni et al., 2024; Untari et al., 2022)

Previous studies have demonstrated the potential of augmented reality (AR) to support science learning by providing three-dimensional visualization of abstract concepts, increasing students' engagement and motivation, and improving learning outcomes. However, much of the existing research on AR in science education has focused on learning achievement,

conceptual understanding, motivation, or the visualization of scientific phenomena. Comparatively, limited attention has been given to the use of AR specifically to support students' science process skills, particularly in elementary school science learning. This gap is particularly relevant because elementary science instruction is expected to go beyond conceptual understanding by engaging students in meaningful activities that involve observing, identifying, classifying, interpreting, and communicating scientific information through concrete and exploratory learning experiences. In addition, the human respiratory system involves structures and physiological processes that are difficult for elementary school students to observe directly, making it a relevant context for the use of interactive AR media. Therefore, there is a need for AR learning media that is specifically designed for Grade V students, aligned with elementary science learning objectives, and empirically tested for its validity, practicality, and effectiveness in supporting science process skills.

This research focuses on creating an Augmented Reality (AR) learning medium for teaching human respiration in fifth-grade elementary science and evaluating its validity, practicality, and effectiveness in supporting students' science process skills. The proposed medium is positioned not simply as a technological product but as an instructional resource developed around pedagogical considerations, combining visual representations with interactive activities that engage students in the learning process. Using a Research and Development (R&D) methodology, the study seeks to contribute to the advancement of AR-supported science instruction at the elementary school level, particularly by helping learners explore biological concepts that are difficult to understand through conventional representations. From a practical perspective, the resulting medium can serve as an additional instructional option for teachers to represent human respiratory processes in a visual, interactive, and exploratory format. At the same time, its use is intended to encourage students to participate actively in activities involving observation, exploration, interpretation, and other science process skills.

METHOD

A Research and Development (R&D) design was adopted to produce an Augmented Reality (AR)-supported learning medium for teaching human respiration in elementary science. The product development process was adapted from the Borg and Gall framework and implemented through ten sequential phases. These phases comprised: (1) identifying potentials and problems, (2) gathering information related to learning needs, (3) developing the preliminary product design, (4) conducting expert assessment, (5) revising the initial product, (6) carrying out a preliminary field trial, (7) undertaking a subsequent product revision, (8) implementing an operational field trial and evaluating its effectiveness, (9) completing the final revision, and (10) producing the finalized learning medium.

The developed product consisted of an AR application presenting three-dimensional models and animations of the human respiratory system, AR-integrated learning worksheets, and a teacher guide. The study used qualitative and quantitative data. The study generated qualitative evidence through classroom observations, interviews, field documentation, and feedback provided by experts. Quantitative information was collected using expert validation instruments, teacher and student response questionnaires, as well as students' pretest and posttest results.

The subjects consisted of material and media experts, teachers, and fifth-grade students. The experts were selected purposively based on their relevant expertise. Teachers were involved as practitioners to assess the practicality and usability of the product.

Preliminary field testing was designed as a small-group trial involving approximately 8–12 students. In the actual implementation, however, the limited product trial involved five fifth-grade students at SD Negeri Giwangan Yogyakarta. This trial was conducted to obtain students' initial responses and identify usability, visual, instructional, and technical problems before broader testing. The small number of participants was intended to facilitate focused product revision, minimize potential bias from prior product experience, and reduce practice effects before larger-scale testing.

The next phase of the study took place at SD Negeri Pakel Yogyakarta and involved an effectiveness assessment with 58 fifth-grade students. The participants were divided into two groups of equal size, with 29 students assigned to the experimental group and 29 to the control group. Students in both groups were assessed before and after the learning intervention. During the intervention, the experimental group learned with the developed AR medium, whereas the control group received instruction using the learning approach routinely applied in the classroom.

The ten development stages were implemented as follows:

