Hipotenusa : Journal of Mathematical Society
Volume 6 Issue 2 Year 2024
ISSN: 2716-3156
Website: https://ejournal.uinsalatiga.ac.id/index.php/hipotenusa/index

The Global Trend of Augmented Reality-Based Learning and Its Impact on Students' Academic Ability: A Meta-Analysis

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DOI: 10.18326/hipotenusa.v6i2.2454

Article submitted: September 18, 2024
Article reviewed: November 11, 2024
Article published: December 30, 2024

Abstract

Today, there are many studies available in the literature that test the effectiveness of using augmented reality (AR). However, these studies provide varying results. In this regard, a meta-analysis is needed to examine the overall effect of all studies that question the influence of Augmented Reality-Based Learning (ARBL) on students' academic ability. Then, moderator variables need to be investigated to consider their implications. Data were examined from the Scopus and Google Scholar databases using the Publish or Perish application between 2016 and 2023. Data screening resulted in 69 independent groups of 32 eligible primary studies with 2659 subjects. Population estimation was based on a random effects model, and Comprehensive Meta-Analysis (CMA) was used as a calculation tool. The study's results provided an overall effect size of 0.81 (large effect). This shows that ARBL greatly affects students' academic ability, so its application must be considered. Of all the moderator variables analyzed, year of study, educational level differences, and subject matter were associated with differences in effect sizes in the main study. Thus, these three variables need to be considered in educational settings related to the development and implementation of ARBL in the future. Several new findings and research gaps are discussed and will help teachers, lecturers, and practitioners fill them in the future.

Keywords: augmented reality, students' academic ability, meta-analysis, moderator variables, effect size

INTRODUCTION

Augmented reality (AR) is the latest innovation in contemporary visualization technology that can expand sensory perception through digital objects (Buchner & Kerres, 2023). AR technology has great potential in the world of education, more specifically in learning (Sural, 2018; Z. A. Yilmaz & Batdi, 2021). Virtual things through AR interfaces help teachers visualize abstract objects (Demitriadou et al., 2020; Kan,

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2021; Leitão et al., 2014) thus enabling the creation of attractive and engaging environments and promoting student engagement (Kim et al., 2018; Savela et al., 2020; Sudirman et al., 2020).

The main characteristics of AR are that real and virtual objects are displayed simultaneously, the interaction process takes place in real-time, and virtual and real objects are registered geometrically (Buchner & Kerres, 2023). Initially, AR technology was only used by the military, but in 2016, with the release of the AR game Pokémon Go, AR technology began to be widely known and operated using smartphones (Qiao et al., 2019). AR technology is commonly used in learning because it helps teachers communicate (Mingsiritham et al., 2020) and visualize abstract concepts through 3D images (Saidin et al., 2019). AR technology is increasingly relevant to be integrated in various sectors (Cabero-Almenara et al., 2019; M. Silva et al., 2023). In education AR media has been developed for in-flight training (Giannopulu et al., 2022; Li et al., 2022), supporting health services (Balian et al., 2019; Tao et al., 2023; Wan et al., 2022), facilitating assembly adaptation in the construction industry (Grodotzki et al., 2023), and development in the tourism sector (Ronaghi & Ronaghi, 2022).

The development of AR technology in learning has given rise to a new didactic design, Augmented Reality-Based Learning (ARBL). This didactic design is characterized by integrating AR technology with interactive 3D in teaching materials to support students in strengthening their specific abilities (Hamzah et al., 2021; Tuwoso et al., 2021). AR is an innovative technological tool that is very attractive to users, enabling the sharing of information dynamically and realistically (Cardenas-Valdivia et al., 2023). AR-based learning can also help in programming learning and practice (Putra et al., 2021), and reduce the costs of creating conventional media (Samala & Amanda, 2023). AR technology has been considered an alternative learning media that is close to students' lives (Pradibta, 2018) thus triggering a flurry of studies to test its effectiveness.

Previous empirical studies have questioned the effectiveness of using ARBL but have sometimes yielded conflicting results. In the current literature, various studies have concluded that ARBL can support students' learning interests and improve their academic abilities (e.g., (Cahyana et al., 2023; A. C. Silva et al., 2022; Whang et al., 2021)). Meanwhile, other research conditions show different results where the use of ARBL does not affect students' academic abilities. (e.g. Chang et al., 2019; Chien et al., 2017; Yilmaz & Goktas, 2017). Another study shows that the results of the analysis of the achievement of the learning process appear to still be in the sufficient category (Huda et al., 2021). The most recent studies confirm that the integration of AR technology into the classroom has not had a consistent impact on students' academic abilities (Buchner & Kerres, 2023). Temporary, and policy implementers need valid information or conclusions about the magnitude of the overall effect of ARBL use and what conditions need to be considered so that ARBL use achieves maximum results.

This gap can be filled by summarizing primary research results to obtain an overall study effect size. In this case, a meta-analysis study can be applied because, with this work, we can integrate the findings of primary studies and investigate the reasons for the inconsistency of results from all primary studies to consider its implementation in the

future and then analyze (Franzen, 2020; Tamur et al., 2023; Wijaya et al., 2022). Meta-analysis leads to accurate conclusions (Siddaway et al., 2019).

Previous studies have reviewed the use of AR and its contribution to learning (e.g., (Cardenas-Valdivia et al., 2023)). Research conducted by (Hedberg et al., 2018) and (Garzón, 2021) presents findings about the mobile platforms used in AR studies and the pedagogical approaches used. In addition, (Masmuzidin et al., 2022) has reviewed 16 articles presenting five research themes: information, interface, interaction, imagination, and immersion. Several meta-analysis studies on the effects of AR have been conducted in the literature, but these studies still need to be confirmed so that their contribution is clearer. Likewise, the meta-analysis conducted by Jeffri & Awang Rambli (2021) has tested that AR technology is related to device variables, relevance and accuracy of content, user factors, material presentation, and the tasks' characteristics. Apart from that, until 2023, there will be no meta-analysis results regarding trends in ARBL use.

In an effort to obtain a more up-to-date and comprehensive picture regarding the overall influence of the use of ARBL in education, a meta-analysis study needs to be carried out. This research fills a gap in the literature by determining the magnitude of the overall influence of ARBL use on students' academic abilities and investigating several moderating variables that could influence the size of the study effect. In accordance with the research objectives, the moderator variables considered in this research are the year of research, class capacity, education level, and subject matter.

This study will contribute to the literature, teachers, lecturers, and practitioners who will implement ARBL in the future by considering existing moderator variables. The results of this study can be used to consider differences in educational levels in implementing ARBL, and also appropriate subject matter. The focus of this work is to answer two main problems, namely: (1) is the average ES of all studies examining the influence of ARBL on students' academic abilities significantly different from zero? and (2) Are the moderator variables considered in this work related to differences in effect sizes between primary studies?

METHODS

Meta-analysis is applied to solve research problems because its conclusions are more valid than primary studies (Cooper, 2017). This research begins with problem formulation, followed by data tracking, continues with data coding, statistical calculation stages, and ends by discussing the results and findings (Borenstein et al., 2009).

Literature Search

This research chose the Google Scholar and Scopus databases as document search locations.

