Macrothink Institute™

Journal of Public Administration and Governance
ISSN 2161-7104
2025, Vol. 15, No. 3

Development Techniques in Creating Augmented Reality Applications for Education Sustainability: A Systematic Literature Review

Che Musazaki Yusoff
Faculty of Educational Studies, Universiti Putra Malaysia
43400 Serdang, Selangor, Malaysia

Norliza Ghazali (Corresponding author)
Faculty of Educational Studies, Universiti Putra Malaysia
43400 Serdang, Selangor, Malaysia

Puteri Suhaiza Sulaiman
Faculty of Computer Science and Information Technology, Universiti Putra Malaysia
43400 Serdang, Selangor, Malaysia

Wan Rizhan
Faculty of Informatics and Computing, Universiti Sultan Zainal Abidin
22200 Besut, Terengganu, Malaysia

Mohd Fadzil Abdul Hanid
Faculty of Social Sciences and Humanities, Universiti Teknologi Malaysia
81310 Skudai, Johor, Malaysia

Received: Sep. 5, 2025 Accepted: Nov. 6, 2025 Online published: Dec. 31, 2025
doi:10.5296/jpag.v15i3.23481 URL: https://doi.org/10.5296/jpag.v15i3.23481

Abstract

The development of augmented reality (AR) technology as a teaching tool in education is expanding, as it can boost interest in learning and improve the visual understanding of abstract concepts. However, most application developments currently rely on marker-based techniques, which are based on existing research. Recognizing this research gap not only highlights an unexplored area but also indicates a promising direction for future research and sustainability in education. Therefore, this systematic literature review highlights the importance of utilizing markerless and 3D object recognition techniques in developing AR applications to enhance visual skills during the learning process. The Scopus database was used to identify eligible articles, following the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines. A total of 25 articles from 2019 to 2023 met the criteria for final review, and they were categorized into three main themes: type of augmented reality technology, target subject, and theory and model used in developing AR applications for education. This study provides educational researchers and developers with a comprehensive understanding of the potential benefits of creating AR applications that utilize markerless and 3D object recognition techniques in education.

Keywords: sustainability, augmented reality, marker-based type, markerless type, 3d object recognition technique, systematic literature review

1. Introduction

The fourth Sustainable Development Goal (SDG) is to provide quality education. One of the targets to be achieved by 2030 is to build and upgrade educational facilities, providing a safe, inclusive, and effective learning environment. Recent technologies, such as augmented reality (AR), can be used in the education system to replace conventional methods as learning tools for knowledge delivery. For instance, AR provides an interactive experience of a real-world environment enhanced by computer-generated virtual reality (Shakirova et al., 2020), in addition to providing opportunities for improving student performance (AlNajdi, 2022; Nadzri et al., 2023).

AR is a digital layer that overlays the physical environment, attaching virtual elements to the real world (Ronaghi & Ronaghi, 2022). AR is classified into five types: marker-based, markerless, location-based, projection-based, and outlining-based (Devagiri et al., 2022). In contrast to Aggarwal & Singhal (2019), AR applications can be categorized into four types: marker-based, markerless, projection-based, and superimposition-based. The technology has undergone significant development over the years, resulting in its widespread availability for various applications and fields, such as tourism (Iglesia & Iglesia, 2023), indoor tracking systems (Shewail et al., 2023), automotive (Zuben & Viana, 2022), and education (Wen, 2021).

Digital learning tools can revolutionize teaching and learning in the classroom. AR technology offers a different perspective compared to traditional methods, such as blackboards, whiteboards, and PowerPoint presentations, which can be considered somewhat outdated. (Arulanand et al., 2020). He added that using AR can help students boost their creativity, increase motivation, and encourage teamwork.

Moreover, the educational process can be improved by accelerating the transfer of knowledge and experience when AR technology is used (Lavrentieva et al., 2020). In addition, student achievement improves through the integration of AR into learning activities, and their attitude towards learning becomes more positive (Fidan & Tuncel, 2019). For instance, (Dreimane & Daniela, 2021) found that students can understand both the external and internal dimensions of the body through the integration of AR technology in learning anatomy, without needing to be in a specialized anatomy laboratory.

In summary, AR technology plays a crucial role as a learning tool for enhancing teaching and learning activities by visualizing content in 3D forms. Therefore, development techniques should be varied to enhance visualization during the learning process. The results of this study collectively support the significant impact of AR technology on enhancing 3D visualization and facilitating a transition from static to dynamic states in education. With the ongoing advancements in technology, it is anticipated that AR will play a more significant role as a learning tool, enhancing learning strategies and improving learning outcomes.

This comprehensive review of the literature aims to provide an in-depth analysis of state-of-the-art AR development techniques specifically designed to enhance visualization in educational contexts. Through careful examination and integration of recent studies, research outcomes, and emerging trends, this review provides a comprehensive overview of current approaches to AR technology development within the education sector. The emphasis on enhancing visualization highlights AR's capacity to convert abstract ideas into concrete and interactive experiences, thereby promoting deeper comprehension and involvement among students.

2. Method

This section discusses the method used to retrieve articles related to the development of AR applications in education. The reviewers used the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement (Moher et al., 2009) and the inclusion and exclusion rules guided by (Mohamed Shaffril et al., 2019). The Scopus database was used to identify eligible articles on the development of AR applications, specifically in the education sector. The review processes, including identification, screening, eligibility, and data extraction, are also discussed in this section.

2.1 Identification

The systematic review process involved three main stages for selecting relevant articles for this study. The first stage is keyword identification, which involves related or similar terms based on thesaurus, dictionaries, and past research. After all relevant keywords were identified, a search string was developed on Scopus in October 2023 (see Table 1).

Table 1. The search strings.

