Virtual – Augmented Reality (VAR) for Science Learning: Development and Impact on Students' HOTS Skills

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Abstract: This study focuses on the role of innovation in educational technology, especially the use Virtual – Augmented Reality (VAR) at the junior high school level. The COVID-19 pandemic has widened the existing gap associated with technology and learning, calling for the need to provide interactive learning tools to develop students' higher-order thinking skills (HOTS). This study aimed to design and determine the effectiveness of VAR learning tools on students' HOTS skills. The research method used was Research and Development (R&D) using the Alessi and Trollip model, which includes three steps: planning, design, and development. The research population consisted of 242 junior high school students from Surakarta City, Indonesia, who were recruited through cluster sampling. Observations, interviews, and product feasibility questionnaires were used as instruments. The results showed that the students' HOTS skills improved significantly with the use of VAR-integrated learning tools in science subjects. The learners' mean scores on the post-test had a marked rise as opposed to the pre-test, signifying the effectiveness of the medium in greatly augmenting HOTS skills. This study suggests that VAR-based learning tools can be used as an effective means to overcome the digital divide and improve the quality of education by developing students' higher-order thinking skills, which are essential for 21st century learning.

Keywords: VAR, Science learning, HOTS, Technology, Skills

1. Introduction

The COVID-19 pandemic has caused significant tragedic changes in human paradigms and habits. It goes without saying that This event fundamentally affected global education, requiring an immediate shift from physical to online or e-learning (Rakhmetov et al., 2022). However, this transition has not been universal, as students from families with low socioeconomic status (SES) face considerable challenges in obtaining the necessary digital tools and stable internet connections, which hinders their ability to participate in online learning (Bismala and Manurung, 2021). Students from families with lower socioeconomic status often face challenges in accessing digital devices and the Internet, which restricts their participation in e-learning activities (Yao et al., 2022). In addition, many teachers are found to have low digital competency, which affects their ability to teach in an online environment. This problem exists because not all teachers have a reasonable level of digital skills, and they need to transition to a new digital environment (Garad, Al-Ansi and Qamari, 2021). These issues highlight the urgent need for alternative learning innovations that can bridge the digital divide and enhance learning experiences for all students.

One potentially effective alternative is the implementation of Virtual – Augmented Reality (VAR) technologies in the teaching of science subjects because they provide engaging learning experiences beyond the reach of conventional digital facilities (Rukayah et al., 2022; Kamińska et al., 2019). As stated previously, Augmented Reality (AR) technology is an enhancement of the real world with virtual elements in real-time interactions, in which users are provided with digital information that interacts with their environment (Septinaningrum et al., 2022). Virtual Reality technology refers to the ability to immerse the user in an interactive virtual world, severing the limitations imposed by the real world, and permitting the user to engage with the virtual environment without any restrictions (Raja and Priya, 2021). In this study, we introduce VAR as a new interactive media that integrates both Virtual Reality (VR) and Augmented Reality (AR) into a single platform. Unlike conventional VR or AR applications, VAR provides users with an immersive learning experience by leveraging the strengths of both technologies. These immersive tools have revolutionized the educational landscape by providing innovative ways to enhance learning experiences (Elmqaddem, 2019). In addition, VAR can foster higher-order thinking skills (HOTS) by motivating learners to analyze, evaluate, and create in virtual environments on essential skills needed in science education and learning in the 21st century (Lee et al., 2022). Nevertheless, there is little

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empirical evidence for integrated VAR technology to improve students' HOTS in junior secondary level science classes. This highlights the necessity for additional investigation of how VAR can close existing educational gaps and aid in the development of vital intellectual abilities in learners.

Looking at some of the information above, it cannot be denied that the use of AR and VR in education has revolutionized teaching and learning methods, making the learning experience more interactive, impressive, and fun (Saravanan et al., 2022). In addition, AR and VR help in real contextual learning in history, for example, where students can visit historical sites to learn, while simultaneously helping in remote education for people who are in distant places and are able to use supporting technological devices (Serin, 2020). As stated, AR and VR technologies have become indispensable in the ongoing educational revolution alongside Information Communication Technology (ICT) since they have improved the overall quality of education and the effectiveness with which learners achieve the set educational outcomes. Nonetheless, there is still a need to systematically investigate the effectiveness of these technologies across diverse distances and their relevance to the essential cognitive skills of critically analyzing and reasoning, known as HOTS.

To successfully integrate VAR technology into educational systems, institutions face multiple challenges, including operating within a constrained budget, which can make acquiring the necessary software and equipment exceedingly difficult (Scavarelli, Arya and Teather, 2021). Support and training from auxiliary technical staff are also required. Many teachers lack the ability to effectively utilize VAR tools, which poses a challenge, as educators must be trained to build their confidence and skills (Yusof, 2019; Oleksiuk and Oleksiuk, 2020). The adoption rates at the beginning tend to be low, as research has shown that learners rarely utilize VAR laboratories for engineering subjects, signifying the early phases of innovation dissemination (Yanto et al., 2022). While these findings highlight technical and financial barriers to VAR adoption, they do not fully account for pedagogical constraints or sociocultural factors that may influence the effectiveness of VAR-based learning. Therefore, additional studies are needed to explore these dimensions in greater depth.