Inclusion Criteria

After the data was collected using the Publish or Perish application, it was then selected using the following provisions; a). articles written in English or Indonesian and taken from the Scopus and Google Scholar databases between 2016-2023; b) The study provides the necessary statistical data. Studies with incomplete data were excluded (e.g., Saleem et al., 2021)); c) Quantitative research and experimental classes were compared

with control classes. Development research that only used one sample or a qualitative approach was not included in the analysis (e.g., (Ratnawati et al., 2022)). In this study, suggestions from (Pigott & Polanin, 2020), namely using the PRISMA protocol. The data filtering process using the PRISMA protocol is available in Figure 1.

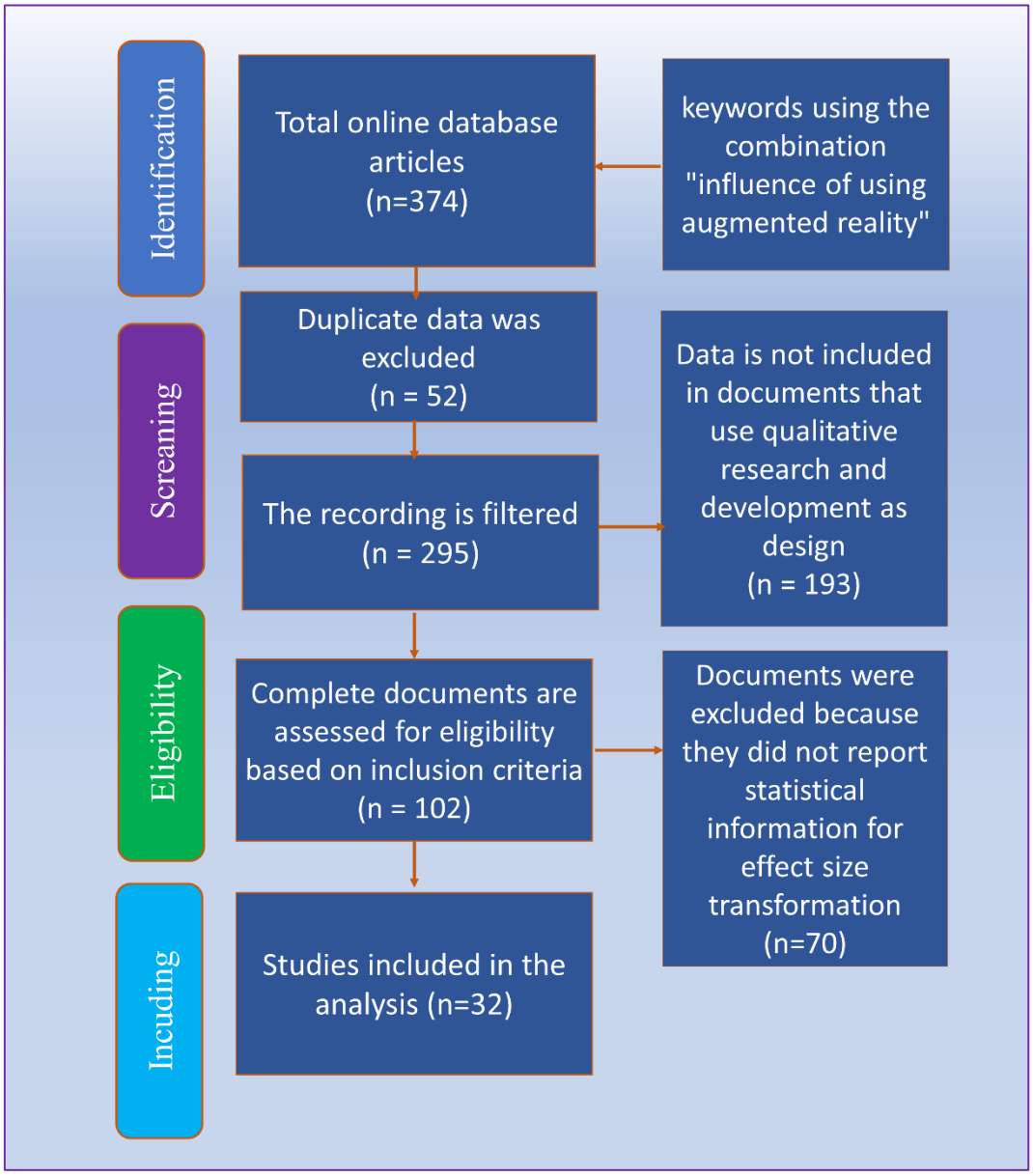

Figure 1. Data selection process

Figure 1 shows the stages of the data screening process. At the identification stage, the total articles related to ARBL from the online database were 374. At the screening stage, 52 identical articles were identified and were excluded. Then, based on the inclusion requirements, 193 articles were excluded from the analysis. Furthermore, 102 articles were checked for completeness, especially information on statistical reports to obtain effect size values. A total of 70 articles were declared incomplete and were excluded from the analysis. Thus, the number of primary studies eligible for analysis was 32. However, several primary studies analyzed more than one group so that the total

independent samples analyzed were 69. A list of 31 research journal articles used as data in this study has been attached.

Coding Process

In this study, the variables coded were year of research, class capacity, education level, and subject matter. A detailed coding sheet served as the research instrument. With this instrument, two coders coded all data separately according to (Cooper, 2017) guidelines. The level of agreement between the two coders is determined using Cohen's Kappa formula (McHugh, 2012), namely:

$$k = \frac{Pr(a)-Pr(e)}{Pr(e)} \quad (1)$$

In equation (1), the observed agreement is represented by Pr (a), and the deal due to chance is represented by Pr (e). An index of 0.85 or more significant has been previously determined to be considered high (McHugh, 2012). An index k = 0.97 was obtained which was interpreted as meaning that the two coders achieved an almost perfect level of agreement.

Statistic Analysis

The CMA v3 software was used to assist in calculating the ES for each study. This work uses the classification (Cohen et al., 2018) to categorize study effect sizes as more than 1.3 (very large), 0.8 to 1.3 (large), 0.5 to 0.8 (medium), 0.2 to 0.5 (small), and 0.2 or less (negligible). If the p-value <0.05, then the ES of each study is inconsistent (Borenstein et al., 2009).

In addition, publication bias should be analyzed to ensure there are no errors in the presentation of research findings. This was anticipated by examining funnel plots, and trim and fill procedures were used to assess the impact of publication bias (Borenstein et al., 2009). There is no indication of publication bias if the distribution of ES is symmetrical. Next, the trim and fill procedure is used if the visualization results of the effect size (ES) are asymmetrically distributed.

RESULTS AND DISCUSSION

First, this research aims to answer the first question: analyzing the average ES of using augmented reality in education. From the results of data filtering, there were 69 independent samples included in this analysis. The hit plot of this study is shown in Figure 2. Based on Figure 2, it can be seen that the level of confidence and the level of response are generally different. This can be seen from the distribution of effect sizes symbolized by square boxes where the location is not in one vertical line. This means that descriptively, the effect sizes of each study are distributed heterogeneously. However, it still needs to be tested statistically to ensure that the estimation method meets the initial assumptions. Table 1 is a summary of the analysis to answer the first research question.

