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EFFECTS OF SCIENCE AUGMENTED REALITY LEARNING MEDIA ON STUDENT LEARNING OUTCOMES: A META ANALYSIS

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Abstract. The background of this research is the inconsistency of findings in various previous studies regarding the effectiveness of Augmented Reality (AR) in improving learning outcomes. This study aims to analyze the influence of Augmented Reality (AR) learning media on student learning outcomes in the subject of Science through meta-analysis methods. The type of research used is this meta-analysis conducted on 38 relevant articles published between 2013 and 2024, selected based on PICOS inclusion criteria. The analysis used effect size calculations and statistical tests using the JASP application. The results showed that AR had a strong and significant effect on student learning outcomes. The findings also revealed that the strongest effect appeared in elementary school students, especially in physics material and on the aspect of knowledge and critical thinking skills. These results indicate that AR-based learning media is highly effective in improving conceptual understanding and cognitive engagement in science learning. abstract should be clear, concise, and descriptive.

Keywords: Learning Media, Augmented Reality, Learning Outcomes, Science Education

Abstrak. Latar belakang penelitian ini adalah adanya ketidakkonsistenan temuan dalam berbagai penelitian sebelumnya terkait efektivitas AR dalam meningkatkan hasil belajar. Penelitian ini bertujuan untuk menganalisis pengaruh media pembelajaran Augmented Reality (AR) terhadap hasil belajar siswa pada mata pelajaran IPA melalui metode meta-analisis. Jenis penelitian yang digunakan adalah Meta-analisis ini dilakukan terhadap 38 artikel relevan yang diterbitkan antara tahun 2013 hingga 2024, dipilih berdasarkan kriteria inklusi PICOS. Analisis dilakukan dengan perhitungan effect size dan uji statistik menggunakan aplikasi JASP. Hasil menunjukkan bahwa AR memiliki pengaruh yang kuat dan signifikan terhadap hasil belajar siswa. Temuan juga menunjukkan bahwa pengaruh paling kuat terjadi pada siswa sekolah dasar, terutama pada materi fisika dan aspek pengetahuan serta keterampilan berpikir kritis. Hasil ini menunjukkan bahwa media pembelajaran berbasis AR sangat efektif dalam meningkatkan pemahaman konsep dan keterlibatan kognitif dalam kajian IPA.

Kata Kunci: Media Pembelajaran, Augmented Reality, Hasil Belajar, IPA

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INTRODUCTION

The integration of technology in education has become essential in the era of the Fourth Industrial Revolution. Augmented Reality (AR) represents a technological advancement that merges virtual objects with the real world, enabling interactive and immersive learning experiences (Muntahanah et al., 2017). In Indonesia, the implementation of the Kurikulum

Merdeka emphasizes the need for innovative learning approaches, including the use of digital media like AR to foster higher-order thinking skills and prepare students for global challenges (Kemendikbud, 2022). However, the effectiveness of AR in enhancing learning outcomes varies across studies. While some report substantial improvements (Amelia et al., 2020), others find marginal effects (Cai et al., 2013; Ibáñez et al., 2014). Furthermore, challenges such as limited access to technology, teacher readiness, and infrastructure constraints in Indonesian schools often affect the successful integration of AR (Putri et al., 2023).

Low literacy and numeracy skills remain a significant issue in Indonesian education, as reflected in the PISA 2018 results, where Indonesia's average science score was 396, below the OECD average of 489 (OECD, 2019). This data highlights the urgent need for innovation in learning media to improve students' understanding of science concepts. AR is seen as a promising solution, capable of enhancing engagement, supporting conceptual understanding, and fostering critical thinking. Its integration into science learning is expected to provide students with meaningful learning experiences, aligning with the demands of the 21st century and the goals of SDG 4.

This study aims to synthesize findings across diverse educational levels and learning domains (knowledge and critical thinking) to inform effective AR integration in Indonesian science classrooms. By doing so, it contributes to the achievement of Sustainable Development Goal 4 (Quality Education).

METHOD

The research method in the research is meta analysis. Meta-analysis is a type of systematic review research (Retnawati et al., 2018). Analyzing findings from previous scientific publications is known as a systematic review. This systematic review research found and analyzed effect size values from previous publications. The data found in the article can be said to be quantitative data. Meta-analysis research on the effect of science augmented reality media learning on student learning outcomes.

At the data collection stage from the *Scopus*, *Web of Science*, dan *Google Scholar* database, Researchers used the Publish or Perish (PoP) application version 8.17.4863.9118 as a tool to comprehensively collect research data. There are 4794 search results were obtained and then 38 articles were selected that met the criteria. The selection of articles used used selection based on inclusion and exclusion criteria. The inclusion criteria in this study were determined based on the PICOS approach (Population, Intervention, Comparator, Outcome, and Study Design) (Liberati et al., 2009). The population includes students across various school levels in

Indonesia or several other countries. The intervention involves students who use Augmented Reality (AR)-based learning media, while the comparator consists of students who do not or have not yet used AR learning media. The primary outcome focuses on learning achievement and critical thinking skills in science education. The study design is limited to experimental research. Additionally, the main studies must report statistical data such as mean, standard deviation, effect size, sample size, and t-value. Finally, eligible studies must be published in national or international journals between 2013 and 2024.