Alignment with national educational objectives greatly affects acceptance and attitudes, indicating that teachers' feelings are pivotal as well (Bima, Saputro and Efendy, 2021). The need for constant assessment and modifications to ensure that VAR meets educational goals and its subsequent integration into existing educational systems adds to the already existing complexity (Shepa et al., 2021; Wang et al., 2023). In contrast to past research that has mostly examined barriers to implementation, few studies have looked at the equity of benefits from VAR learning within different socioeconomic contexts and the impact of these diverse contexts on students. To meet these challenges, there must be sufficient funds, adequate training, infrastructure improvement, and support to enable successful VAR integration into education. In addition, there is still no answer to the question of which practices are most effective in the use of VAR aimed at maximizing students' educational achievements.

Studies have revealed that the adoption and effectiveness of VAR technologies in educational settings are greatly impeded by inherent complications. In Wibowo et al.'s (2021) study, VAR adoption was linked to other factors in secondary schools, such as the allocation and management of resources, the presence of adequate teacher support, and the attitudes of teachers towards the technology, indicating the presence of other influences (Wibowo et al., 2021). Munje and Jita (2020) suggested that in Africa, the lack of adequate training, insufficient infrastructure, and VAR adoption are all interconnected with a more general lack of adequate power supply. There is also an inability to systematically assess the appropriateness of a given technology to the schools or regions that compose the problem. These studies are helpful in clarifying the logistical and financial impediments to adopting VAR technologies, but they miss how different VAR pedagogies can be employed to develop HOTS. This deficiency marks a shift towards a more comprehensive reconsideration of teaching strategies designed to optimize the outcome of VAR in different classroom environments. The proposed solution emphasizes the development of holistic strategies that address the complex interrelationship between inadequate training, infrastructure, and user-centered strategies, while providing thorough evaluations of VAR integration into educational practices. Instead of checking the plausibility of adopting VAR technology, further investigations should focus on the impact of different teaching styles on the integration of such technologies, especially in developing HOTS for learners from different educational settings.

Although there are numerous challenges that some countries may face in implementing new technologies, such as AR and VR, several studies have shown that in some developed countries, AR and VR are being utilized for educational activities. A comprehensive review conducted by previous researchers successfully explored deep applications of VR in the educational context. Research has indicated that there is potential for VR to create engaging and interactive learning environments that can enhance knowledge retention and student motivation

(Strand, 2020). In line with this, another study asserted that VR has an impact on science education, noting that VR can significantly enhance students' attitudes and learning motivation, especially in immersive virtual environments designed to improve students' learning outcomes (Al-Amri, Osman and Musawi, 2020). However, there is a lack of consensus on the extent to which motivation and engagement directly contribute to HOTS development, as some studies have suggested that increased engagement does not necessarily translate into deeper cognitive processing. This discrepancy suggests that further research is needed to clarify the relationship between student motivation, engagement, and HOTS acquisition in VAR-based learning. Furthermore, a meta-analysis study has also highlighted the advancements in AR in education over the past decade, with a focus on its implementation in STEM-based learning to support scientific literacy and enhance student engagement and understanding (Pedaste, Mitt and Jürivete, 2020). AR and VR technology can also be said to be flexible because they can be accessed and integrated via smartphones (Muñoz-Saavedra, Miró-Amarante, and Domínguez-Morales, 2020; Bukhori et al., 2019), where currently almost the majority of students already have smartphones. Despite these advantages, there is still limited research investigating how mobile-based AR and VR applications compare with full-scale VAR systems in fostering HOTS. This distinction is critical, as mobile technology may provide a more accessible, yet potentially less immersive, learning experience.

One important skill for students is higher-order thinking skills (HOTS), which comprise the core cognitive activities of analysis, evaluation, and synthesis. These skills support the achievement of complex problem-solving activities and advanced thinking skills. These skills allow students to transfer skills, solve problems, and engage in critical and creative thinking (Astrid and Hasanah, 2022). As a goal of modern education, the acquisition of HOTS has accelerated in the present millennial era, aiming to enhance students' ability to analyze, evaluate, and create (Tong et al., 2022). For example, in mathematics education, instruments for assessing the HOTS have been developed to measure these skills. These instruments were tested for reliability and their difficulty index to be used in judging the students' ability to analyze (C4), evaluate (C5), and create (C6), as described in Bloom's taxonomy (Zainil et al., 2023; Muhayimana, Kwizera, and Nyirahabimana, 2022). Within the framework of teaching English as a foreign language, HOTS integrated into examinations is aimed at developing high school students' critical and creative thinking skills. Examination analysis showed that there are many questions that seek to assess critical thinking skills, which are then designed to test creative thinking and problem-solving abilities (Permana et al., 2019; Arifin, 2020). In addition, the application of the HOTS in elementary schooling is still in its early stages, but it shows good prospects, especially with the development of valid, practical, and reliable assessment instruments that allow teachers to support the development of these skills among fifth graders (Parmiti, Antara and Wulandari, 2022). The integration of HOTS in its dimensions of planning, implementation, and assessment enables the learners' activities to be not only designed to be effortless, but also stimulating and meaningful to ensure higher-order thinking is developed.

