JPPIPA 12(4) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

The Role of Augmented Reality-Based Inquiry Learning in Enhancing Elementary Students' Scientific Literacy for Sustainable Quality Education

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Received: February 08, 2026
Revised: March 26, 2026
Accepted: April 25, 2026
Published: April 30, 2026

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DOI: 10.29303/jppipa.v12i4.14948

Abstract: This study examined the effect of an Augmented Reality (AR)-supported inquiry learning model on elementary school students' scientific literacy. This study employed a quasi-experimental non-equivalent group design involving two instructional groups: an experimental group receiving AR-supported inquiry learning and a comparison group receiving guided inquiry learning without AR support. Data were collected through scientific literacy pretests and posttests administered to both groups. The findings showed that the experimental group achieved greater improvement in scientific literacy, with mean scores increasing from 64.71 to 78.63, whereas the guided inquiry group showed a smaller increase from 52.66 to 55.10. Paired-sample *t*-test results indicated a significant improvement in the experimental group ($p < .05$), while the guided inquiry group did not demonstrate a statistically significant change ($p > .05$). In addition, an independent-samples *t*-test revealed a significant difference between the two groups after treatment ($p < .05$). Effect size analysis produced a Cohen's d value of 0.95, indicating a large practical effect. These findings suggest that AR-supported inquiry learning is more effective than guided inquiry learning without AR support in enhancing elementary school students' scientific literacy.

Keywords: Augmented reality; Elementary education; Inquiry learning; Quasi-experiment; Scientific literacy

Introduction

Scientific literacy is a fundamental competency required for students to respond to the challenges of the 21st century. It involves not only understanding scientific concepts but also the ability to evaluate scientific information, solve problems, and make evidence-based decisions in everyday contexts (OECD Publishing, 2019; Ogunkola, 2013; Syahidi et al., 2023; Ledia et al., 2024; Sisi et al., 2025). In elementary education, scientific literacy serves as an essential foundation for developing critical thinking and inquiry skills through observation, experimentation, and interpretation of scientific phenomena.

Despite its importance, students' scientific literacy in Indonesia remains relatively low. According to the 2022 Programme for International Student Assessment (PISA), Indonesia ranked 69th out of 81 participating countries, with an average science score of 383, which remains below the OECD average (OECD Publishing, 2019). These findings indicate that many students still experience difficulty applying scientific concepts to real-life situations and interpreting scientific evidence. At the elementary level, this issue becomes more critical because conceptual understanding formed during early

How to Cite:
Yonatan, A., Silitonga, H. T. M., Afandi, A., Suratman, D., Wardoyo, E. R. P., & Zakaria, M. Z. (2026). The Role of Augmented Reality-Based Inquiry Learning in Enhancing Elementary Students' Scientific Literacy for Sustainable Quality Education. *Jurnal Penelitian Pendidikan IPA*, *12*(4), 832–839. https://doi.org/10.29303/jppipa.v12i4.14948

education strongly influences later scientific reasoning abilities.

Preliminary observations conducted at the research site indicated that students faced difficulties in understanding abstract biological concepts, particularly the functions of plant body parts. Classroom observations showed that science learning was still dominated by textbook explanations and teacher-centered instruction, resulting in limited student exploration and low engagement during learning activities. In addition, several students demonstrated misconceptions when identifying plant structures and their functions, indicating that learning media and instructional approaches had not yet optimally supported conceptual understanding.

One pedagogical approach that has strong potential to improve scientific literacy is inquiry-based learning. Inquiry learning encourages students to investigate problems, formulate questions, analyze evidence, and construct conclusions through scientific processes (Pedaste et al., 2015; Kuhlthau, 2021). This model aligns with constructivist theory, which emphasizes that knowledge is actively constructed through meaningful learning experiences (Piaget, 1973). Through inquiry-based activities, students become active participants in the learning process rather than passive recipients of information.

Alongside pedagogical innovation, technological integration has become increasingly important in supporting meaningful science learning. Educational technology, according to the Association for Educational Communications and Technology (AECT), includes the ethical practice of facilitating learning through the design, development, utilization, management, and evaluation of technological processes and resources. In this context, the utilization aspect is particularly relevant because technology can function as a learning medium that enhances interaction, visualization, and engagement.