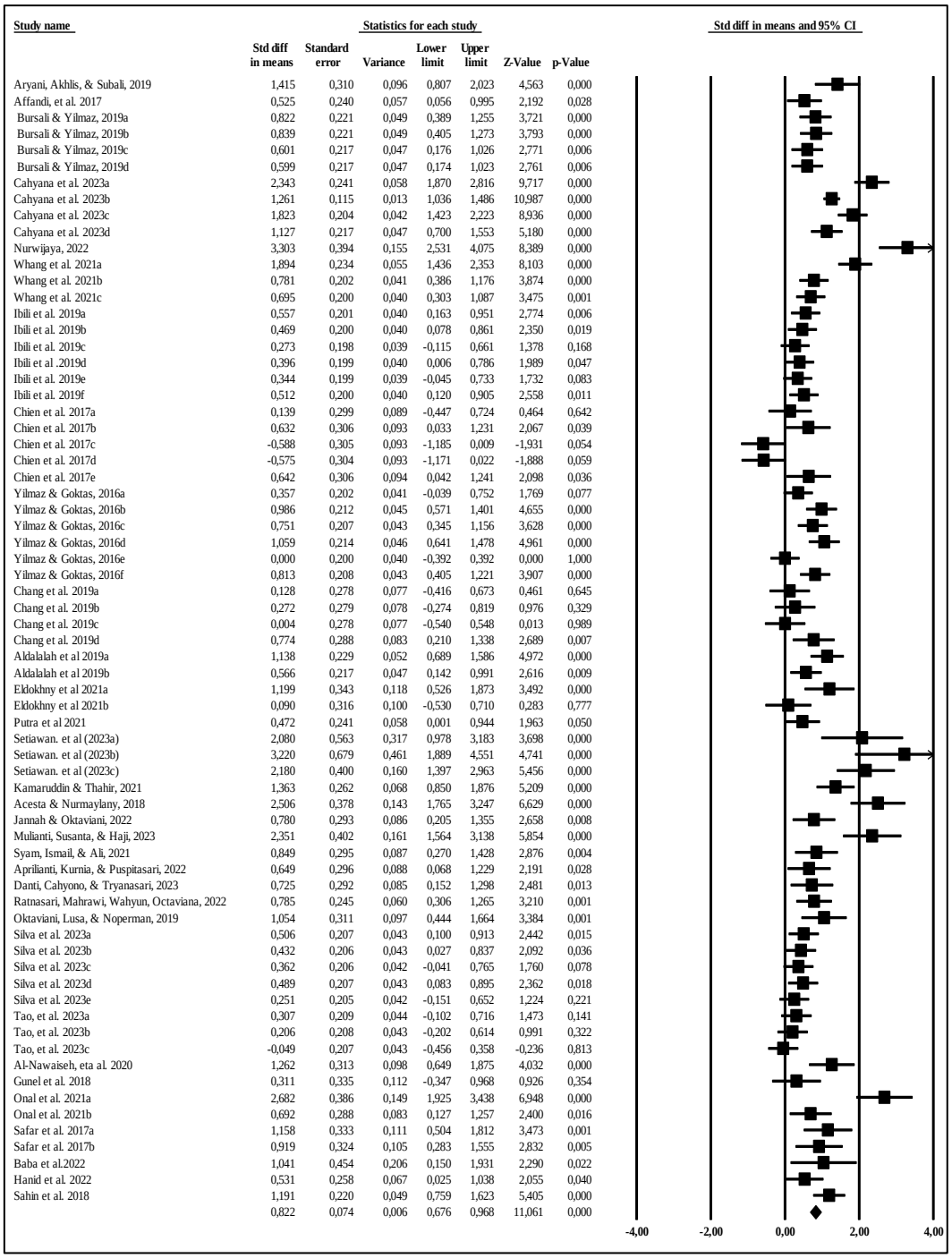

Figure 2. Research forest plot

Table 1. Summary of main results

Model	N	ES Average (Hedges's g)	Standard error	Test of null		Q	P
				Z-value	P-value		
Fixed-effects (FE)	69	0.74	0.03	24,34	0.00	427.67	0.00
Random-effects (RE)	69	0.81	0.07	11,22	0.00		

When Table 1 is evaluated, the P value for the test of null < 0 based on the RE model. This result provides an answer to the first question that the average ES representing the intervention for each study on the effect of ARBL on students' academic ability is significantly different from zero. Thus, overall, the research results clarify the superiority of the experimental group using ARBL with an average ES of 0.81, which is accepted as a significant effect according to (Cohen et al., 2018). Next, it is necessary to pay attention to whether these results are resistant to publication bias. This can be seen by looking at the research funnel plot in Figure 3.

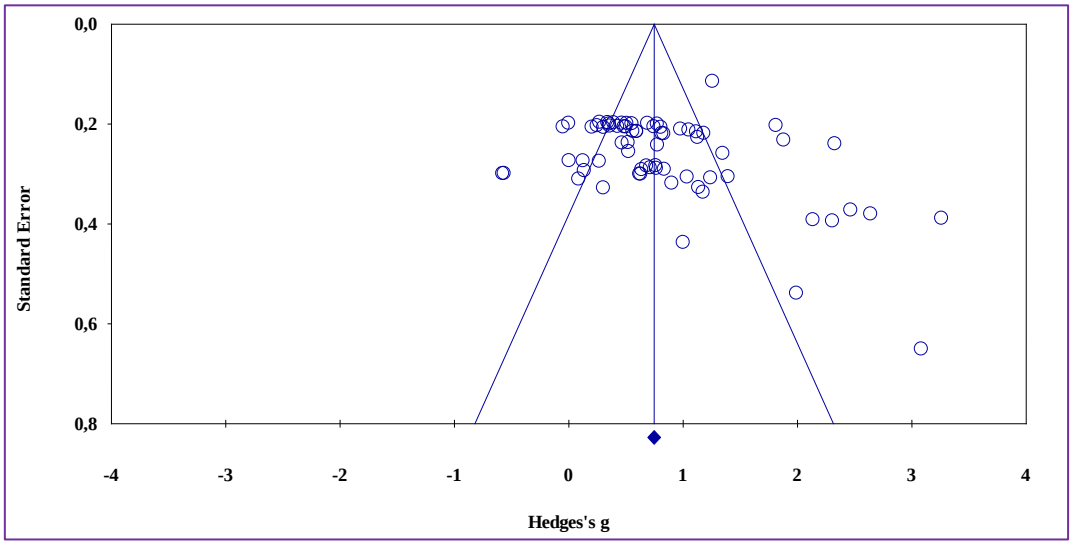

Figure 3. Funnel Plot of 60 Independent Samples

From the distribution of effect sizes in Figure 3, it can be seen that the distribution is not symmetrical. Trim and Fill procedures were performed to assess the impact of publication bias on this study. Evaluated the extent of the effects associated with publication bias in the ES obtained from meta-analyses conducted according to the RE model, and the results are presented in Table 2.