Incorporating HOTS into educational settings is crucial for preparing students to tackle complex problems with enhanced cognitive skills. Higher-order thinking skills are not limited to knowledge recall; they encompass problem-solving, critical thinking, creative thinking, argumentation, and decision-making, which are fundamental for 21st century skills (Yusof, 2019). Several studies have revealed that HOTS-based assessment tools notably improve students' cognitive, affective, and psychomotor skills, allowing them to comprehend and apply scientific concepts (Ramos, Dolipas and Villamor, 2013). For example, HOTS-based worksheets in trigonometry have proven to be valid, practical, and effective in enhancing problem-solving abilities among high school students (Maryani et al., 2021; Tanjung, Nababan and Sa'dijah, 2020). In the context of science education, HOTS play a crucial role in helping students grasp abstract concepts, conduct experiments effectively, and cultivate a scientific mindset, which is fundamental for innovation and technological advancement. Because of these expectations, infusing higher-order thinking skills (HOTS) can no longer be considered optional when preparing learners for an ever-changing world. The development of VAR technologies provides a new avenue for improving HOTS through more engaging and convincing active learning, which ensures a higher level of comprehension and participation. VAR allows experiential learning through simulation and live interaction, which enables students to investigate scientific processes and use critical thinking to explain them in ways that are not possible in traditional teaching (Oleksiuk and Oleksiuk, 2020).

Another investigation highlighted the prospect of AR in depicting science concepts that are highly abstract and can pose difficulties to students with various educational backgrounds and teaching experiences (Yang, 2023). In addition, self-directed learning, creative thinking, critical thinking, and knowledge creation efficacy skills were positively affected by the use of AR under QIMS, particularly for low-achieving students (Syawaludin, Gunarhadi and Rintayati, 2019). Along the same lines, Wehrmann and Zender (2024) noted that VAR provides useful opportunities for immersive learning and helps overcome gaps in understanding concepts, as well as boosting the interest of students, especially in science education. Combining these technologies transforms education with VAR, which can solve well-known issues related to traditional teaching methods by providing simpler and more attractive ways to present subjects (Averbeck et al., 2019; Averbeck et al., 2024). The results change the perception of science education by using VR, AR, and VAR technology for junior high school children, which provides hope for better interactive and immersive learning experiences.

Drawing from several analyses of previous studies, it appears that, despite their benefits, the application of VAR technologies continues to face significant challenges, particularly in developing countries. The widening digital divide exacerbated by the COVID-19 pandemic has created significant barriers, particularly in rural areas that have limited infrastructure and connectivity. Furthermore, the lack of digital literacy among teachers and students from low socioeconomic status (SES) backgrounds serves as a barrier to the effective implementation of VAR-based learning. While later studies emphasized the impact of AR and AI technologies on the improvement of motivational and conceptual understanding, adoption is hindered by financial barriers, inadequate training, and difficulty integrating these technologies into preexisting educational systems (Mariscal et al., 2020; Wehrmann and Zender, 2024). Apart from these gaps, other outstanding issues include the absence of pertinent research on the application of VAR in education and the development of concepts and functioning of science education at the junior high school level, especially the integration of higher-order thinking skills and science education. There is also a lack of research on the use of VAR in educational settings with limited resources that face issues, such as low levels of infrastructure development and digital literacy. Therefore, there is a pressing need for well-defined steps to enable the effective use of VAR in education so that it is not focused merely on knowledge acquisition but on the development of HOTS, which is critical for 21st-century learners.

To address this gap, this study examines whether the use of VAR improves HOTS in junior high school science education. More specifically, it designs and assesses a problem-solving, analytical thinking, and cognitive development-enhancing learning model that is VAR-based. The research is directed by the question, "Does the use of VAR technology improve the HOTS in junior high school science education?". This study is part of an effort to address the educational digital divide, with a particular focus on how VAR facilitates the strengthening of HOTS as a crucial 21st century competency. VAR technology's impact on devising strategies for HOTS is evaluated to address the gap within educational literature and transform its findings into practical guidance for the use of immersive learning technologies.