1. Analysis of Potentials and Problems: Classroom observations and teacher interviews were conducted to identify learning problems and the need for interactive media in teaching the human respiratory system.
2. Needs Data Collection: Curriculum analysis, literature review, and information from teachers and students were used to determine the content and features required in the AR media.
3. Initial Product Design: The AR application, three-dimensional respiratory organ models, animations, learning worksheets, and teacher guide were designed.
4. Expert Validation: Material and media experts assessed the accuracy, suitability, visual quality, navigation, and technical aspects of the product.
5. First Revision: The product was revised based on expert suggestions.
6. Preliminary Field Testing: A small-group trial was designed for 8–12 students, but the actual trial involved five fifth-grade students at SD Negeri Giwangan Yogyakarta. The trial focused on students' initial responses, ease of use, clarity of instructions, appearance, and technical constraints.
7. Second Revision: Improvements were made based on findings from the preliminary trial.
8. Operational Field Testing and Effectiveness Testing: The effectiveness trial was carried out at SD Negeri Pakel Yogyakarta involving 58 fifth-grade students. The participants were divided into an experimental group and a control group, with 29 students assigned to each group. Pretest and posttest assessments were administered to both groups to identify changes following the learning intervention. The experimental group received instruction supported by the developed AR medium, while the control group participated in learning activities using the approach ordinarily implemented in the classroom.
9. Final Revision: The product was refined based on the results of the operational testing and user feedback.
10. Final Product: The final AR application, learning worksheets, and teacher guide were prepared for use in elementary school science learning.

Information required for the study was obtained from several sources, including classroom observations, interviews, questionnaires, achievement tests, and supporting documentation. The results of expert evaluations and responses from teachers and students were summarized quantitatively by converting the obtained scores into percentages. Meanwhile, qualitative evidence derived from observations, interviews, field records, and expert feedback was examined through a systematic process involving data condensation, presentation of the findings, and formulation of conclusions.

To determine the learning impact of the developed product, students' pretest and posttest results from the experimental and control groups were compared. The gain score represented the change between the posttest and pretest results, whereas normalized gain (N-Gain) was determined using the following formula:

$$N - Gain = \frac{(Post Test - Pre Test)}{(Maximum Score - Pre Test)} \dots\dots\dots(1)$$

The resulting N-Gain values were classified into three levels: high (≥ 0.70), moderate (0.30–0.69), and low (< 0.30). Prior to conducting the comparative analysis, the data were examined for normality and homogeneity. An independent-samples t-test was subsequently applied to determine whether the two groups differed significantly. Analysis of the pretest scores was intended to identify the comparability of the groups before treatment, whereas posttest analysis was used to determine differences in learning outcomes following the intervention.

The quality of the developed medium was determined according to three aspects: validity, practicality, and effectiveness. Validity was established based on whether the expert evaluation met the specified validity standard. Practicality was determined from teacher and student responses in relation to the established practicality criterion. Effectiveness was evaluated by considering changes between pretest and posttest scores, N-Gain results, and statistical comparisons between groups. The product was regarded as effective when these indicators demonstrated learning improvement and group differences that corresponded with the objectives of the study.

RESULT AND DISCUSSION

Result

The AR learning medium was developed through an adaptation of the Borg and Gall R&D framework. The development procedure comprised ten sequential activities, beginning with the identification of potential and learning problems, followed by information gathering, preliminary product design, expert review, initial revision, limited-scale testing, further revision, operational use testing, final refinement, and completion of the final product.

The initial analysis was conducted with Grade V teachers and students at SD Negeri Pakel Yogyakarta. The teacher interviews indicated that learning on the human respiratory system primarily relied on textbooks and two-dimensional images. Student interviews indicated an interest in more interactive learning media. The initial assessment also indicated that students' understanding of the human respiratory system material still required improvement. These findings were used as the basis for developing AR media that presents respiratory organs and respiratory mechanisms through three-dimensional visualization.

Data collection involved analysis of the Grade V IPAS textbook, literature review, teacher and student interviews, and analysis of learning media needs. The developed product consists of AR media presenting three-dimensional representations of the human respiratory system. The media contains two QR codes: the first provides visualization of the lung organs, while the second presents the processes of inspiration and expiration. The product was designed with a simple interface and visual elements appropriate for elementary school students.

The preliminary AR product underwent assessment by two specialists, namely a material expert and a media expert. The material evaluation resulted in 39 of the maximum 40 points, equivalent to 97.5%, whereas the media evaluation obtained 38 points from 40, corresponding to 95%. Based on the predetermined feasibility criteria, both assessments placed the developed medium in the highly feasible category.

Table 1. Product Validation Results

Validator	Score	Maximum Score	Percentage	Criteria
Material Expert	39	40	97.5%	Highly Feasible
Media Expert	38	40	95.0%	Highly Feasible

Source: Researcher's Processed Data, 2026

The material expert recommended improving the alignment of the content with the Grade V IPAS textbook and clarifying the explanation of inspiration and expiration. The media expert recommended enlarging images and arrows and using different colors for respiratory organs. These suggestions were incorporated into the product before the limited trial.

