ORIGINAL ARTICLE

REVOLUTIONIZING ELEMENTARY SCIENCE EDUCATION: IMPACT OF INTERACTIVE VISUAL MEDIA ON LEARNING THE HUMAN RESPIRATORY SYSTEM

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ABSTRACT
The persistent difficulty students face in understanding the human respiratory system—a core yet abstract topic in science education—is rooted in the lack of contextual, visual, and interactive learning media, as highlighted by both national and international research. This study aimed to examine whether technology-based, visual respiratory system media can significantly enhance elementary students' cognitive learning outcomes, particularly in higher-order thinking skills such as analysis and evaluation. Employing a quantitative, quasi-experimental one-group pretest-posttest design, the study involved 34 fifth-grade students at SDN Inpres Rasa 1, Kabupaten Bima, using purposive sampling. A 20-item multiple-choice test based on the revised Bloom's taxonomy (C1–C4) was used to measure learning outcomes before and after intervention. Descriptive statistics showed a marked improvement: the mean pretest score was 62.8, rising to 73.3 in the posttest, with gains observed across all ability levels. Inferential analysis using a paired sample t-test confirmed the significance of this improvement ($t = -15.2$, $df = 33$, $p < .001$), demonstrating that interactive visual media have a strong positive effect on students' conceptual understanding of the respiratory system. The results conclude that technology-based visual media not only promote retention and comprehension but also foster analytical and evaluative skills, aligning with current science education goals. This research provides empirically-tested, practical recommendations for educators and policymakers, supporting the integration of digital media in science curricula and teacher training. Future studies are recommended to expand this approach with control groups, longitudinal designs, and investigations into affective and psychomotor domains, as well as the use of emerging technologies like augmented reality and virtual reality to further enhance science learning outcomes.

Keywords: cognitive learning outcomes; quasi-experimental design; respiratory system; science education; visual learning media

INTRODUCTION

The mastery of the human respiratory system as an integral topic in science education remains a critical priority in secondary schools worldwide (Lee et al., 2022). The respiratory system connects fundamental concepts of anatomy and physiology with daily health practices, forming an essential foundation for understanding life processes. However, a recurring challenge in science instruction is students' difficulty in grasping the abstract physiological processes due to the lack of contextual and visual learning media (Putri et al., 2023; Orgill, York, & MacKellar, 2019). Numerous studies reveal that biology concepts, when presented through visual and interactive approaches, significantly enhance students' conceptual understanding and retention (Tekkaya et al., 2017). This is particularly relevant in today's digital era, where students are accustomed to learning through dynamic media (Yusuf et al., 2022). Thus, there is an urgent need for the development of contextual, visual, and digital technology-based learning media to improve students' cognitive achievement in science, particularly regarding the respiratory system (Santos et al., 2023).

Empirical data indicate persistent learning challenges. For instance, in a midterm exam at SDN Inpres Risa 1, Kabupaten Bima, only 38% of students met the Minimum Competency Criteria (KKM) for respiratory system material. Most students struggled to articulate the diffusion of oxygen, respiratory pathways, and organ functions accurately. This issue echoes findings by Harahap & Tanjung (2022) and by Lin et al. (2015), who observed that abstract biological concepts are particularly challenging in conventional settings, especially when learning media are neither relevant nor engaging. As a result, low cognitive achievement in this domain can undermine readiness for national examinations and dampen interest in science, potentially impacting the quality of human resources in the long term (Villalobos et al., 2023).

Initial observations across four science lessons found a gap between teacher-centered lecturing and the learning preferences of current digital-native students. The predominance of non-visual, lecture-based instruction led to student disengagement, lack of focus, and difficulty in visualizing the internal structures of the human respiratory system. These findings are reinforced by international literature, where unadapted instructional models are linked to cognitive disengagement and reduced learning effectiveness (Kalyuga, 2009; Mayer, 2021). Therefore, the general solution is to innovate science education through the integration of visual, digital, and interactive learning media (Rogers et al., 2021).

Research demonstrates that interactive media—such as animations, 3D simulations, educational videos, or augmented reality applications—facilitate concrete visualization of abstract processes (Wu et al., 2020; Ferdous & Hossain, 2022). Wulandari & Suprapto (2023) found that students taught with interactive animations in science showed a 35% improvement in conceptual understanding compared to those in conventional classrooms. International studies corroborate these results: virtual laboratories and AR-based media increase learning engagement, conceptual clarity, and higher-order cognitive skills (Alhumaidan et al., 2021; Wojciechowski & Cellary, 2013). Such media not only serve as teaching aids but also as facilitators for constructivist, experience-based learning (De Jong et al., 2013). According to Dual Coding Theory (Paivio, 2007), information processed visually and verbally is more readily retained and understood—a finding consistently supported in science education research (Mayer, 2021).