2. Method

This study utilizes the Research and Development (R&D) approach, which is consistent with the study's objective of creating a VAR, which is suitable for enhancing higher-order thinking skills (HOTS) among junior high school students (Gall, Gall and Borg, 2003). This study adopts the development model proposed by Alessi and Trollip (Alessi and Trollip, 2001). Overall, this development model comprises three main stages: planning, design, and development (Yaniawati et al., 2021). The scope and limitations of the product were determined during the planning stage. The design stage involved the design of content and documentation. The development stage involved the production of media, validation of media feasibility, and testing of media to measure the impact of the developed product. All the steps for this research and development summarized in figure 1.

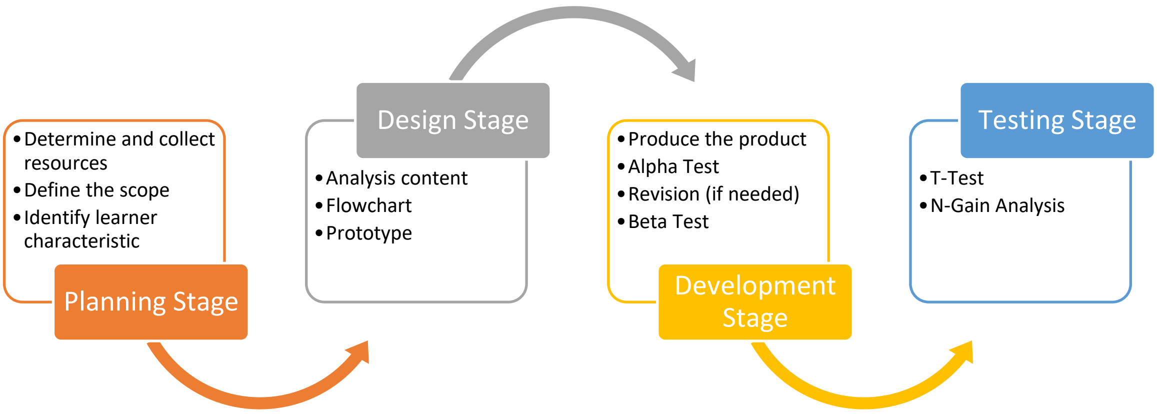

Figure 1: Research and Development Model

The participants of this study were high school students and teachers who taught the subject of natural science. Therefore, the subjects involved in this research consisted of 242 students from six junior high schools in Solo

Raya, including Junior High School (SMP) Kalam Kudus Surakarta, SMP Tarakanita Sukoharjo, SMP Widya Wacana Surakarta, SMP Negeri 3 Surakarta, SMP Negeri 4 Surakarta, and SMP Negeri 1 Masaran Sragen. The students were selected using a cluster sampling technique (Rejekiningsih, Sudiyanto and Budiarto, 2022). Cluster sampling was chosen to ensure diverse representations across multiple schools while maintaining the practical feasibility of implementing the VAR-based learning model. This method allows for efficient selection of participants within naturally occurring classroom groups, reducing logistical complexity compared to simple random sampling. For the development phase of the product feasibility assessment, 24 students, three teachers, two media experts, and two subject matter experts were selected to evaluate the quality of the product. Schools were chosen based on their relevance to the study and representativeness of different school environments (Saputri, Rukayah and Indriayu, 2018).

Data collection was conducted concurrently with product development activities using non-test techniques, including observations, interviews, and product feasibility questionnaires (Budiyono, 2017). The instruments used included stratified Likert-like scale questionnaires derived from Dinayusadewi and Agustika (2020) to measure the feasibility of VAR products, which were estimated using a 4-point like scale where 1 means Strongly Disagree' and 4 means Strongly Agree. The neutral point for the response set was eliminated to ensure that all the respondents offered their opinions. Moreover, an observation checklist was used to assess the learners' participatory level during the lesson, while the teachers' interviews gave us some impression on the effectiveness of the lesson media qualitatively (Setiawan, Pusporini and Dardjito, 2020). Data collection techniques to measure students' HOTS skills were performed through tests (Fuad et al., 2017). The tests included topics students were learning in science during junior high school and provided a scope of research on assessing HOTS for junior high school students (Rofiah, Aminah and Sunarno, 2018; Widiyawati et al., 2021; Dasilva et al., 2019).

The validity of the assessment was determined using content validity through expert evaluations from the field of education (Surbhi, 2019). The expert judgment process ensured that the instrument was aligned with Bloom's taxonomy and the cognitive levels required for the HOTS assessment. Moreover, construct validity was verified with factor analysis, confirming that the instrument synergistically measured the separate components of analysis (C4), evaluation (C5), and creation (C6) of higher-order thinking skills (HOTS) within their respective constituent parts. The outcomes shown in Table 1 illustrate that all parameters of the indicators of higher order thinking skills (HOTS) were valid and fulfilled the requirements.