One emerging technology that has shown considerable promise in science education is Augmented Reality (AR). AR enables the integration of virtual objects into real environments, allowing students to observe abstract concepts through interactive three-dimensional visualization (Billinghurst et al., 2014). Previous studies have shown that AR can increase motivation, engagement, and conceptual understanding in science learning (Akçayır & Akçayır, 2017; Chen et al., 2017; Dunleavy & Dede, 2014; Radu, 2014). For elementary students, AR is particularly beneficial because it provides concrete representations that help bridge the gap between abstract scientific content and real-world experiences.

Although previous research has examined the effectiveness of inquiry learning and AR separately, limited studies have specifically investigated the integration of inquiry-based learning with AR to improve scientific literacy at the elementary school level. Existing studies often focus on learning motivation, engagement, or conceptual understanding without directly examining scientific literacy as a multidimensional outcome. Furthermore, few studies have explored AR-supported inquiry learning in biology-related content at the elementary level, particularly regarding plant structure and function.

The novelty of this research lies in three main aspects. First, this study integrates inquiry-based learning with AR technology into a unified instructional model specifically designed to strengthen elementary students' scientific literacy. Second, this study focuses on scientific literacy as the primary outcome variable rather than solely measuring achievement or motivation. Third, this research investigates the implementation of AR-supported inquiry learning in elementary biology content related to plant body functions, an area where abstract visualization is often challenging for students.

This study is important for several reasons. Practically, it offers an alternative instructional model that can address students' difficulties in understanding abstract science concepts through interactive and inquiry-driven experiences. Theoretically, it contributes to the growing body of research on constructivist learning supported by emerging technologies. Empirically, it provides evidence regarding the effectiveness of AR-supported inquiry learning in improving scientific literacy among elementary school students. Therefore, this study aims to examine the effect of implementing an Augmented Reality-based inquiry learning model on elementary school students' scientific literacy, particularly in learning about the functions of plant body parts.

Educational technology according to AECT (1994) includes the process of designing, developing, utilizing, managing and evaluating learning resources (Awaluddin et al., 2021). In this study, the focus is on the utilization aspect, namely the use of technology in learning to increase student engagement and understanding (Baroroh et al., 2024; Johnson et al., 2016). One form of this utilization is the use of Augmented Reality (AR), which is able to integrate real and virtual objects, thus helping students understand abstract concepts in a more concrete and interactive way (Prayogi et al., 2025; Sipayung et al., 2025; Afandi & Mahmudah, 2024). However, its implementation still faces challenges such as limited access and variations in students' digital abilities (Subroto et al., 2023).

Theoretically, this research is based on constructivism which states that knowledge is actively constructed through learning experiences (Piaget, 1973).

This process is strengthened through discovery learning which emphasizes independent discovery of concepts (Damayanti et al., 2025), which is the basis of inquiry learning. The inquiry learning model encourages students to ask questions, investigate, and draw conclusions through scientific stages (Gormally et al., 2009; Kuhlthau, 2021; Pedaste et al., 2015). The integration of inquiry with AR technology is in line with the principles of constructivism because it allows for interactive learning experiences, thus being proven to increase student engagement, conceptual understanding, and critical thinking skills (Akçayır & Akçayır, 2017).

Method

This study employed a quantitative approach using a quasi-experimental non-equivalent group design to examine the effect of an Augmented Reality (AR)-supported inquiry learning model on elementary school students' scientific literacy. Two instructional groups participated in the study: an experimental group receiving inquiry learning integrated with AR and a comparison group receiving guided inquiry learning without AR support. Both groups completed pretests and posttests to measure changes in scientific literacy before and after the intervention.

The independent variable in this study was the type of inquiry learning model implemented, consisting of AR-supported inquiry learning in the experimental group (AR supported inquiry) and guided inquiry learning in the comparison group. The dependent variable was students' scientific literacy. Several control variables were maintained across both groups to ensure comparability, including learning duration, instructional materials, grade level, and teacher.