Table 2. Trim and Fill Results

	Studies Trimmed	Random-Effects Point Estimate	Lower Limit	Upper Limit	Q Value
Observed values		0.81	0.66	1.96	427.67
Adjusted values	0	0.81	0.66	1.96	427.67

Based on Table 2, the observed and virtual effect sizes are the same. This emphasizes that there is no need to trim or add studies due to publication bias. Thus, the study ES accepted as 0.81 (large effect) does not indicate publication bias. In other words, this value can be trusted to estimate the effect of ARBL in the population on students' academic abilities.

Further sensitivity analyses are needed to explore potential abnormal ES data sources. Table 3 presents the findings based on a random effects model where the average ES of the study was g = 0.81. Sensitivity analysis used the “One study removed” tool in

the CMA software. The analysis results give g = 0.95 as the highest average and g = 0.66 as the lowest average. These results are the same as the study mean intervals presented in Table 2 before using the "One study removed" method. This provides essential information: this study's ES data set is still stable even though one or more ES data are not included. This means that the data analyzed in this study are not sensitive to differences in ES.

Table 3. Results of Sensitivity Analysis Using the "One study removed" Method

Number of ES	Point Estimate (g)	95%CL
69	0.81	[0.66; 0.96]

Next, substantial moderator variables are examined to achieve the second objective or question. According to (Arik & Yilmaz, 2020) moderator variables must be explored further because the estimation method chosen corresponds to a RE model (Table 4).

Table 4. Moderator Variable Analysis

Moderator Variables	Category	N	Hedge's g	Heterogeneity (Qb)	df(Q)	P
Year of Study	2016-2017	14	0.52	36.03	3	0.00
	2018-2019	21	0.63			
	2020-2021	11	0.92			
	2022-2023	23	0.98			
Educational stage	Primary School (PS)	27	1.34	92.69	3	0.00
	Junior high school (JHS)	8	0.68			
	Senior high school (SHS)	18	0.63			
	College	15	0.53			
Class Capacity	30 or less	30	0.82	0.18	1	0.12
	31 or over	38	0.71			
Subject Matter	Biology	3	1.35	40.32	6	0.00
	Chemistry	9	0.87			
	Language	12	0.69			
	Mathematics	14	0.64			
	Natural science	20	0.61			
	Physics	6	0.51			
	Social science	4	0.92			

Discussion

The results of the calculations and analysis provide an average ES study of 0.81, which is included in the large influence category based on Cohen's category (Cohen et al., 2018). In general, these results are surprising because they are pretty different from the results of previous meta-analyses where the average ES of studies on ARBL influences was in the medium category with a range of 0.6 to 0.8 (e.g., Jeffri & Awang Rambli, 2021; Lin & Yu, 2023; Ozdemir et al., 2018; Yilmaz & Batdi, 2021)). It can be said that these results strengthen the empirical validity related to the influence of ARBL on students' academic abilities. Even though previous meta-analysis research was carried

out at different times, it showed almost the same findings. This shows an almost similar global trend of ARBL influence. It should be noted that previous studies limited the data analyzed to less than 2019. In contrast, this study limited the research to 2016 to 2023 to clarify trends in education and be able to consider their implications.

This research involved 2659 subjects, and the average sample size was 41. The ES of 0.81 can be interpreted to mean that students ranked 21st in the experimental class are considered the same as students ranked 9th in the control class. This illustrates the strength of ARBL's influence on students' academic abilities. This is because by using ARBL, students feel satisfaction from their participation, and there is a desire to use it repeatedly (Bursali & Yilmaz, 2019; Kim et al., 2018; Savela et al., 2020; Sudirman et al., 2020). This is possible because ARBL offers contemporary visualization that can expand students' sensory perceptions (Buchner & Kerres, 2023). Apart from that, using ARBL helps teachers to visualize objects in real-time (Demitriadou et al., 2020; Kan, 2021; Leitão et al., 2014; Mailizar & Johar, 2021).

Next, Table 3 shows the results of the moderator variable analysis. First, the summary analysis implied that the year of study consisting of four categories was shown to mediate the average ES of the study (P<0.00). From these four categories, the study ES is larger in the most recent group of studies. This clearly shows that the trend of using ARBL between 2020 and 2023 is getting stronger and providing maximum results. Meanwhile, the average ES in the group of studies under 2020 was almost the same as the results of previous meta-analyses in the range of 0.6 to 0.8 (e.g., Lin & Yu, 2023; Ozdemir et al., 2018; Yilmaz & Batdi, 2021). From these results, it is interesting that there is an increase in the influence of ARBL use worldwide from year to year. This global trend provides a new direction for teachers, lecturers, stakeholders, and professionals to develop the ARBL didactical framework to support its future implementation.

Table 3 also shows the results of the analysis of the educational level variable where the P value <0.00 indicates that the academic level of the study group being analyzed mediates the difference in the average ES of the main study. From the analysis results, the application of ARBL in tertiary and junior high schools should be preferred because it provides higher effectiveness. This result is almost the same as the meta-analysis findings from (Ozdemir et al., 2018) that using ARBL must consider educational level. However, the analysis results of academic-level variables must be further verified by involving many related study groups to provide a clearer picture.

Furthermore, Table 3 also summarizes the results of the moderator analysis of class capacity or sample size in the experimental group. From the investigation results, it can be seen that the P value is> 0.05, which indicates no difference in ES between the two categories. This result is surprising because it differs from the results of other meta-analyses, especially for using technology other than AR. Several previous meta-analyses provide different effects that small sample sizes should be more considered in educational settings (Juandi, 2021; Juandi, Tamur, et al., 2022; Tamur et al., 2021, 2023). This difference is possible because the application of ARBL requires students to work individually, for example, by using an intelligent pin when exploring AR. Meanwhile,

learning using computers usually involves several students on one computer. However, this can be verified again in further research to see a clearer picture.

Finally, this study considers Subject Matter as a moderator variable with seven categories: Chemistry, Language, Mathematics, Natural science, Physics, and Social science. The analysis results found a P value <0.00, which means there are differences in the ES of the seven categories or subgroups. Interestingly, the ES for the social science study group was lower than for the other categories. This is also supported by a meta-analysis conducted by (Ozdemir et al., 2018) which found the superiority of natural science study groups over social sciences. From these results, it is also clear that the application of ARBL seems to achieve more optimal results in chemical and biological subjects. Meanwhile, the fields of mathematics, language, and natural sciences provide almost the same effect size.

CONCLUSION

This research analyzed 69 independent samples from 32 primary studies. The analysis results concluded that the implementation of ARBL significantly impacted students' academic abilities. The analysis results also show that statistically, there is an increase in the influence of ARBL use worldwide from year to year. This global trend provides a new direction for teachers, lecturers, stakeholders, and professionals to develop the ARBL didactic framework to support its implementation in the future.

The results of the analysis also provide differences in ES between primary studies mediated by various categorical variables. However, these results still need to be stronger because quite a lot of data cannot be retrieved. After all, it is paid or must be obtained through institutional collaboration. For example, Scopus articles in the IEEE database cannot be downloaded because they have to be paid for.