Table 1: Validity and Reliability Test Results of HOTS Instrument for Science Learning

Indicator	Validity Method	Results	Reliability Method	Cronbach's Alpha
Analysis (C4)	Expert Judgment (Content Validity)	Valid	Internal Consistency (Cronbach's Alpha)	0.78
Evaluation (C5)	Factor Analysis (Construct Validity)	Valid	Internal Consistency (Cronbach's Alpha)	0.81
Creation (C6)	Expert Judgment (Content Validity)	Valid	Internal Consistency (Cronbach's Alpha)	0.85
Overall HOTS Test	Combined Expert Judgment & Factor Analysis	Highly Valid	Overall Reliability	0.81 (Reliable)

Simultaneously, the reliability of the instrument was checked using Cronbach's alpha (internal consistency). The obtained reliability coefficient was 0.81, which means that the instrument is reliable for measuring students' HOTS skills (Widyaningsih et al., 2020). The reliability scores of each of the HOTS indicators ranged from 0.78 to 0.85, which is acceptable, providing assurance of the consistency of most students' HOTS assessment results over different attempts to administer the tests. This thorough validation and reliability analysis increased the trustworthiness of the instrument in measuring the impact of VAR-based learning on students' HOTS development in science education.

Both descriptive and inferential statistical methods were used to analyze the collected data. The interviews and observations of the learning activities were analyzed using descriptive analysis (Patten and Newhart, 2018). The observations examined included student engagement, problem solving, collaboration with VAR, and interaction with the content that reflects cognitive engagement and learning behavior that provide value. Thematic analysis of interview data was performed through coding, categorization, and identifying patterns regarding VAR implementation, students' perceptions, and teaching effectiveness. Statistical Descriptive Analysis is also relevant when considering the feasibility of media VAR, as validated by the Teacher, Media Expert, and Content Expert. The assessment of media feasibility involved computing the total score values to find the mean score percentages (Septinaningrum et al., 2022). For the VAR to be declared suitable as a learning medium, table 1 shows that the feasibility level analysis must obtain a minimum percentage score of 63%. table 2 shows the conversion criteria for the feasibility of VAR.

Table 2: VAR eligibility criteria

Percentage	Qualification	Decision
81 – 100%	Very good	Very Eligible
61 – 80%	Good	Eligible
41 – 60%	Enough	Less Eligible
21 – 40%	Deficient	Not Eligible
1 – 20%	Very Deficient	Rejected

This study employed a pre-test and post-test control group design to evaluate the effectiveness of VAR-based learning in enhancing Higher-Order Thinking Skills (HOTS). The experimental group used VAR-based learning, whereas the control group followed conventional methods, allowing for a direct comparison of learning outcomes.

Based on this design, the research hypotheses are formulated as follows:

- **H_0 (Null Hypothesis):** VAR-based learning has **no significant effect** on students' HOTS compared to conventional methods.
- **H_1 (Alternative Hypothesis):** VAR-based learning has a **significant positive effect** on students' HOTS compared to conventional methods.

To test these hypotheses, paired sample t-tests were used to analyze improvements within each group, while independent sample t-tests were used to compare post-test scores between the groups. Additionally, N-gain analysis was used to measure the magnitude of learning improvement. Table 3 shows the pre/post-test design used in this study.

Table 3: Research Design: Pre-Test and Post-Test Control Group

Group	Pre-Test	Treatment	Post-Test
Experimental	✓	VAR-Based Learning Model	✓
Control	✓	Conventional Learning Methods	✓

To assess learning effectiveness, an inferential analysis was conducted using a t-test and N-gain analysis (Supianti et al., 2022). The t-test was used to test the research hypothesis, analyzing improvements within groups (paired sample t-test) and between groups (independent sample t-test) to determine whether VAR-based learning significantly impacted HOTS. N-Gain analysis measured normalized learning gains based on the following criteria, as displayed in table 4.

Table 4: N-Gain Criteria

N-Gain (g)	Interpretation
$g > 0.7$	High
$0.3 < g \leq 0.7$	Medium
$g < 0.3$	Low

Adapted from (Winarni and Purwandari, 2019)

The VAR product was specifically developed for this study using the Alessi and Trollip R&D model, integrating augmented reality (AR) and virtual reality (VR) simulations to enhance spatial and conceptual visualization. The key features include interactive 3D models, real-time feedback, and problem-based scenarios designed to foster HOTS development. These methodological refinements provide a clear justification for the research design, statistical analyses, and interventions used, ensuring an in-depth assessment of VAR's impact of VAR on HOTS.

3. Result and Discussions

3.1 Results of the Planning Stage

Planning this research and development involves examining student characteristics and needs, identifying learning activities, and establishing the scope of VAR products. Student characteristics, instructor needs, and present learning activities were assessed through observation and interviews. At *SMP Kalam Kudus Surakarta*, *SMP Tarakanita Sukoharjo*, and *SMP Negeri* 3 *Surakarta*, teachers mostly used textbooks and presented content via LCD projectors with minimally interactive PowerPoint presentations of text and a few examples. Thus, students seemed bored and indifferent to teacher questions, creating a teacher-centered learning environment.