The population comprised all fourth-grade students at SD Plus Gembala Baik Pontianak during the 2025/2026 academic year, totaling 69 students across three classes. The sample was selected using purposive sampling based on the similarity of academic characteristics between classes. Two classes were chosen as research participants: Class IV B served as the experimental group, while Class IV C served as the comparison group.

The intervention was conducted over six learning sessions within a four-week period. In the experimental group, students engaged in inquiry-based learning supported by AR visualization to facilitate observation, exploration, and concept discovery related to plant body functions. In the comparison group, students participated in guided inquiry learning without AR support while receiving the same learning objectives, content, and instructional duration.

Data were collected using a scientific literacy test consisting of 30 multiple-choice items developed according to the PISA 2022 scientific literacy framework. The instrument assessed three domains of scientific literacy: explaining phenomena scientifically, evaluating and designing scientific investigations, and interpreting scientific data and evidence. The test was administered twice, namely before treatment (pretest) and after treatment (posttest).

Instrument validity and reliability were evaluated using the Rasch model with the assistance of Winsteps software. The analysis included item fit evaluation using Infit and Outfit Mean Square statistics and standardized Z values, item and person reliability analysis, Wright Map interpretation, unidimensionality testing through Principal Component Analysis (PCA) of residuals, and Differential Item Functioning (DIF) analysis to identify item bias. Content validity was also assessed through expert judgment covering material, construct, and language aspects and strengthened through the Content Validity Index (CVI) at both item (I-CVI) and scale (S-CVI) levels.

Data analysis was performed using descriptive and inferential statistics with SPSS version 26. Descriptive statistics included mean, median, and standard deviation values. Prior to hypothesis testing, prerequisite analyses were conducted using the Shapiro-Wilk test for normality and Levene's test for homogeneity. If the assumptions of normality and homogeneity were met, paired-sample *t*-tests were used to examine within-group differences, while independent-samples *t*-tests were used to compare differences between groups. If assumptions were not satisfied, nonparametric alternatives were applied, including the Wilcoxon signed-rank test and Mann-Whitney U test.

To determine the magnitude of treatment effectiveness, effect size analysis was calculated using Cohen's *d*. Effect size interpretation followed standard criteria: 0.20 indicated a small effect, 0.50 indicated a moderate effect, and 0.80 or greater indicated a large effect. Through this analytical procedure, the study aimed to provide valid and reliable evidence regarding the effectiveness of AR-supported inquiry learning in improving elementary school students' scientific literacy.

Results and Discussion

Prior to data analysis, the research instrument underwent validity and reliability testing to ensure measurement quality. Content validity analysis using the Content Validity Index (CVI) showed that item-level CVI (I-CVI) values ranged from 0.60 to 1.00. Most items obtained values ≥ 0.80, indicating acceptable validity.

However, three items (numbers 8, 14, and 28) achieved an I-CVI value of 0.60 and were revised before implementation.

The Scale-Level Content Validity Index Average (S-CVI/Ave) was calculated using the following formula (Lynn, 1986):

$$\frac{\text{S-CVI}}{\text{Ave}} = \frac{(15 \times 1.00) + (12 \times 0.80) + (3 \times 0.60)}{30} = \frac{15 + 9.6 + 1.8}{30} = \frac{26.4}{30} = 0.88$$

The S-CVI/Ave value of 0.88 indicates that the instrument achieved a valid category. Meanwhile, the Universal Agreement Scale-Level Content Validity Index (S-CVI/UA) was calculated as follows:

$$\frac{\text{S-CVI}}{\text{UA}} = \frac{15}{30} = 0.50$$

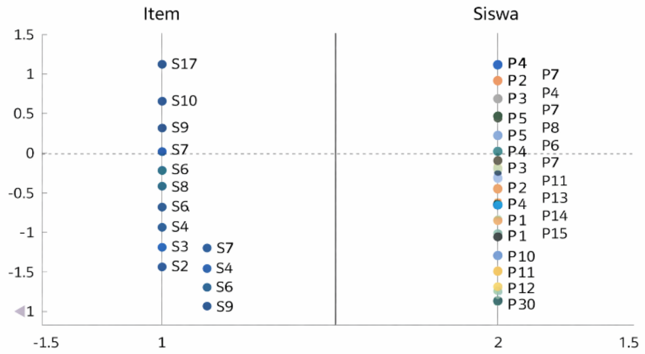

Figure 1. Wright map distribution of student ability and item difficulty

The S-CVI/UA value indicates a moderate level of agreement among validators. Therefore, after revision of several items with lower validity, the scientific literacy instrument was considered appropriate for research implementation.