Meta-analysis of the influence of science augmented reality learning media on student learning outcomes. Important research variables influence research results. Meta-analysis research variables use moderator variables. The moderator variables used are type of level of education, subject, and type of skill. To see the influence of each moderator variable, a meta-analysis was carried out on the articles to obtain 38 articles. This research obtained data by conducting a metaanalysis of articles from journals. The meta-analytic nature is to carry out comparative descriptive analysis. Analyze the results of the article data and make comparisons with other articles then state conclusions. "Strict inclusion criteria ensured quality standards (Page et al., 2021). Following PRISMA guidelines (Liberati et al., 2009), we conducted: (1) database identification, (2) title/abstract screening, (3) full-text eligibility assessment, and (4) final inclusion. The PRISMA diagram illustrated article flow from identification to inclusion."

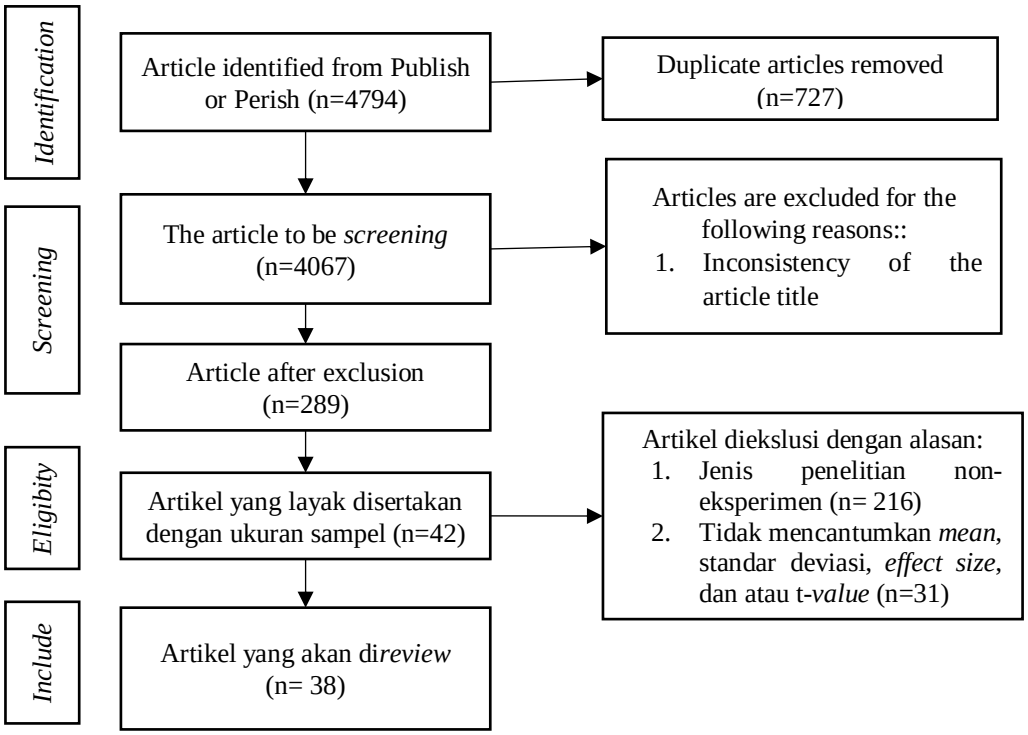

Figure 1. PRISMA flow diagram

Quantitative research states the analysis of data that states the relationship between variables in the article. Determining the relationship between variables can be determined using the effect size. The steps for tabulating effect size data are: identifying research variables, identifying statistical data in the article, calculating the effect size using the effect size formula.

Table 1. Classification of Effect Sizes

***Effect size* (ES)**	**Classification**
$0 \leq ES \leq 0,2$	Weak Effect
$0,2 < ES \leq 0,5$	Modest Effect
$0.5 < ES \leq 0.8$	Moderate Effect
$ES > 0,8$	Strong Effect

The results of the meta-analysis are expressed in effect size values. Results of data analysis using Ms. Excel and JASP software to calculate effect size statistical data. The effect size value obtained will be categorized based on Cohen's standards (Cohen, 2018). Then the Q parameter value is obtained as a determinant that the data obtained is heterogeneous. If the values are heterogeneous, then proceed with hypothesis testing using random effects and it can be seen that the p value is small from the alpha value = 0.05. The classification of effect size value categories is shown in Table 1.