The limited product trial involved five Grade V students at SD Negeri Giwangan Yogyakarta. The trial was conducted to obtain students' initial responses to the developed AR media.

The media obtained a score of 195 out of 200, corresponding to 97.5%, and was categorized as excellent. The questionnaire covered aspects of interest, ease of use, appearance, understanding, motivation, interaction, comfort, benefits, effectiveness, and expectations regarding the use of the media.

The usage trial was conducted with Grade V students at SD Negeri Pakel Yogyakarta. The data included student responses, teacher responses, observations, interviews, and pretest–posttest scores.

Student responses obtained a score of 1,135 out of 1,160 (97.8%), while the teacher response obtained 38 out of 40 (95.0%). Both were categorized as excellent.

Table 2. User Response Results

Respondent	Score	Maximum Score	Percentage	Criteria
Students	1,135	1,160	97.8%	Excellent

Respondent	Score	Maximum Score	Percentage	Criteria
Teacher	38	40	95.0%	Excellent

Source: Researcher's Processed Data, 2026

Observation data showed that students participated in learning activities, used the AR media according to the instructions, and engaged in discussion. Some students required initial guidance when using the media. Interview data indicated that students generally reported that the media was easy to use and visually interesting, while the teacher reported that the media could be integrated into the learning process.

The product effectiveness assessment was conducted with 58 fifth-grade students, divided equally between the experimental and control groups, with 29 students in each group. Before comparing the learning outcomes, the distribution of the data was examined using the Shapiro-Wilk normality test. In the experimental group, the significance values were 0.199 for the pretest and 0.060 for the posttest. Meanwhile, the control group recorded significance values of 0.086 and 0.099 for the pretest and posttest, respectively. Since all significance values exceeded 0.05, the data in both groups met the normality assumption.

Variance equality was then examined through a homogeneity test. The analysis yielded significance values of 0.140 for the pretest and 0.138 for the posttest. Both results were above the 0.05 threshold, suggesting that the variances of the experimental and control groups were homogeneous.

Following the prerequisite tests, differences between the two groups were examined using an independent-samples t-test. The analysis of pretest scores resulted in a significance value of 0.276, indicating that the groups did not differ significantly prior to the intervention. In contrast, the posttest analysis generated a significance value of 0.000, demonstrating a statistically significant difference in learning outcomes between the experimental and control groups following the intervention.

Table 3. Pretest, Posttest, and Gain Scores

Class	Mean Pre-Test	Mean Post-Test	Gain Score
Experimental	52.31	85.90	33.59
Control	49.72	61.90	12.18

Source: Researcher's Processed Data, 2026

The comparison of learning outcomes showed an increase in both groups. In the experimental group, the average score rose from 52.31 on the pretest to 85.90 on the posttest, corresponding to an increase of 33.59 points. The control group showed a smaller change, with the mean score increasing from 49.72 to 61.90 and producing a gain of 12.18 points.

Further analysis using normalized gain indicated that students who learned with the AR medium achieved an average N-Gain of 0.7009 (SD = 0.09675). Individual N-Gain values ranged from 0.50 to 0.88. According to the predetermined interpretation criteria, the average N-Gain obtained by the experimental group fell within the high category.

For the control class, the mean N-Gain score was 0.2221 (SD = 0.19435), with scores ranging from -0.27 to 0.49. This value was categorized as low.

Table 4. N-Gain Results

Class	N	Mean N-Gain	SD	Category
Experimental	29	0.7009	0.09675	High
Control	29	0.2221	0.19435	Low

Source: Researcher's Processed Data, 2026

Overall, the descriptive results show a greater increase in the experimental class than in the control class. The inferential analysis also showed a significant posttest difference between the two groups ($p < 0.001$), while no significant pretest difference was found ($p = 0.276$). These findings provide the basis for further discussion of the potential effectiveness of the developed AR media.

Discussion

Expert evaluation demonstrated that the developed AR-based learning medium met a high level of feasibility. The material expert score of 97.5% and media expert score of 95% indicate that the product met the assessed criteria for content and media quality. These results can be attributed to the systematic development process in which expert feedback was incorporated into product revisions. Adjustments to the alignment of the material with the Grade V IPAS textbook, clarification of inspiration and expiration processes, enlargement of visual elements, and differentiation of organ colors improved the suitability of the product for its intended users.