The Wright Map analysis indicated that the distribution of item difficulty was generally aligned with students' ability levels. Several items were positioned above the average student ability level, indicating relatively difficult questions that required higher-order reasoning and interpretation of scientific evidence. Conversely, easier items measured basic conceptual understanding. The alignment between person ability and item difficulty demonstrates that the instrument was appropriately targeted for measuring elementary school students' scientific literacy.

Rasch model analysis on person fit showed that Infit Mean Square (MNSQ) values ranged from 0.91 to 1.10, while Outfit MNSQ values ranged from 0.90 to 1.13. Infit standardized Z values ranged from −1.47 to 1.57, whereas Outfit standardized Z values ranged from −1.47 to 1.61. Based on Rasch fit criteria, acceptable MNSQ values range from 0.5 to 1.5 and ZSTD values range from −2.0 to +2.0. All respondents met these criteria, indicating that no misfit respondents were identified.

Table 1. Summary of Rasch model validity results

Indicator	Minimum Value	Maximum Value	Mean	Standard Deviation	Fit Criteria
Infit MNSQ	0.91	1.10	1.00	0.05	Fit
MNSQ Outfit	0.90	1.13	1.00	0.06	Fit
Infit ZSTD	-1.47	1.57	-0.01	0.64	Fit
ZSTD Outfit	-1.47	1.61	0.00	0.66	Fit
Respondent Score	8	18	13.5	2.1	
Exact Match Percentage	44.0%	76.0%	59.8%	7.9	

The mean values of Infit MNSQ and Outfit MNSQ were both 1.00, suggesting strong consistency between student responses and the Rasch model. Low standard deviation values indicated minimal variation in response inconsistency. These findings confirm that the instrument produced reliable measurements for assessing scientific literacy.

Normality testing using the Shapiro-Wilk test demonstrated that all datasets had significance values above 0.05, indicating that the data were normally distributed. Specifically, the guided inquiry comparison group obtained significance values of 0.101 for the pretest and 0.200 for the posttest, while the AR-supported inquiry group showed values of 0.371 for the pretest and 0.233 for the posttest.

Homogeneity testing using Levene's test produced a significance value of 0.076 ($p > .05$), indicating homogeneous variance between groups. These results confirm that the assumptions required for parametric statistical analysis were satisfied, allowing the use of paired-sample *t*-tests and independent-samples *t*-tests for hypothesis testing.

Table 2. Pretest posttest difference test results

Group	Mean Pretest	Mean Posttest	Mean Difference	t	df	Sig. (2-tailed)	Information
Guided Inquiry Class	52.66	55.10	-2.44	-1,042	22	0.309	Not significant
AR Supported Inquiry Class	64.71	78.63	-13.92	-5,161	22	0,000	Significant

The paired-sample t-test in the guided inquiry class produced a significance value of 0.309 ($p > .05$), indicating that guided inquiry learning did not significantly improve students' scientific literacy during the intervention period. Although the mean score increased slightly, the improvement was not statistically significant. This suggests that guided inquiry may provide a positive learning tendency but was insufficient to produce substantial improvement within the implemented treatment duration.

In contrast, the experimental class showed a significance value of 0.000 ($p < .05$), indicating a statistically significant improvement after AR-supported inquiry learning. These findings suggest that the integration of Augmented Reality with inquiry-based learning effectively enhances students' scientific literacy.

The significant improvement observed in the experimental group may be explained by the interactive and visual nature of AR technology. Through three-dimensional visualization, students can directly observe abstract concepts that are otherwise difficult to imagine through conventional instruction. This supports the principles of constructivist learning, where students actively construct knowledge through meaningful experiences.