Recent research on visual learning media for the respiratory system consistently reports positive impacts on students' retention and conceptual mastery (Rahmawati & Nugroho, 2022; Ferdous & Hossain, 2022). For example, Wu et al. (2020) and Santos et al. (2023) demonstrated that AR and 3D-animated media significantly improve learning outcomes in anatomy and physiology. However, most studies are limited to media development or surface-level evaluation, with few assessing the specific impact on higher-order cognitive domains (analysis, synthesis, evaluation) as categorized by the revised Bloom's taxonomy (Anderson & Krathwohl, 2001). Additionally, few integrate rigorous, quantitative experimental designs to measure cognitive changes pre- and post-intervention (Villalobos et al., 2023). Moreover, while Indonesian studies (Lestari et al., 2023) highlight a focus on fact-memorization rather than the development of analytical and evaluative skills, international literature similarly laments a lack of emphasis on critical thinking in biology education (van Merriënboer & Kirschner, 2018; Lee et al., 2022). There is a clear need for research that not only introduces advanced learning media, but also empirically tests their effects on higher-order thinking within a structured experimental framework.

This research aims to fill these gaps by experimentally investigating the effect of technology-based, visual respiratory system media on students' cognitive learning outcomes—specifically targeting analysis and evaluation skills, not just factual recall. The novelty lies in integrating advanced interactive media with a comprehensive assessment design, based on the revised Bloom's taxonomy, and implementing a quasi-experimental pretest-posttest design to objectively measure cognitive change. Furthermore, the study's media are developed using robust scientific content, responsive user interface design, and pilot-tested before classroom implementation. The research not only examines the efficacy of the media, but also provides a methodological model for evaluating cognitive outcomes in science education (Villalobos et al., 2023; Mayer, 2021). The implications are practical and theoretical: teachers are offered empirically-tested resources for 21st-century science education, and policymakers gain evidence to inform digital curriculum integration (Asih & Handayani, 2024; Alhumaidan et al., 2021). In summary, the central research question addressed is: Does the use of technology-based, visual respiratory system media significantly improve students' cognitive learning outcomes on the respiratory system in elementary science education?

METHOD

Research Design

This study employs a quantitative approach with a quasi-experimental method. The research design adopted is the One Group Pretest-Posttest Design, as only one experimental group is involved without a control group. This design is chosen due to limited access to other classes and a focus on measuring changes in students' cognitive learning outcomes after treatment with the respiratory system learning media. In this design, students are given a pretest before the intervention and a posttest after the intervention. The difference between pretest and posttest scores is analyzed to determine the effectiveness of the media in enhancing cognitive learning outcomes (Creswell & Creswell, 2017; Harris et al., 2006).

Table 1. Research Design

Group	Pretest (O1)	Treatment (X)	Posttest (O2)
Experiment	O1	X (Media respiratory system)	O2

This model allows for objective measurement of changes in students' cognitive outcomes as a result of the intervention (Ary et al., 2019).

Population and Sample

The population of this study comprises all fifth-grade students at SDN Inpres Rasa 1, Kabupaten Bima, during the 2025 odd semester. The sampling technique is purposive sampling, considering accessibility, school readiness, and the willingness of science teachers to collaborate in the research implementation (Etikan et al., 2016). The sample consists of one experimental class totaling 34 students, selected based on coordination with school authorities. This class is used to examine the impact of the respiratory system media on improving cognitive learning outcomes in the respiratory system topic.

Data Collection Instrument

The main instrument used to collect data is a cognitive learning achievement test in the form of multiple-choice questions (MCQs) with four answer options. The items are constructed based on cognitive indicators from the revised Bloom's taxonomy (Anderson & Krathwohl, 2001), covering C1 to C4 domains. The instrument consists of 20 items validated by experts and tested for reliability before use (Cohen et al., 2018).