The teacher provides explanations and resources, followed by group assignments during the core learning activities. Teacher-prepared tasks prompt group discussions and presentations. Due to the lack of systematic group activity preparation, students talk a lot and bother their peers, making talk unproductive. In addition, some groups assigned tasks to one member. Administrative difficulties that decrease time for creativity and lack of knowledge about the newest technology breakthroughs that can be used as learning media have prevented teachers from developing effective interactive media for learning. Non-interactive media such as text and images bores and demotivates the students. Therefore, students are more engaged and science lessons should deliver knowledge and interesting experiences.

Additionally, semi-structured interviews with junior high natural science teachers yielded additional data. About three topics teachers were interviewed to learn about learning, instructional media, and classroom teaching practices. The data from oral interviews with junior high science subject teachers will be used as a benchmark for student and teacher needs for innovation in VAR instructional media for science learning. The interview results from SMP Kalam Kudus, SMP Tarakanita Sukoharjo, and SMP Negeri 3 Surakarta science instructors are as follows: Teachers reported that student participation in science learning has decreased in recent years. These teachers taught science through lectures and assignments. As most pupils are passive learners, these strategies are poor at engaging with them. Some teachers employ debate and problem-based learning but struggle to create an engaged and compelling learning environment.

According to the teachers, media such as textbooks, PowerPoint presentations, and the Internet are commonly used in ICT-based learning media. However, the use of ICT-based learning media is still limited, and has not been fully utilized to create more interactive learning experiences. Teachers recognize that ICT-based learning media have the potential to help students better understand natural sciences (i.e., *IPA*) materials, but limitations in time and knowledge of current technology pose obstacles to its implementation. Teachers also agree that VAR-based learning media have great potential for application in science learning. Interviews and observations at *SMP Kalam Kudus Surakarta*, *SMP Tarakanita Sukoharjo*, and *SMP Negeri 3 Surakarta* highlight the urgent need for VAR-based learning media that students can independently use. Current methods, which are dominated by lectures and assignments, have decreased student involvement and participation. The existing ICT-based media are limited and less interactive. Teachers concur that enhancing students' critical thinking skills requires interactive media. Implementing VAR in science learning can foster a more engaging and efficient environment that optimally stimulates students' critical thinking skills.

Considering the great potential of VAR, which has not been widely implemented in the context of science learning, the development of this medium is expected to replicate real-life situations and present materials dynamically through videos and animations. This research is crucial for addressing these needs and directing the development of innovative learning media in line with the latest technological advancements.

3.2 Results of the Design Stage

The design phase involved preparing the content and program outline for a VAR product. This stage includes a comprehensive analysis of the previous results to minimize errors during development and testing. The material for the augmented reality media is sourced from the national curriculum guidebook for grade VIII, semester II, including the lesson plan (i.e., *RPP*) and curriculum, which encompasses Core Competencies and Basic Competencies. These competencies, derived from the analysis of augmented reality media needs, focus on knowledge, skills, and attitudes with an emphasis on knowledge. The contents cover the human respiratory and excretory systems, as shown in table 5.

Table 5: Content Competencies for VAR Material in Science Learning

Basic Competencies		Indicator	
3.9.	Analyzing the human respiratory system and understanding disorders of the respiratory system, as well as efforts to maintain the health of the respiratory system	3.9.1	Identify respiratory organs
		3.9.2	Understand the mechanics of breathing
		3.9.3	Understand various disorders of the respiratory system
3.10.	Analyzing the excretory system in humans and understanding disorders of the excretory system and efforts to maintain the health of the excretory system	3.10.1	Analyze the structure and function of the excretory system
		3.10.2	Analyze disorders of the excretory system
		3.10.3	Analyze efforts to maintain the health of the excretory system

3.3 Development Stage Results

The development stage is the implementation of the previous stages, and some of the activities carried out during this stage are developing the initial product that is truly complete in terms of its components. Subsequently, validation is carried out by experts, and if there is anything that needs to be improved, it is immediately fixed. There was then a validation stage by the subject teachers and students. The results of the development stage are as follows.

The next step involves an initial evaluation of the product developed by experts. Two media experts assessed Visual Appearance, Interactivity, Design Consistency, Accessibility, and Technological Compatibility. Two subject matter experts evaluated Content Quality and Learning Effectiveness. Additionally, three practitioners, specifically science teachers, will assess the product's alignment with the teaching practices and practical applications. Overall, evaluations by experts and teachers during the alpha test deem the product 'eligible' for use as learning media and for proceeding to the next stage. The feasibility evaluation results are listed in Table 6.