Furthermore, the independent-samples t-test revealed a significant difference between the AR supported inquiry class and guided inquiry class ($p < .05$), confirming that AR-supported inquiry learning was more effective than guided inquiry learning alone.

Table 3. Test differences between groups

Variables	t	df	Sig. (2-tailed)	Mean Difference	Information
Mark	-5,232	37,395	0,000	-13,917	Significant

Furthermore, the results of the independent sample t-test showed a significance value of 0.000 ($p < 0.05$), indicating a significant difference between the AR supported inquiry class and the guided inquiry class. This confirms that the augmented reality-based inquiry learning model is more effective than the guided inquiry learning model in improving students' scientific literacy. To determine the magnitude of the treatment effect, the effect size was calculated using the Cohen's d formula, which was obtained as follows.

Cohen's d Formula

To determine the magnitude of treatment effectiveness, effect size analysis was conducted using Cohen's *d* formula:

$$d = \frac{M_2 - M_1}{SD_{pooled}} \quad (1)$$

where:

$$SD_{pooled} = \sqrt{\frac{SD_1^2 + SD_2^2}{2}}$$

$$SD_{pooled} = \sqrt{\frac{12.933^2 + 11.223^2}{2}}$$

$$= \sqrt{\frac{167.30 + 125.96}{2}}$$

$$= \sqrt{\frac{293.26}{2}} = \sqrt{146.63} = 12.11$$

$$d = \frac{11.48}{12.11} = 0.95$$

Cohen's d = 0.95

The effect size value of Cohen's $d = 0.95$ falls within the large category, indicating that the Augmented Reality (AR)-based inquiry learning model exerted a strong influence on students' scientific literacy. This finding demonstrates that AR-supported inquiry learning not only produced statistically significant improvement but also generated meaningful practical impact in elementary science learning.

Overall, the findings indicate that only the AR-based inquiry learning model significantly improved students' scientific literacy, whereas guided inquiry learning did not demonstrate statistically significant improvement during the intervention period. Although the guided inquiry group showed a slight increase in mean score, the improvement was insufficient to reach statistical significance. This suggests that guided inquiry may contribute to learning development; however, its effectiveness may depend on additional instructional support, extended intervention duration, or more concrete learning media.

The superiority of AR-supported inquiry learning can be explained by the capability of AR technology to present abstract concepts through interactive and realistic visualization. In science learning, particularly in elementary education, students often encounter difficulties understanding concepts that cannot be directly observed. AR bridges this gap by integrating virtual objects into real learning environments, enabling students to explore scientific phenomena more concretely and contextually.

These findings align with constructivist learning theory, which states that knowledge is actively constructed through meaningful experiences. Inquiry learning encourages students to investigate, observe, and formulate conclusions independently, while AR strengthens this process by providing visual support that enriches exploration. Through this integration, students engage more deeply in concept discovery and scientific reasoning.

The results also support Dual Coding Theory, which suggests that learning becomes more effective when verbal explanations are reinforced by visual representations. In this study, AR provided simultaneous visual and textual information, helping students process scientific concepts through multiple cognitive pathways. This multimodal representation may reduce cognitive load because students no longer rely solely on abstract imagination to understand scientific material.

Previous studies have similarly demonstrated the benefits of AR in education. Research by Akçayır & Akçayır (2017) reported that AR enhances conceptual understanding and student motivation by making learning experiences more interactive. Likewise, Radu (2014) found that AR contributes positively to learning outcomes because it combines digital visualization with real-world interaction. These findings reinforce the present study, which shows that AR integration within inquiry-based learning creates a more effective learning environment.

The findings further indicate that guided inquiry learning without interactive media support may be less effective in significantly improving scientific literacy, particularly when students must understand complex and abstract concepts. Although guided inquiry encourages exploration, the absence of strong visualization tools may limit students' ability to fully construct conceptual understanding.

The integration of AR into inquiry learning therefore provides a pedagogical advantage by combining student-centered learning with immersive technology. Students are not only encouraged to investigate scientific concepts independently but are also supported through interactive representations that facilitate deeper understanding.