REFERENCES

Altinpulluk, H. (2019). Determining the trends of using augmented reality in education between 2006-2016. *Education and Information Technologies*, *24*(2), 1089–1114. https://doi.org/10.1007/s10639-018-9806-3

Arik, S., & Yilmaz, M. (2020). The effect of constructivist learning approach and active learning on environmental education: A meta-analysis study. *International Electronic Journal of Environmental Education*, *10*(1), 44–84. https://files.eric.ed.gov/fulltext/EJ1239355.pdf

Balian, S., McGovern, S. K., Abella, B. S., Blewer, A. L., & Leary, M. (2019). Feasibility of an augmented reality cardiopulmonary resuscitation training system for health care providers. *Heliyon*, *5*(8), e02205. https://doi.org/10.1016/j.heliyon.2019.e02205

Borenstein, M., Hedges, L. V, & Rothstein, H. R. (2009). *Introduction Meta-Analysis* (Issue January). John Wiley & Sons.

Buchner, J., & Kerres, M. (2023). Media comparison studies dominate comparative research on augmented reality in education. *Computers and Education*, *195*(August

2022), 104711. https://doi.org/10.1016/j.compedu.2022.104711

Bursali, H., & Yilmaz, R. M. (2019). Effect of augmented reality applications on secondary school students' reading comprehension and learning permanency. *Computers in Human Behavior*, *95*(June 2018), 126–135. https://doi.org/10.1016/j.chb.2019.01.035

Cabero-Almenara, J., Fernández-Batanero, J. M., & Barroso-Osuna, J. (2019). Adoption of augmented reality technology by university students. *Heliyon*, *5*(5). https://doi.org/10.1016/j.heliyon.2019.e01597

Cahyana, U., Roland, L., Lestari, I., Irwanto, I., & Suroso, J. S. (2023). Improving Students' Literacy and Numeracy Using Mobile Game-Based Learning with Augmented Reality in Chemistry and Biology. *International Journal of Interactive Mobile Technologies (IJIM)*, *17*(16), 4–15. https://doi.org/10.3991/ijim.v17i16.42377

Cardenas-Valdivia, J., Flores-Alvines, J., Iparraguirre-Villanueva, O., & Cabanillas-Carbonell, M. (2023). Augmented Reality for Quechua Language Teaching-Learning: A Systematic Review. *International Journal of Interactive Mobile Technologies*, *17*(6), 116–138. https://doi.org/10.3991/ijim.v17i06.37793

Chang, K. E., Zhang, J., Huang, Y. S., Liu, T. C., & Sung, Y. T. (2019). Applying augmented reality in physical education on motor skills learning. *Interactive Learning Environments*, *28*(6), 685–697. https://doi.org/10.1080/10494820.2019.1636073

Chien, Y. C., Su, Y. N., Wu, T. T., & Huang, Y. M. (2017). Enhancing students' botanical learning by using augmented reality. *Universal Access in the Information Society*, *18*(2), 231–241. https://doi.org/10.1007/s10209-017-0590-4

Cohen, L., Manion, L., & Morrison, K. (2018). *Research Methods in Education* (8th ed.). Routledge Taylor & Francis Group.

Cooper, H. M. (2017). *Research Synthesis and Meta-Analysis : A Step-by-Step Approach* (Fifth). SAGE Publications. https://doi.org/10.4135/9781071878644

Demitriadou, E., Stavroulia, K. E., & Lanitis, A. (2020). Comparative evaluation of virtual and augmented reality for teaching mathematics in primary education. *Education and Information Technologies*, *25*(1), 381–401. https://doi.org/10.1007/s10639-019-09973-5

Franzen, M. (2020). Meta-analysis. In H. V. Zeigler & T. . Shackelford (Eds.), *Encyclopedia of Personality and Individual Differences* (p. 5925). Springer, Cham. https://doi.org/10.1007/978-3-319-24612-3_1326

Garzón, J. (2021). An overview of twenty-five years of augmented reality in education. *Multimodal Technologies and Interaction*, *5*(7). https://doi.org/10.3390/mti5070037

Giannopulu, I., Brotto, G., Lee, T. J., Frangos, A., & To, D. (2022). Synchronised neural signature of creative mental imagery in reality and augmented reality. *Heliyon*, *8*(3). https://doi.org/10.1016/j.heliyon.2022.e09017

Grodotzki, J., Müller, B. T., & Tekkaya, A. E. (2023). Enhancing manufacturing education based on controller-free augmented reality learning. *Manufacturing*

Letters, *35*, 1246–1254. https://doi.org/10.1016/j.mfglet.2023.08.068

Hamzah, M. L., Ambiyar, Rizal, F., Simatupang, W., Irfan, D., & Refdinal. (2021). Development of Augmented Reality Application for Learning Computer Network Device. *International Journal of Interactive Mobile Technologies*, *15*(12), 47–64. https://doi.org/10.3991/ijim.v15i12.21993

Hedberg, H., Nouri, J., Hansen, P., & Rahmani, R. (2018). A systematic review of learning through mobile augmented reality. *International Journal of Interactive Mobile Technologies*, *12*(3), 75–85. https://doi.org/10.3991/ijim.v12i3.8404

Huda, A., Azhar, N., Almasri, A., Wulansari, R. E., Mubai, A., Sakti, R. H., Firdaus, F., & Hartanto, S. (2021). Augmented Reality Technology as a Complement on Graphic Design to Face Revolution Industry 4.0 Learning and Competence: The Development and Validity. *International Journal of Interactive Mobile Technologies*, *15*(5), 116–126. https://doi.org/10.3991/ijim.v15i05.20905

Jeffri, N. F. S., & Awang Rambli, D. R. (2021). A review of augmented reality systems and their effects on mental workload and task performance. *Heliyon*, *7*(3), e06277. https://doi.org/10.1016/j.heliyon.2021.e06277

Juandi, D. (2021). A meta-analysis of Geogebra software decade of assisted mathematics learning: what to learn and where to go? *Heliyon*, *7*(5). https://doi.org/10.1016/j.heliyon.2021.e06953

Juandi, D., Kusumah, Y. S., & Tamur, M. (2022). A Meta-Analysis of the Last Two Decades of Realistic Mathematics Education Approaches. *International Journal of Instruction*, *15*(1), 381–400. https://doi.org/10.29333/iji.2022.15122a

Juandi, D., Tamur, M., Martadiputra, B. A. P., Suparman, & Kurnila, V. S. (2022). A meta-analysis of a year of virtual-based learning amidst the COVID-19 crisis : Possible solutions or problems ? *AIP Conference Proceedings*, *2468*(1), 1–6.