Table 6: Alpha Test results

No	Expert and Teacher Validator	Average Validation Results (%)	Qualification	Decision
1.	Media I	86%	Very good	Very Eligible
2.	Media II	91%	Very good	
3.	Material I	81%	Very good	Very Eligible
4.	Material II	89%	Very Good	
5.	Teacher I	75%	Good	Very Eligible
6.	Teacher II	83%	Very good	
7.	Teacher III	92%	Very good	
Average Total Alpha Test		85%	Very good	Very Eligible

The Alpha Test results in Table 4 show that expert and teacher validation confirmed that the developed media and materials were excellent and highly suitable for use. Media I and II scored 86% and 91%, respectively, and both were deemed excellent. Materials I and II received 81% and 89%, respectively, and were rated as excellent. Teacher assessment revealed Teacher I at 75% (good), Teacher II at 83% (very good), and Teacher III at 92% (very good). The overall average from the Alpha Test was 85%, qualifying as very good, indicating that the media was very eligible. Validators provided suggestions for improvement: 1) enhance the home display with more attractive buttons and colors, 2) add navigation buttons, and 3) include diverse learning sources beyond textbooks or worksheets.

The next step involved usability testing to evaluate the functionality of the application from the perspective of high school students. The usability testing results inform the final product distribution and assess the impact of the VAR product. Conducted on 24 high school students, the usability testing revealed an average student response score of 88%, qualifying as "Very Good." The detailed results are presented in Table 7.

Table 7: Beta Test Results

No	Test Type	Average Validation Results (%)	Qualification
1.	Preliminary Trial (5 Students)	82%	Very good
2.	Play field trial (12 students)	88%	Very good
3.	Operational trial (24 students)	95%	Very good
Average Total Beta Test		88%	Very good

The beta test results indicate that the VAR learning media product has been tested at several stages with very positive outcomes. A preliminary test involving five students yielded an average validation of 82% with a "very good" qualification. The main field test involving 12 students obtained an average of 88%, also with a 'very good' qualification. Furthermore, the operational test involving 24 students showed very satisfactory results, with an average of 95% remaining in the "very good" qualification. Overall, the total average of the beta test reached 88% with a 'very good' qualification.

3.4 Testing Phase Results

During several classroom learning meetings, the impact or influence of the product on improving students' high-order thinking skills (HOTS) in junior high school was measured. The testing of Students' HOTS skills were done using pretest and posttest methods with a control group. The difference in the average post-test scores was then analyzed using an Independent-sample T-test to determine the significance of the difference between the two classes. The results of the t-tests are presented in Table 8.

Table 8: T-test results

Group	Number of Students	Average	Standard Deviation	t-statistic	p-value
Experimental Class	121	87.714	9.948	14.283	0.000
Control Class	121	70.52	10.26	3.12	0.0019

With a p-value of 0.001985, which is smaller than 0.05, we rejected the null hypothesis (H0). This means that there was a significant influence on increasing students' HOTS skills between the experimental and control classes.

After conducting a t-test, it was found that the VAR media product significantly improved students' Higher Order Thinking Skills (HOTS). To assess the effectiveness of the product, an N-Gain score analysis was performed by comparing pretest and post-test scores from both the experimental and control groups. Table 9 shows that the experimental group achieved an average N-Gain score of 0.714 (high range), whereas the control group achieved an average N-Gain score of 0.088 (low range). These results suggest that the developed product is more effective than traditional classroom media in enhancing students' HOTS. The Detailed N-Gain test results are presented in Table 9.

Table 9: N-Gain of Students' HOTS Skills

Details	N-Gain Experimental Class	N-Gain Control Class
count	121.000	121.000
mean	0.714	0.088
std	0.288	1.241
min	-0.713	-12.885
25%	0.557	-0.008
50%	0.740	0.209
75%	0.891	0.461
max	1.275	1.013

Implementing VAR media in experimental science classes significantly boosts students' higher-order thinking skills (HOTS), as shown by an average N-Gain score of 0.714, indicating a high improvement. In contrast, the

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control class without VAR media scored an average N-Gain of 0.088, which was categorized as low. This demonstrates that VAR media is highly effective in enhancing HOTS in students.

4. Discussions

Research shows that using VAR technology in junior high science classes improves higher-order thinking skills. The t-test and N-gain analysis demonstrated that the experimental class using VAR media improved more than the control class using conventional media. VAR-based technology-supported learning activities boost students' grasp of complicated concepts and develop HOTS-related abilities, such as analysis and evaluation. Therefore, VAR technology is effective when integrated into a planned teaching method relevant to the content being taught. The use of technology in learning activities must be adjusted and aligned with the strategy or learning model used during the learning process as well as its sophistication.