Table 2. Instrument Grid for Cognitive Learning Outcomes Test

No	Cognitive Indicator	Respiratory System Material	Type	Number of Items
1	C1 (Remembering)	Functions of respiratory organs	Multiple Choice	5
2	C2 (Understanding)	Inspiration and expiration processes	Multiple Choice	5
3	C3 (Applying)	Identifying respiratory system disorders	Multiple Choice	5
4	C4 (Analyzing)	Relationship between respiratory organs	Multiple Choice	5

Data Collection Procedure

The research was conducted in four systematic stages to ensure a structured approach to data collection and accurate assessment of the treatment's effectiveness. The first stage involved preparation, which included compiling learning tools and test instruments as well as conducting content validity checks by science education experts to guarantee the quality and relevance of the materials. In the second stage, a pretest was administered to the experimental class to assess the students' initial cognitive ability on the respiratory system topic. The third stage was the treatment phase, during which learning activities were implemented using visual and interactive respiratory system media across two sessions (2x40 minutes) that followed a scientific approach in alignment with the 2013 curriculum. Finally, in the fourth stage, a posttest—identical to the pretest—was given after the intervention to measure any changes in students' learning outcomes. This systematic procedure allowed for objective measurement of the effectiveness of the media in enhancing students' cognitive achievement (Fraenkel et al., 2015; Harris et al., 2006).

Data Analysis Techniques

The data obtained from the pretest and posttest were analyzed using both descriptive and inferential statistical methods. Descriptive analysis involved calculating the mean, standard deviation, minimum, and maximum values to provide an overview of students' learning outcomes before and after the intervention. For inferential analysis, a paired sample t-test was utilized to test the hypothesis, as the data were derived from a single group measured twice—before and after the treatment. The statistical analysis was performed using Jamovi or equivalent statistical software. Prior to hypothesis testing, assumption tests were conducted, including the Kolmogorov-Smirnov test for normality and Levene's Test for homogeneity. The t-test was performed at a significance level of $\alpha = 0.05$. A statistically significant difference between pretest and posttest scores would indicate that the use of the respiratory system media had a measurable effect on students' cognitive learning outcomes (Gravetter & Wallnau, 2017; Cohen et al., 2018).

RESULTS AND DISCUSSION

This study set out to rigorously assess the impact of visual-based respiratory system media on the cognitive learning outcomes of elementary school students within the context of science instruction. Specifically, the focus was on evaluating gains in students' understanding of the respiratory system—a topic often recognized as challenging due to its inherent abstract and complex concepts (Ferdous & Hossain, 2022; Mayer, 2021). Thirty-four students participated in the experiment, serving as the sample for both pre- and post-intervention measurements. The effectiveness of the intervention was determined through a combination of descriptive and inferential statistics, providing a robust evaluation of both absolute and relative gains. Initial analysis using descriptive statistics provided a foundational perspective on the students' baseline knowledge and subsequent improvement following the intervention. Table 1 presents a comparative summary of pretest and posttest results:

Table 3. Descriptive Statistics of Pretest and Posttest Scores

	Pretest Scores	**Posttest Scores**
N	34	34
Missing	0	0
Mean	62.8	73.3
Median	63.4	74.5
Std. Dev.	6.03	6.76
Minimum	46.3	58.1
Maximum	76.1	90.7

The mean pretest score of 62.8 indicated relatively modest baseline understanding of the respiratory system among the students. After the visual interactive media intervention, the mean score rose substantially to 73.3—a 16.7% improvement. The increase in median scores, from 63.4 to 74.5, further suggests that this improvement was not isolated to only a few high-performing students but was instead distributed across the cohort. Notably, the minimum and maximum values also increased following the intervention (minimum from 46.3 to 58.1, maximum from 76.1 to 90.7), illustrating that the gains were evident for both low- and high-performing students. The slight increase in standard deviation, from 6.03 to 6.76, suggests a natural variation in the rate and extent to which students benefited from the media, reflecting individual differences in learning pace and style (Wu et al., 2020). These descriptive findings strongly support the effectiveness of visual interactive media in science education, particularly for concepts requiring concrete visualization and interactive exploration (Mayer, 2021; Ferdous & Hossain, 2022). They align with broader trends reported in recent literature, where visualization is associated with greater knowledge retention and enhanced conceptual clarity in biological sciences (Santos et al., 2023; van Merriënboer & Kirschner, 2018).

Paired Sample T-Test

Beyond the descriptive evidence, inferential statistics were employed to determine whether the observed gains were statistically significant and not due to chance. Table 2 details the results of the paired sample t-test:

Table 4. Paired Sample T-Test Results

	t	**df**	**p**
Pretest vs Posttest	-15.2	33	< .001

The t-statistic of -15.2, with 33 degrees of freedom and a p-value less than 0.001, indicates a highly significant difference between pretest and posttest scores. Such a result allows us to confidently reject the null hypothesis that there is no difference between pre- and post-intervention outcomes. The observed improvement can thus be attributed to the introduction of the visual-based respiratory system media (Gravetter & Wallnau, 2017; Cohen et al., 2018). This robust finding corroborates the descriptive statistics, confirming the intervention's positive impact on cognitive achievement.