Kan, A. Ü. (2021). The effect of using augmented reality based teaching material on students' academic success and opinions. *African Educational Research Journal*, *9*(1), 273–289. https://doi.org/10.30918/aerj.91.21.035

Kim, S. J., Jeong, Y., Park, S., & Ryu, K. (2018). A Survey of Drone use for Entertainment and AVR (Augmented and Virtual Reality). In *Augmented Reality and Virtual Reality* (pp. 339–352). Springer International Publishing. https://doi.org/10.1007/978-3-319-64027-3

Leitão, R., Rodrigues, J. M. F., & Marcos, A. F. (2014). Game-Based Learning: Augmented Reality in the Teaching of Geometric Solids. *International Journal of Art, Culture and Design Technologies*, *4*(1), 63–75. https://doi.org/10.4018/ijacdt.2014010105

Li, W. C., Zhang, J., Court, S., Kearney, P., & Braithwaite, G. (2022). The influence of augmented reality interaction design on Pilot's perceived workload and situation awareness. *International Journal of Industrial Ergonomics*, *92*(November), 103382. https://doi.org/10.1016/j.ergon.2022.103382

Lin, Y., & Yu, Z. (2023). A meta-analysis of the effects of augmented reality technologies in interactive learning environments (2012–2022). *Computer Applications in*

Engineering Education, *31*(4), 1111–1131. https://doi.org/10.1002/cae.22628

Mailizar, & Johar, R. (2021). Examining students' intention to use augmented reality in a project-based geometry learning environment. *International Journal of Instruction*, *14*(2), 773–790. https://doi.org/10.29333/iji.2021.14243a

Masmuzidin, M. Z., Aziz, N. A. A., & Suhaimi, S. (2022). A Systematic Review of Augmented Reality Design for Young Children. *International Journal of Interactive Mobile Technologies*, *16*(17), 60–71. https://doi.org/10.3991/ijim.v16i17.31837

McHugh, M. L. (2012). Lessons in biostatistics interrater reliability : the kappa statistic. *Biochemica Medica*, *22*(3), 276–282. https://doi.org/10.11613/BM.2012.031

Mingsiritham, K., Chanyawudhiwan, G., & Paiwithayasiritham, C. (2020). Factor Analysis of Smart Social Media Technology to Promote Professional Learning Communities for Teachers. *International Journal of Interactive Mobile Technologies*, *14*(20), 165–173. https://doi.org/10.3991/IJIM.V14I20.17253

Ozdemir, M., Sahin, C., Arcagok, S., & Demir, M. K. (2018). The effect of augmented reality applications in the learning process: A meta-analysis study. *Eurasian Journal of Educational Research*, *2018*(74), 165–186. https://doi.org/10.14689/ejer.2018.74.9

Park, S., & Hong, S. (2016). The empirical review of meta-analysis published in Korea. *Asia Pacific Education Review*, *17*(2), 313–324. https://doi.org/10.1007/s12564-016-9433-x

Pigott, T. D., & Polanin, J. R. (2020). Methodological Guidance Paper: High-Quality Meta-Analysis in a Systematic Review. *Review of Educational Research*, *90*(1), 24–46. https://doi.org/10.3102/0034654319877153

Pradibta, H. (2018). Augmented reality: Daily prayers for preschooler student. *International Journal of Interactive Mobile Technologies*, *12*(1), 151–159. https://doi.org/10.3991/ijim.v12i1.7269

Putra, A. B. N. R., Mukhadis, A., Ulfatin, N., Tuwoso, Subandi, M. S., Hardika, & Muhammad, A. K. (2021). The Innovation of Disruptive Learning Media with Augmented Reality Based 3D Object Concept with Drill Machine Design to Improve Quality of Distance Learning in The Era of Education 4.0. *International Journal of Interactive Mobile Technologies*, *15*(12), 193–200. https://doi.org/10.3991/ijim.v15i12.21579

Qiao, X., Ren, P., Dustdar, S., Liu, L., Ma, H., & Chen, J. (2019). Web AR: A Promising Future for Mobile Augmented Reality-State of the Art, Challenges, and Insights. *Proceedings of the IEEE*, *107*(4), 651–666. https://doi.org/10.1109/JPROC.2019.2895105

Ratnawati, N., Wahyuningtyas, N., Habibi, M. M., Bashofi, F., & Shaharom, M. S. N. (2022). Development of Augmented Reality Practicum Modules to Grow Independent Learning in Cultural Anthropology Courses. *International Journal of Interactive Mobile Technologies*, *16*(22), 59–74. https://doi.org/10.3991/ijim.v16i22.36161

Ronaghi, M. H., & Ronaghi, M. (2022). A contextualized study of the usage of the

augmented reality technology in the tourism industry. *Decision Analytics Journal*, *5*(September), 100136. https://doi.org/10.1016/j.dajour.2022.100136

Saidin, N. F., Halim, N. D. A., & Yahaya, N. (2019). Framework for developing a Mobile Augmented Reality for learning chemical bonds. *International Journal of Interactive Mobile Technologies*, *13*(7), 54–68. https://doi.org/10.3991/ijim.v13i07.10750

Saleem, M., Kamarudin, S., Shoaib, H. M., & Nasar, A. (2021). Influence of augmented reality app on intention towards e-learning amidst COVID-19 pandemic. *Interactive Learning Environments*, *31*(5), 1–15. https://doi.org/10.1080/10494820.2021.1919147

Samala, A. D., & Amanda, M. (2023). Immersive Learning Experience Design (ILXD): Augmented Reality Mobile Application for Placing and Interacting with 3D Learning Objects in Engineering Education. *International Journal of Interactive Mobile Technologies*, *17*(5), 22–35. https://doi.org/10.3991/ijim.v17i05.37067

Savela, N., Oksanen, A., Kaakinen, M., Noreikis, M., & Xiao, Y. (2020). Does Augmented Reality A ff ect Sociability , Entertainment , and Learning ? A Field Experiment. *Applied Sciences*, *10*(4), 1392. https://doi.org/10.3390/app10041392

Schmidt, F. L., & Hunter, J. E. (2015). *Methods of Meta-Analysis: Correcting Error and Bias in Research Findings* (Third). 55 City Road, London: SAGE Publications, Ltd. https://doi.org/10.4135/9781483398105

Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses. *Annual Review of Psychology*, *70*(1), 747–770. https://doi.org/10.1146/annurev-psych-010418-102803

Silva, A. C., Calderon, A. R., Retuerto, M. G., & Andrade-Arenas, L. (2022). Application of Augmented Reality in Teaching and Learning in Engineering Programs. *International Journal of Interactive Mobile Technologies*, *16*(15), 112–124. https://doi.org/10.3991/ijim.v16i15.31695

Silva, M., Bermúdez, K., & Caro, K. (2023). Effect of an augmented reality app on academic achievement, motivation, and technology acceptance of university students of a chemistry course. *Computers & Education: X Reality*, *2*(August 2022), 100022. https://doi.org/10.1016/j.cexr.2023.100022

Sudirman, Mellawaty, Yaniwati, R. P., & Indrawan, R. (2020). Integrating local wisdom forms in augmented reality application: Impact attitudes, motivations and understanding of geometry of pre-service mathematics teachers'. *International Journal of Interactive Mobile Technologies*, *14*(11), 91–106. https://doi.org/10.3991/ijim.v14i11.12183

Sural, I. (2018). Augmented Reality Experience: Initial Perceptions of Higher Education Students,. *International Journal of Instruction*, *11*(4), 565–576. https://doi.org/10.12973/iji.2018.11435a

Tamur, M., Kusumah, Y. S., Juandi, D., Kurnila, V. S., Jehadus, E., & Samura, A. O. (2021). A Meta-Analysis of the Past Decade of Mathematics Learning Based on the Computer Algebra System (CAS). *Journal of Physics: Conference Series*, *1882*(1),

012060. https://doi.org/10.1088/1742-6596/1882/1/012060

Tamur, M., Ndiung, S., Weinhandl, R., Wijaya, T. T., Jehadus, E., & Sennen, E. (2023). Meta-Analysis of Computer-Based Mathematics Learning in the Last Decade Scopus Database: Trends and Implications. *Infinity Journal*, *12*(1), 101. https://doi.org/10.22460/infinity.v12i1.p101-116