The high student and teacher responses also indicate that the media was well accepted in the learning context. The student response of 97.8% and teacher response of 95% suggest that the AR media was perceived as attractive, accessible, and practical to use. The result may be attributed to the integration of three-dimensional representations and a relatively straightforward QR-code-based access mechanism. For elementary school students, visual representations may provide more accessible learning objects when the content involves structures and processes that cannot be directly observed. However, these response results should be interpreted as evidence of acceptance and perceived practicality rather than direct evidence of improved science process skills.

The effectiveness analysis further supports the potential role of the developed medium in fostering students' science process skills. Students in the experimental group achieved a gain score of 33.59 and an average N-Gain of 0.7009, which was classified as high. By comparison, the control group recorded a gain score of 12.18 and an N-Gain of 0.2221, falling into the low category. The statistical analysis also showed that the groups were comparable at the beginning of the intervention, as indicated by the nonsignificant pretest result ($p = 0.276$). Following the intervention, a significant difference was observed in the posttest scores ($p < 0.001$). Taken together, these results show that the experimental group experienced a greater improvement in learning outcomes than the control group, accompanied by a statistically significant difference in posttest performance.

The relatively higher improvement in the experimental group may be associated with the representational and interactive characteristics of AR. The three-dimensional visualization enables students to examine respiratory organs from different perspectives and observe the processes of inspiration and expiration through dynamic representations. Such features are relevant to science process activities, particularly observing, identifying, comparing, and communicating information. In this context, AR does not merely function as a visual display but provides objects that students can explore during learning activities.

The result aligns with evidence from earlier studies of technology-supported science learning, which generally suggests that interactive and visually oriented learning environments can enhance student engagement and make abstract scientific concepts more accessible. However, the present findings should not be interpreted as demonstrating that AR alone caused the observed improvement. The study used a pretest–posttest comparison and an independent sample t-test, while effect size analysis and statistical testing of gain-score differences were not reported. Therefore, the higher gain and N-Gain scores provide descriptive evidence favoring the experimental group, while the significant posttest difference provides inferential evidence of differences between the groups after the learning intervention.

The findings also highlight the importance of integrating AR with learning activities rather than treating the technology as an independent instructional strategy. The developed media was accompanied by learning activities that required students to observe and explore the respiratory system. Consequently, the observed improvement may reflect the combined contribution of the AR visualization, learning activities, teacher facilitation, and students' engagement during instruction.

The study suggests that the developed AR media is highly feasible, well accepted by teachers and students, and shows a favorable pattern of improvement in the measured science process skills. The findings provide practical evidence for the use of AR in teaching the human respiratory system in elementary schools. Nevertheless, further research involving larger samples, effect-size analysis, and statistical comparison of gain scores or ANCOVA is needed to provide stronger evidence regarding the effectiveness of AR in developing students' science process skills.

CONCLUSION

The Augmented Reality (AR)-based learning media for the human respiratory system was successfully developed for Grade V elementary school science learning. Expert validation indicated a high level of feasibility, with a score of 39 out of 40 (97.5%) from the material expert and 38 out of 40 (95%) from the media expert. The limited trial produced a student response of 97.5%, while the wider implementation resulted in a student response of 97.8% and a teacher response of 95%. These findings indicate that the developed media was highly feasible and well accepted by users.

Analysis of the measured science process skills revealed different patterns of improvement between the two groups. In the experimental group, the mean score increased from 52.31 in the pretest to 85.90 in the posttest, producing a gain of 33.59 points and an N-Gain value of 0.7009, which was classified as high. The control group, in contrast, showed an increase from 49.72 to 61.90, corresponding to a gain of 12.18 points and an N-Gain of 0.2221, categorized as low. Although the initial comparison showed no significant difference between the groups ($p = 0.276$), the post-intervention analysis identified a statistically significant difference in posttest scores ($p < 0.001$). The results therefore demonstrate a more pronounced improvement in the experimental group and a significant difference in achievement following the learning intervention.

Despite this pattern, the results should be interpreted with appropriate caution. The analysis did not incorporate an effect-size measure or a direct statistical comparison of gain scores. Consequently, the findings demonstrate a favorable improvement pattern associated with the AR-supported learning intervention, but they do not by themselves establish a definitive causal effect of AR media on students' science process skills.

From an instructional perspective, the developed AR medium shows potential as a learning resource for representing the human respiratory system through three-dimensional visualization. To strengthen the evidence in future studies, research should include larger and more heterogeneous participant groups and apply additional statistical procedures, including effect-size analysis, direct gain-score comparisons, or ANCOVA. Such approaches would allow a more comprehensive assessment of the contribution of AR-based learning to the development of students' science process skills.

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