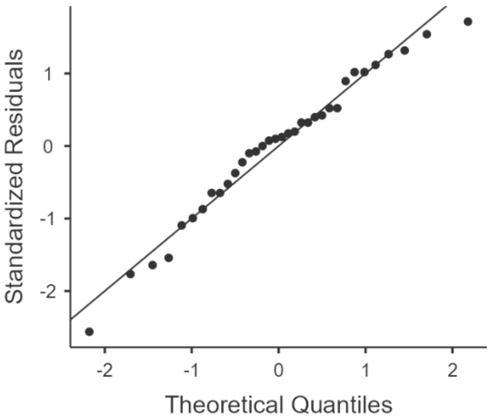
Normality Assessment: Q-Q Plot

Before accepting the results of parametric testing, it is essential to verify the assumption of normality for residuals. The Q-Q plot (Figure 1) demonstrates that most data points closely follow the diagonal reference line, indicating that the distribution of residuals approximates a normal distribution. This validation supports the appropriateness of the paired sample t-test and enhances confidence in the inferential conclusions drawn from the data (Field, 2018; Gravetter & Wallnau, 2017).

The significant improvement observed in students' cognitive outcomes following the use of visual-based respiratory media is well-supported by a growing body of international research. Wu et al. (2020) and Mayer (2021) emphasize that multimedia learning, especially with strong visual and interactive elements, leads to improved comprehension of complex and abstract biological content. This is particularly crucial in anatomy and physiology, where students struggle to form mental models of internal structures and dynamic physiological processes (Mayer, 2021; Ferdous & Hossain, 2022). Similarly, studies by Santos et al. (2023) and Alhumaidan et al. (2021) highlight the effectiveness of augmented reality (AR), animation, and interactive visualizations in deepening student engagement and conceptual mastery. Ferdous & Hossain

(2022) further report that 3D animation can significantly increase information retention and facilitate understanding of processes that are otherwise invisible to the naked eye.

Figure 1. Q-Q Plot of Pretest-Posttest Residuals



Instrumentation and Cognitive Measurement

An essential contribution of this research is the use of assessment instruments based on the revised Bloom's taxonomy, as advocated by Anderson & Krathwohl (2001). Rather than relying solely on rote memorization, this approach measures multi-level cognitive outcomes—ranging from remembering and understanding, to applying and analyzing. Such rigorous cognitive assessment enables educators to capture meaningful changes in student understanding and to document the effectiveness of instructional interventions (Lestari et al., 2023; Cohen et al., 2018). Other international studies (e.g., van Merriënboer & Kirschner, 2018; De Jong et al., 2013) have also demonstrated that the use of visual media scaffolds higher-order thinking, allowing students to integrate, analyze, and synthesize information across domains. In the present research, improvements in both the mean and the spread of scores suggest that visual media not only assist in foundational knowledge acquisition but also in the development of higher-level cognitive skills.

Limitations and Differential Effects

Despite the overwhelming positive evidence, some research suggests that the benefits of visual and interactive media are not uniformly experienced by all students. Factors such as prior knowledge, digital literacy, motivation, and learning preferences can mediate the effectiveness of these interventions (Rogers et al., 2021; Lee et al., 2022). For instance, Lee et al. (2022) found that students with higher baseline digital literacy and intrinsic motivation were more likely to derive maximum benefit from digital and visual tools. In this study, the slight increase in standard deviation post-intervention reflects such variability among learners. While the overall trend is positive, it is essential for educators to recognize and address individual differences by providing additional support, differentiated instruction, and scaffolding as needed (Rogers et al., 2021; Mayer, 2021).

Nationally, Indonesian scholars such as Wulandari and Suprapto (2023) and Lestari et al. (2023) have similarly identified the potential of interactive media to facilitate understanding of biology among elementary and secondary school students. Their findings, consistent with the current study, reinforce the argument for integrating visual digital tools within Indonesia's rapidly evolving educational landscape. However, much of the existing literature within Indonesia focuses on media development and qualitative outcomes, with less emphasis on rigorous quantitative measurement and experimental design. The present research addresses this gap by providing a robust statistical analysis of learning gains, thereby offering a methodological model for future studies in the region.