Overall, the results reinforce previous evidence that AR-supported inquiry learning is an effective instructional approach for improving elementary students' scientific literacy. The combination of inquiry pedagogy and interactive visualization creates a more meaningful learning experience, supporting conceptual understanding, scientific reasoning, and student engagement in science learning.

Conclusion

Based on the findings of this study, it can be concluded that Augmented Reality (AR)-based inquiry learning is effective in improving elementary school students' scientific literacy. Students who participated in AR-supported inquiry learning demonstrated greater improvement in scientific literacy compared to those who learned through guided inquiry without AR support. The integration of AR into inquiry learning provided interactive and concrete visualization that helped students understand abstract scientific concepts more effectively. These findings suggest that combining inquiry pedagogy with AR technology creates a more meaningful learning experience by supporting active exploration, conceptual understanding, and scientific reasoning. Therefore, AR-based inquiry learning can serve as an effective instructional approach for strengthening scientific literacy in elementary science education. Future research is recommended to investigate the long-term effects of AR-supported inquiry learning, involve larger and more diverse samples, and explore its implementation across different science topics and educational levels. Further studies may also examine how AR integration influences other dimensions of learning, such as motivation, engagement, and critical thinking skills.

Acknowledgments

The authors would like to express sincere gratitude to the administration, teachers, and students of SD Plus Gembala Baik Pontianak for their cooperation and participation throughout the research process. Appreciation is also extended to the experts and validators who contributed to the instrument validation process and provided valuable feedback to improve the quality of this study. The authors further acknowledge the academic support provided by the postgraduate program at Universitas Tanjungpura and collaborative contributions from Universiti Teknologi MARA.

Author Contributions

Conceptualization, A.Y. and H.T.M.S.; methodology, resources, A.Y., H.T.M.S., and A.; formal analysis, A.Y. and D.S.; investigation, A.Y., H.T.M.S., and E.R.P.W.; writing original draft preparation, project administration, A.Y.; writing—review and editing, H.T.M.S., D.S., and M.Z.Z.; visualization, A.; supervision, H.T.M.S. and D.S.; All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Conflicts of Interest

All authors declare no conflict of interest.

References

Afandi, T., & Mahmudah, U. (2024). Utilizing Augmented Reality as an Innovative Media in Science Learning to Conserve Natural Resources. *Indonesian Journal of Education and Citizenship*, *1*(4), 126–138. https://doi.org/10.61132/jupenkei.v1i4.95

Akçayır, M., & Akçayır, G. (2017). Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Review of the Literature. *Educational Research Review*, *20*, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Baroroh, A. Z., Diyah, A. K., & Kamal, R. (2024). Utilization of Technology in Learning. Perspective: *Journal of Education and Language Studies*, *2*(4), 269–286. https://doi.org/10.59059/perspektif.v2i4.1952

Awaluddin, A., Ramadhan, F., Charty, N. A. F., Salsabila, R., & Firmansyah, M. (2021). Peran Pengembangan dan Pemanfaatan Teknologi Pendidikan dan Pembelajaran dalam Meningkatkan Kualitas Mengajar. *JURNAL PETISI (Pendidikan Teknologi Informasi)*, *2*(2), 48-59. https://doi.org/10.36232/jurnalpetisi.v2i2.1241

Billinghurst, M., Clark, A., & Lee, G. (2014). A Survey of Augmented Reality. *Foundations and Trends in Human-Computer Interaction*, *8*(2–3), 73–272). https://doi.org/10.1561/1100000049

Chen, P., Liu, X., Cheng, W., & Huang, R. (2017). A Review of Using Augmented Reality in Education from 2011 to 2016. *Lecture Notes in Educational Technology*, (9789811024184), 13–18. https://doi.org/10.1007/978-981-10-2419-1_2

Kuhlthau, P. E. C. (2021). Guided Inquiry: Learning in the 21st Century. *IASL Annual Conference Proceedings*. https://doi.org/10.29173/iasl7647