Tao, B., Fan, X., Wang, F., Chen, X., Shen, Y., & Wu, Y. (2023). Comparison of the accuracy of dental implant placement using dynamic and augmented reality-based dynamic navigation: An in vitro study. *Journal of Dental Sciences*, *xxxx*. https://doi.org/10.1016/j.jds.2023.05.006

Tuwoso, Putra, A. B. N. R., & Muhammad, A. K. Bin. (2021). The Innovation of Augmented Reality Learning Media with Interactive Component Model to Improve Special Ability of Vocational Education Knowledge in the Digital Era. *International Journal of Interactive Mobile Technologies*, *15*(21), 188–198. https://doi.org/10.3991/ijim.v15i21.24833

Wan, X., Shen, L., Fang, Z., Dong, S., Zhang, S., & Lin, C. (2022). A novel motionless calibration method for augmented reality surgery navigation system based on optical tracker. *Heliyon*, *8*(12), e12115. https://doi.org/10.1016/j.heliyon.2022.e12115

Whang, J. Bin, Song, J. H., Choi, B., & Lee, J. H. (2021). The effect of Augmented Reality on purchase intention of beauty products: The roles of consumers' control. *Journal of Business Research*, *133*(November 2019), 275–284. https://doi.org/10.1016/j.jbusres.2021.04.057

Wijaya, T. T., Cao, Y., Weinhandl, R., & Tamur, M. (2022). A meta-analysis of the effects of E-books on students' mathematics achievement. *Heliyon*, *8*(6), e09432. https://doi.org/10.1016/j.heliyon.2022.e09432

Yilmaz, R. M., & Goktas, Y. (2017). Using augmented reality technology in storytelling activities: examining elementary students' narrative skill and creativity. *Virtual Reality*, *21*(2), 75–89. https://doi.org/10.1007/s10055-016-0300-1

Yilmaz, Z. A., & Batdi, V. (2021). Meta-Analysis of the Use of Augmented Reality Applications in Science Teaching. *Journal of Science Learning*, *4*(3), 267–274. https://doi.org/10.17509/jsl.v4i3.30570

Attachment

List of articles that meet the analysis requirements

No	Authors	Title, Journal Name, Vol, Issue, and DOI
1	Nurwijaya, S. (2022)	Pengaruh Media Pembelajaran Berbasis Augmented Reality Terhadap Hasil Belajar Siswa Kelas X Pada Konsep Dinamika Partikel [The Influence of Augmented Reality-Based Learning Media on the Learning Outcomes of Class X Students on the Concept of Particle Dynamics]. TARBIYA: Journal of Education in Muslim Society, 2(1), 61–72. https://doi.org/10.15408/tjems.v1i1.1111
2	Oktaviani, Y., Lusa, H., & Noperman, F. (2020).	Pengaruh Augmented Reality sebagai Media Pembelajaran terhadap Minat Belajar Siswa Mata Pelajaran IPA SD Kota Bengkulu [The Influence of Augmented Reality as a Learning Media on Students' Interest in Learning in Science Subjects at Elementary Schools in Bengkulu City]. JURIDIKDAS: Jurnal Riset Pendidikan Dasar, 2(3), 202–208. https://doi.org/10.33369/juridikdas.2.3.202-208
3	Danti, D. R., Cahyono, B. E. H., & Tryanasari, D. (2023)	Pengaruh Media Augmented Reality Pada Mata Pelajaran IPAS Terhadap Hasil Belajar Siswa [The Influence of Augmented Reality Media in Science Subjects on Student Learning Outcomes]. Prosiding Konferensi Ilmiah Dasar, 4, 864–871. http://prosiding.unipma.ac.id/index.php/KID
4	Syam, A. S., Ismail, W., & Ali, A. (2021).	Media Augmented Reality dan Power Point serta Pengaruhnya Terhadap Motivasi Belajar Peserta Didik [Augmented Reality and Power Point Media and Their Influence on Students' Learning Motivation]. Jurnal Binomial, 4(2), 95–108. https://ejournals.umma.ac.id/index.php/binomial/article/view/1058
5	Mulianti, S., Susanta, A., Hanifah, H., & Haji, S. (2023).	Pengaruh Pendekatan Problem Based Learning (Pbl) Berbantuan Augmented Reality (Ar) Terhadap Kemampuan Pemecahan Masalah Matematika Di Smk Negeri 1 Lebong [The Influence of the Problem Based Learning (Pbl) Approach Assisted by Augmented Reality (Ar) on Mathematical Problem Solving Ability at SMK Negeri 1 Lebong]. Jurnal Lebesgue : Jurnal Ilmiah Pendidikan Matematika, Matematika Dan Statistika, 4(2), 930–939. https://doi.org/10.46306/lb.v4i2.358
6	Jannah, R., & Oktaviani, R. N. (2022).	Pengaruh Penggunaan Media Augmented Reality terhadap Kemampuan Literasi Numerasi Digital pada Pembelajaran Matematika Materi Penyajian Data Kelas V MI At-Taufiq [The Effect of Using Augmented Reality Media on Digital Numeracy Literacy Ability in Mathematics Learning Data Presentation Material for Class V MI At-Taufiq]. Jurnal Ibriez : Jurnal Kependidikan Dasar Islam Berbasis Sains, 7(2), 123–138. https://ibriez.iainponorogo.ac.id/index.php/ibriez/article/view/283
7	Acesta, A., & Nurmaylany, M. (2018).	Pengaruh Penggunaan Media Augmented Reality Terhadap Hasil Belajar Siswa [The Influence of Using Augmented Reality Media on Student Learning Outcomes]. Didaktik : Jurnal Ilmiah PGSD STKIP Subang, 4(2), 346–352. https://doi.org/10.36989/didaktik.v4i2.79
8	Thahir, R., & Kamaruddin, R. (2021).	Pengaruh Media Pembelajaran Berbasis Augmented Reality (Ar) Terhadap Hasil Belajar Biologi Siswa Sma [The Influence of Augmented Reality (Ar) Based Learning Media on High School Students' Biology Learning Outcomes]. Jurnal Riset Dan Inovasi Pembelajaran, 1(2), 24–35. https://doi.org/10.51574/jrip.v1i2.26
9	Setiawan, B., Rachmadtullah, R., Farid, D. A. M., Sugandi, E., & Iasha, V. (2023).	Augmented Reality as Learning Media: The Effect on Elementary School Students' Science Processability in Terms of Cognitive Style. Journal of Higher Education Theory and Practice, 23(10), 58–69. https://doi.org/10.33423/jhetp.v23i10.6182
10	Putra, A. K., Sumarmi, A. S., Fajrilia, A., Islam,	Effect of Mobile-Augmented Reality (MAR) in Digital Encyclopedia on The Complex Problem Solving and Attitudes of Undergraduate Student. International Journal of Emerging Technologies in Learning, 16(7), 119–134. https://doi.org/10.3991/ijet.v16i07.21223