Theoretical Contributions

The findings of this study contribute to the theoretical understanding of how digital and visual media can transform science education. By confirming that visual interactive media significantly enhance cognitive outcomes in complex topics like the respiratory system, this research supports theories of multimedia learning and dual coding (Paivio, 2007; Mayer, 2021). These theories posit that information presented in both verbal and visual formats is more readily understood, retained, and recalled by learners. Furthermore, the study demonstrates the value of aligning instructional interventions with contemporary cognitive theories and curriculum frameworks such as the revised Bloom's taxonomy (Anderson & Krathwohl, 2001). By assessing learning across multiple cognitive domains, educators can obtain a more comprehensive picture of student progress and adapt teaching strategies accordingly (Santos et al., 2023; van Merriënboer & Kirschner, 2018).

Practical Implications for Education

On a practical level, the results of this research offer clear guidance for educators, curriculum designers, and policymakers seeking to improve science education outcomes. The robust gains in student learning demonstrate that investing in visual and interactive learning media is a highly effective strategy for promoting conceptual understanding and engagement in science (De Jong et al., 2013; Mayer, 2021). For teachers, the study suggests that incorporating multimedia and interactive tools can address longstanding challenges associated with teaching abstract and complex scientific concepts. Such tools can also cater to diverse learning styles and provide differentiated support for students with varying levels of prior knowledge and digital skills (Handayani & Asih, 2024; Rogers et al., 2021). School leaders and policymakers should take note of the strong empirical evidence supporting the integration of digital media in the science curriculum. As Indonesia transitions toward the Kurikulum Merdeka and embraces 21st-century learning, the results of this study can inform strategic decisions related to teacher training, technology procurement, and curriculum design.

Limitations and Recommendations for Future Research

While this study provides compelling evidence of the benefits of visual-based learning media, several limitations should be acknowledged. First, the quasi-experimental design with a single group pretest-posttest structure, although robust, does not control for all potential confounding variables. Future studies could include control groups, random assignment, and longitudinal tracking to further validate and extend these findings (Cohen et al., 2018; Gravetter & Wallnau, 2017). Second, while the study focused on cognitive outcomes, additional research could examine the impact of visual media on affective and psychomotor domains, as well as long-term retention and transfer of knowledge. The integration of emerging technologies such as augmented reality (AR) and virtual reality (VR) offers exciting avenues for future exploration (Alhumaidan et al., 2021; Wojciechowski & Cellary, 2013). Finally, qualitative investigations into student experiences, preferences, and engagement could enrich our understanding of how and why visual media exert their effects, supporting more nuanced and effective implementation (Field, 2018).

The findings of this research hold significant implications for the broader movement to reform science education in Indonesia and globally. As education systems increasingly prioritize inquiry, problem-solving, and critical thinking, visual and interactive media can play a crucial role in meeting these goals (Santos et al., 2023; Rogers et al., 2021). By demonstrating measurable improvements in student learning, this study provides strong justification for scaling up the use of visual-based learning tools in science classrooms.

Such initiatives will not only enhance cognitive achievement but also help foster the scientific literacy and skills required in an increasingly complex and technological world (Lee et al., 2022; Mayer, 2021).

CONCLUSION

The objective of this research was to rigorously evaluate the impact of visual-based respiratory system media on the cognitive learning outcomes of elementary school students, focusing on whether interactive visual media could effectively enhance understanding of the complex respiratory system material. The findings reveal a significant improvement in students' cognitive achievement, as evidenced by a mean score increase from 62.8 on the pretest to 73.3 on the posttest—a gain supported by both descriptive and inferential statistics, with the paired sample t-test showing a statistically significant difference ($t = -15.2$, $df = 33$, $p < .001$). These results not only validate the effectiveness of visual learning tools but also align with international research emphasizing the benefits of multimedia and visualization for comprehension and retention in science education. The research contributes theoretically by reinforcing multimedia learning and dual coding theories and methodologically by employing assessment tools based on the revised Bloom's taxonomy to capture higher-order cognitive gains. Practically, the study provides actionable insights for educators, curriculum designers, and policymakers, demonstrating the value of integrating visual and interactive media to address persistent challenges in science instruction and advocating for broader implementation in curricula, teacher training, and technology integration. Ultimately, by filling a critical gap in the Indonesian educational research landscape with robust quantitative evidence, this study serves as a blueprint for future innovation in science education, including the exploration of emerging technologies such as augmented reality and virtual reality to support diverse learning outcomes.

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