Damayanti, D. A. J., Saputra, A. D., Yana, I. W. D., & Werang, B. R. (2025). Jerome S. Bruner Cognitive Development Theory. *International Journal of Education, Vavation and Social Science*, *4*(04), 793-799. https://doi.org/10.63922/ijevss.v4i04.2481

Dunleavy, M., & Dede, C. (2014). Augmented Reality Teaching and Learning. In: Spector, J., Merrill, M., Elen, J., Bishop, M. (eds) *Handbook of Research on Educational Communications and Technology*. New York: Springer. https://doi.org/10.1007/978-1-4614-3185-5_59

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (2009a). Effects of Inquiry-based Learning on Students' Science Literacy Skills and Confidence. *International Journal for the Scholarship of Teaching and Learning*, *3*(2). https://doi.org/10.20429/ijsotl.2009.030216

Johnson, L. A., Becker, S., Cummins, M., Extrada, V., Freeman, A., & Hall, C. (2016). *NMC Horizon Report 2016: Higher Education Edition*. The New Media Consortium.

Ledia, S., Mauli, B., & Bustam, R. (2024). Implementation of the Independent Curriculum in Improving the Quality of Education. *RESLAJ: Religion Education Social Laa Roiba Journal*, *6*(1). https://doi.org/10.47476/reslaj.v6i1.2708

OECD Publishing. (2019). *PISA 2018 Assessment and Analytical Framework*. Retrieved from https://www.oecd.org/en/publications/pisa-2018-assessment-and-analytical-framework_b25efab8-en.html

Ogunkola, B. J. (2013). Scientific Literacy: Conceptual Overview, Importance and Strategies for Improvement. *Journal of Educational and Social Research*, *3*(1). https://doi.org/10.5901/jesr.2013.v3n1p265

Pedaste, M., Mäeots, M., Siiman, L.A., Jong, T. D., Riesen, S. A. N. V., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of Inquiry-Based Learning: Definitions and the Inquiry Cycle. *Educational Research Review*, *14*, 47–61. https://doi.org/10.1016/j.edurev.2015.02.003

Piaget, J. (1973). *Cognitive Development Cognition Acquisition of Knowledge Acquire and Process Knowledge Many Theories*.

Prayogi, A., Laksono, R. D., Sari, C. R., Gilaa, T., Andriani, N., Fuad, J., Sutopo, S., & Ulviani, M. (2025). *Psikologi Digital Kependidikan*. Padang: Akiopedia Press.

Radu, I. (2014). Augmented Reality in Education: A Meta-Review and Cross-Media Analysis. *Personal and Ubiquitous Computing*, *18*(6), 1533–1543. https://doi.org/10.1007/s00779-013-0747-y

Sipayung, N., Gultom, P. W., Damanik, J. D. A., Siregar, S. E., Sidauruk, N., Sitorus, H. P., & Limbong, W. S. (2025). Pengaruh Penggunaan Media Pembelajaran Interaktif Berbasis Augmented Reality Terhadap Hasil Belajar IPA Kelas VI SD. *Jurnal Pendidikan Tambusai*, *9*(2), 26250–26255. https://doi.org/10.31004/jptam.v9i2.31016

Sisi, L., Zibar, C., & Parisu, L. (2025). Eksplorasi Outdoor Learning dalam Mengembangkan Keterampilan Sains Siswa Sekolah Dasar. *JHUSE*, *1*(3), 40–52. https://doi.org/10.64690/jhuse.v1i3.51

Subroto, D. E., Supriandi, S., Wirawan, R., & Rukmana, A. Y. (2023). Implementasi Teknologi dalam Pembelajaran di Era Digital: Tantangan dan Peluang bagi Dunia Pendidikan di Indonesia. *Jurnal Pendidikan West Science*, *1*(07), 473–480. https://doi.org/10.58812/jpdws.v1i07.542

Syahidi, K., Jufri, A. W., Doyan, A., Kosim, K., Rokhmat, J., & Sukarso, A. (2023). Strengthening Science Literacy and Character Education in 21st Century Science Learning. *Kappa Journal*, *7*(3), 538–542. https://doi.org/10.29408/kpj.v7i3.25036