RESULTS

The research results obtained effect size data for each article and a heterogeneity test was carried out. The heterogeneity test will obtain data on the Q, p, and I values. The heterogeneity value can be seen from the Q and I values. For the p value, the hypothesis is accepted if the p value <0.05. Then it is stated that there is an influence science augmented reality learning media on student learning outcomes. Heterogeneous data on the influence influence science augmented reality learning media on student learning outcomes are presented in Table 2.

Table 2. Metaanalysis results

Variables	**Estimate**	**95% Confidence Interval**	
		Lower	**Upper**
Number of samples (K)	38		
Degrees of freedom (df)	37		
Heterogeneity test (Q)	464.543		
Probability value (p)	<0.001		
Standard score (z)	6.805	1.270	2.298
Summary Effect size (M)	1.784		
Heterogeneity test (τ^2)	2.452	1.701	4.990
Heterogeneity test (τ)	1.566	1.304	2.234
Heterogeneity test (I^2 %)	97.341	96.211	98.676
Uji Heterogenitas (H^2)	37.612	26.392	75.510

The data analysis revealed a highly significant effect of Augmented Reality-based science learning media on student learning outcomes ($p < 0.001$ at a 0.05 confidence level). The I^2 value of 97.341% indicates substantial heterogeneity among the included studies, which is categorized as extremely high. This substantial heterogeneity suggests that the random effects model was the most appropriate choice for this meta-analysis, as it accounts for the significant variation between studies.

The meta-analysis revealed that AR learning media had a strong and statistically significant effect on student learning outcomes in science education (average effect size = 1.86). AR was most effective at the elementary school level (effect size = 2.15) and in physics subjects (effect size = 2.25). AR also demonstrated a strong impact on both knowledge acquisition (effect size = 1.94) and critical thinking skills (effect size = 1.73).

Table 3. Summary of effect sizes in AR-based learning studies

Moderator Category	Group	N Studies	Average Effect Size	Effect Size Category
Educational Level	Elementary School	15	2.15	Strong
	Junior High School	14	1.56	Moderate
	Senior High School	13	1.34	Moderate
Subject Area	Physics	18	2.25	Strong
	Biology	12	1.41	Moderate
	Chemistry	7	1.38	Moderate
	Integrated Science	5	1.29	Moderate
Outcome Aspect	Knowledge	26	1.94	Strong
	Critical Thinking Skills	16	1.73	Strong

The data in Table 3 illustrates the distribution of AR's effectiveness across various educational levels, subject areas, and outcome aspects. The strongest effect size is observed at the elementary level (2.15), suggesting that AR is particularly beneficial for younger students who require concrete, visual learning aids. In contrast, the effect size decreases progressively at higher education levels, possibly due to differences in content complexity and student autonomy. Among subject areas, physics shows the highest effect size (2.25), highlighting AR's strength in visualizing abstract phenomena like forces and motion. Biology and chemistry show moderate effects, while integrated science has the lowest. For learning outcomes, AR has a substantial impact on both knowledge and critical thinking, with knowledge showing slightly higher effect size. These findings emphasize the need for AR integration in science learning, particularly at the elementary level and in physics content.

DISCUSSION

The strong influence of AR in elementary school is linked to cognitive development stages, where concrete and visual learning is essential (Helen et al., 2023). AR enables young learners to visualize abstract phenomena, enhancing motivation and understanding. For example, AR applications allow students to manipulate 3D models of cells, planets, or forces, providing a hands-on experience that fosters engagement (Amelia et al., 2020). The pronounced effect of AR in physics subjects is attributed to the visual nature of physical phenomena. AR helps learners conceptualize forces, motions, and energy flows that are otherwise difficult to grasp through text or static images (Ibáñez et al., 2014). Moreover, AR's interactive features promote inquiry-based learning, where students formulate hypotheses, test predictions, and refine understanding.

Regarding learning outcomes, AR's multimodal presentations (visual, auditory, kinesthetic) enhance knowledge acquisition by catering to diverse learning styles (Putri et al., 2023). For critical thinking, AR provides simulated environments that challenge students to analyze, evaluate, and create solutions—skills essential for 21st-century learning (Zubaidah, 2010; Fajari & Meilisa, 2022). These findings underscore AR's potential as a transformative tool in science education, particularly in Indonesia's context of digital literacy development and equitable access to quality education.

CONCLUSION

This meta-analysis confirms that Augmented Reality learning media significantly enhances student learning outcomes in science education, particularly at the elementary school level and in physics subjects. AR is highly effective in improving both knowledge acquisition and critical thinking skills through interactive and immersive learning experiences. These results highlight the need for integrating AR into Indonesian classrooms to support Kurikulum Merdeka, digital literacy, and the achievement of SDG 4. Future research should explore AR's impact on affective and psychomotor domains, long-term retention, and its integration with emerging technologies like artificial intelligence and virtual reality.

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