The research findings showed a significant difference in HOTS skills between the experimental and control classes. The results confirm this, with a higher average post-test score in the experimental group (87.714) than in the control group (70.52), with a t-statistic of 14.283 and a p-value of 0.000, indicating a statistically significant effect of VAR-based learning. Observations and motivation questionnaires further revealed greater student engagement, active interaction with VAR content, and improved HOTS skills in the experimental group. Students who learned using VAR media were more enthusiastic and actively engaged in learning activities (Ansari, KG and Baby, 2023). They were more likely to ask questions, participate in discussions, and show a high level of interest in the material being studied, indicating that VAR technology not only enhances cognitive skills but also the affective aspects of learning (Rudnik, 2023; Almaguer et al., 2023).

The findings of this research cannot be separated from those of comprehensive preliminary studies. As is well known, the analysis of needs in the development of digital learning products plays a crucial role in ensuring that the resulting product is effective and efficient in supporting the learning process (Ambarsari et al., 2021). Through a needs analysis, developers deeply understand what end users, in this case, learners and educators, need to meet the intended instructional goals (Rejekiningsih et al., 2023). Budiarto, Rejekiningsih, and Sudiyanto (2021) highlighted the personal, skill, organizational, and facility requirements for the creation of a digital learning aid needed during instruction. Moreover, needs analysis also prevents developed products from being erroneous and discrepant (Rosalina and Suhardi, 2020). Hence, fully knowing the user requirements together with the capability of digital media allows developers to accomplish effective learning products that satisfy the requirements of contemporary technological and educational development.

These findings are relevant to the field of education, specifically junior high school science education. VAR technology can be an effective opti9n for boost students' interest and involvement in lessons (Saravanan et al., 2022). Furthermore, it helps students acquire the ability to think critically and creatively, which is very important for the 21st century (Nicolaou et al., 2019; Syawaludin et al., 2019). With VAR technology, learning becomes more interactive and enjoyable, which can improve students' overall learning outcome.

The current results corroborate earlier works that argue in favor of the use of VR and AR technologies for educational purposes. For instance, the use of mobile AR apps for project-based learning has been proven to have far-reaching benefits for the innovation, creativity, problem-solving skills, and information literacy of students, especially in chemistry education (Chen, Huang and Chou, 2017). The application of Virtual Reality (VR) and Augmented Reality (AR) in the teaching of Natural Science (IPA) has remarkably increased students' 21st-century competencies. Studies show that the use of VR and AR technology has improved students' academic performance and satisfaction in several subjects and areas, particularly in science education. Moreover, integrating VR and AR into the educational process may contribute to forming students' digital skills, literacy, and other skills of the twenty-first century that are needed today (Hughes and Maas, 2019; Hughes and Maas, 2018).

Moreover, using VR and AR in education can improve critical thinking, creativity, communication, and collaboration (4C skills), which are fundamental to tackling issues in the modern world. With the help of VR and AR technologies, educators can develop interesting and integrated learning environments where students can acquire skills that meet the needs of time (Lee et al., 2022; Monterubbianesi et al., 2022). Thus, the use of AR and VR technologies in teaching science not only aids learners in comprehending the subject matter but also equips them with the skills they need to thrive in the future (Rudnik, 2023; Dilmen and Atalay, 2021).

In the context of 21st century education, the use of VAR technology can also help students prepare for deep and interactive learning experiences that develop adaptability, problem-solving, and technology skills that are highly needed in today's digital era (Safri and Sheikh, 2022; Rejekiningsih et al., 2023). Therefore, the implementation of VAR in IPA learning not only enhances the quality of education, but also helps create a generation that is ready to face future challenges with relevant and up-to-date skills (Singh, 2024; Fu, 2021).

Although the benefits of VAR technology are obvious, its actual implementation poses a challenge. Software and equipment costs can be crippled by budget-constrained institutions. Furthermore, effective application of the technology necessitates specialized technical assistance, as well as thorough educator training. The lack of adequate infrastructure, especially in rural regions where the Internet and technological devices are scarce, adds to the challenges of implementation. These issues can be addressed through collaborative participation in technology infrastructure improvements and teacher training. The results of this study are intended to assist educational media designers, educators, and teachers adopting VAR technology, while emphasizing the importance of infrastructure aid and teacher professional development concerning technology use in education.

5. Conclusion and Suggestions

In general, the findings of this study show that VAR technology has great prospects for improving higher-order thinking skills (HOTS) of junior high school students in science education. While implementation concerns need to be addressed, VAR can be incorporated to foster active and meaningful learning. This study aims to develop innovative educational media and contribute to the growing concern for improving education through technology integration pedagogy. Subsequent studies should examine the use of VAR in fields other than science education to include mathematics, social sciences, and language learning. In addition, further research on long-term learning retention, adaptability of students, and readiness of teachers in VAR environments is needed. Varied approaches will assist educational practitioners, and VAR could benefit educational levels and contexts. Moreover, educational policymakers and institutions should concentrate on teacher training as well as the provision of infrastructure and tools that will permit the injection of VAR into different educational contexts.

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