	M. N., & Yembuu, B. (2021).	
11	Chien, Y. C., Su, Y. N., Wu, T. T., & Huang, Y. M. (2017).	Enhancing students' botanical learning by using augmented reality. Universal Access in the Information Society, 18(2), 231–241. https://doi.org/10.1007/s10209-017-0590-4
12	İbili, E., Çat, M., Resnyansky, D., Şahin, S., & Billinghurst, M. (2020).	An assessment of geometry teaching supported with augmented reality teaching materials to enhance students' 3D geometry thinking skills. International Journal of Mathematical Education in Science and Technology, 51(2), 224–246. https://doi.org/10.1080/0020739X.2019.1583382
13	Chang, K. E., Zhang, J., Huang, Y. S., Liu, T. C., & Sung, Y. T. (2019).	Applying augmented reality in physical education on motor skills learning. Interactive Learning Environments, 28(6), 685–697. https://doi.org/10.1080/10494820.2019.1636073
14	Yilmaz, R. M., & Goktas, Y. (2017).	Using augmented reality technology in storytelling activities: examining elementary students' narrative skill and creativity. Virtual Reality, 21(2), 75–89. https://doi.org/10.1007/s10055-016-0300-1
15	Whang, J. Bin, Song, J. H., Choi, B., & Lee, J. H. (2021).	The effect of Augmented Reality on purchase intention of beauty products: The roles of consumers' control. Journal of Business Research, 133(November 2019), 275–284. https://doi.org/10.1016/j.jbusres.2021.04.057
16	Aryani, P. R., Akhlis, I., & Subali, B. (2019).	Penerapan Model Pembelajaran Inkuiri Terbimbing Berbentuk Augmented Reality pada Peserta Didik untuk Meningkatkan Minat dan Pemahaman Konsep IPA [Application of the Guided Inquiry Learning Model in the Form of Augmented Reality to Students to Increase Interest and Understanding of Science Concepts]. Unnes Physics Education Journal, 8(2), 91–101. http://journal.unnes.ac.id/sju/index.php/upej
17	Cahyana, U., Roland, L., Lestari, I., Irwanto, I., & Suroso, J. S. (2023).	Improving Students' Literacy and Numeracy Using Mobile Game-Based Learning with Augmented Reality in Chemistry and Biology. International Journal of Interactive Mobile Technologies (IJIM), 17(16), 4–15. https://doi.org/10.3991/ijim.v17i16.42377
18	Bursali, H., & Yilmaz, R. M. (2019).	Effect of augmented reality applications on secondary school students' reading comprehension and learning permanency. Computers in Human Behavior, 95(June 2018), 126–135. https://doi.org/10.1016/j.chb.2019.01.035
19	Aldalalah, O., Ababneh, Z. W. M., Bawaneh, A. K., & Alzubi, W. M. M. (2019).	Effect of Augmented Reality and Simulation on the Achievement of Mathematics and Visual Thinking Among Students. In International Journal of Emerging Technologies in Learning (Vol. 14, Issue 18, pp. 164–185). https://doi.org/10.3991/ijet.v14i18.10748
20	Nurwijaya, S. (2022).	Pengaruh Model Pembelajaran Problem Based Learning Berbantuan Augmented Reality Terhadap Kemampuan Spasial Siswa [The Influence of the Problem Based Learning Model Assisted by Augmented Reality on Students' Spatial Abilities]. EQUALS: Jurnal Ilmiah Pendidikan Matematika, 5(2), 107–116. https://doi.org/10.46918/equals.v5i2.1563
21	Eldokhny, A. A., & Drwish, A. M. (2021).	Effectiveness of Augmented Reality in Online Distance Learning at the Time of the COVID-19 Pandemic. International Journal of Emerging Technologies in Learning, 16(9), 198–218. https://doi.org/10.3991/ijet.v16i09.17895
22	Baba, A., Zorlu, Y., & Zorlu, F. (2022).	Investigation of the Effectiveness of Augmented Reality and Modeling-based Teaching in " Solar System and Eclipses " Unit To cite this article : Investigation of the Effectiveness of Augmented Reality and Modeling- based Teaching in "

		Solar System and Ecl. International Journal of Contemporary Educational Research, 9(2), 283–298. https://doi.org/10.33200/ijcer.1040095
23	Abdul Hanid, M. F., Mohamad Said, M. N. H., Yahaya, N., & Abdullah, Z. (2022).	Effects of augmented reality application integration with computational thinking in geometry topics. In Education and Information Technologies (Vol. 27, Issue 7). Springer US. https://doi.org/10.1007/s10639-022-10994-w
24	Safar, A. H., & Al-jafar, A. A. (2017).	The Effectiveness of Using Augmented Reality Apps in Teaching the English Alphabet to Kindergarten Children : A Case Study in the State of Kuwait. EURASIA Journal of Mathematics Science and Technology Education, 8223(2), 417–440. https://doi.org/10.12973/eurasia.2017.00624a
25	Önal, N. T., & Önal, N. (2021).	The effect of augmented reality on the astronomy achievement and interest level of gifted students. Education and Information Technologies, 26(2), 4573–4599. https://doi.org/10.1007/s10639-021-10474-7
26	Al-nawaiseh, S. J. (2020).	The Impact of Using Augmented Reality on the Developing the Tenth Graders Motivation Towards Learning : An Applied Study on the Chemistry Courses . European Journal of Business and Management, 12(15), 118–122. https://doi.org/10.7176/EJBM/12-15-13
27	Sahin, D., Yilmaz, R. M., & Yilmaz, M. (2018).	Effect of Science Teaching with the Augmented Reality Technology on Secondary School Students' Attitude. 7th International Conference on "Innovations in Learning for the Future": Digital Transformation in Education, 20–25.
28	Günel, A., & Demir, S. (2018).	The Impact of Using Augmented Reality Technology (AR) to Student's Perception in Science Classes. Proceedings of the International Future-Learning Conference on Innovations in Learning for the Future: E-Learning, 44–47.
29	Tao, B., Fan, X., Wang, F., Chen, X., Shen, Y., & Wu, Y. (2023).	Comparison of the accuracy of dental implant placement using dynamic and augmented reality-based dynamic navigation: An in vitro study. Journal of Dental Sciences, xxxx. https://doi.org/10.1016/j.jds.2023.05.006
30	Silva, M., Bermúdez, K., & Caro, K. (2023).	Effect of an augmented reality app on academic achievement, motivation, and technology acceptance of university students of a chemistry course. Computers & Education: X Reality, 2(April), 100022. https://doi.org/10.1016/j.cexr.2023.100022
31	Ratnasari, D., Mahrawi, M., Wahyuni, I., & Risdatika, V. (2022).	Pengaruh Augmented Reality Berbasis Web Dengan Model Problem Based Learning Terhadap Sikap Konservasi Peserta Didik. Al-Ulum: Jurnal Sains Dan Teknologi, 8(1), 6. https://doi.org/10.31602/ajst.v8i1.7904
32	Aprilianti, K., Kurnia, R., & Puspitasari, E. (2023).	Pengaruh Media Scan Cards Augmented Reality terhadap Kecerdasan Naturalis Anak Usia 5-6 Tahun [The Influence of Scan Cards Augmented Reality Media on the Naturalist Intelligence of Children Aged 5-6 Years]. Journal on Education, 06(01), 3926–3935.