Database	Keyword
Scopus	TITLE-ABS-KEY ("Augmented Reality" AND ("Education" OR "Learning") AND "School" AND ("Design" OR "Evaluation")) AND PUBYEAR > 2018 AND PUBYEAR < 2024 AND (LIMIT-TO (SUBJAREA , "SOCI") OR LIMIT-TO (SUBJAREA , "MATH")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))

2.2 Screening

Based on previous stages of the systematic review process, 765 papers were collected from the Scopus database. During this stage, the articles underwent a filtering process based on several criteria. The primary and initial criteria are literature, namely, in the form of a research article, and limited to journal sources only. The criteria for exclusion in recent research encompass systematic reviews, reviews, meta-syntheses, meta-analyses, books, book series, chapters, and conference proceedings. Furthermore, this review was limited to English-language publications. It is essential to remember the scope of the publication for a period of five years (2019-2023). A total of 626 articles were successfully removed from the entire database, resulting in the remaining 139 articles.

2.3 Eligibility

The third stage was eligibility, which contained a comprehensive collection of 139 articles. At this stage, the titles of all articles and the main text content were thoroughly reviewed to ensure that the inclusion criteria were met and that the articles were suitable for the research objectives of the present study. Thus, 114 articles were excluded from the study because their titles and abstracts were not substantially relevant to the research purpose. A total of 25 articles were available for review (Table 2).

Table 2. The selection criteria.

Criterion	Inclusion	Exclusion
Language	English	Non-english
Timeline	2019-2023	<2019
Subject area	Social Sciences and Mathematics	Others
Literature type	Journal (only research articles)	Journal (book chapter, conference proceeding)

2.4 Data Extraction

The expert study aimed to identify the relevant topics and subtopics. The data-collection phase is a crucial step in developing the theme. As shown in Figure 1, the authors meticulously examined 25 publications for claims or materials relevant to the topics of this study. Based on the selected publications, the general characteristics and findings of the studies were recorded, including the title of the articles, author, research question, objectives, research approach, theory or model, population or sample, augmented reality type, topic or target area, technique, evaluation, and results. The researchers began a collaborative discussion to systematically derive themes from the data in the context of this research.

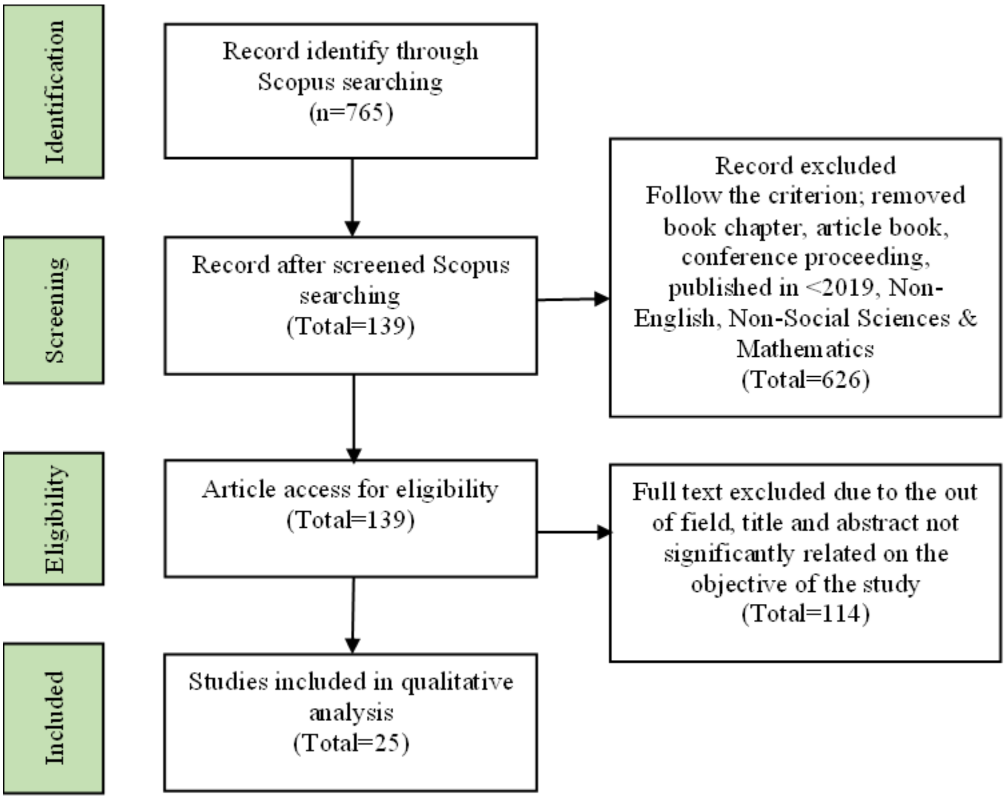

Figure 1. Flow diagram of the proposed searching study

3. Findings and Discussion

All articles were categorized based on three main themes: the type of augmented reality technology, the target subject, and the theory and model used in developing AR applications for education. There were also reviews of evaluations, theories and models, and populations or samples. The interpretations of the studies' results were extracted and summarized in a table (see Table 3).

Table 3. Summary of augmented reality technology usage in education.

No.	Author	Type of Augmented Reality	Target Area / Subject	Evaluation	Theory / Model	Population / Sample
1.	Suprapto et al. (2020) (Indonesia)	Marker	Physics	Product quality, students' abstract thinking skills, outcome of research project (publication &	ADDIE model	Private high school (33 students)

				property right)		
2.	Uiphanit et al. (2020) (Thailand)	Marker	Chinese Language	Achievement, attitude	TAM model	Secondary school (40 teacher and students)
3.	Suprapto et al. (2021) (Indonesia)	Marker	Physics	Product quality, students' achievement, research outcome	ADDIE model	Public high school (30 students)
4.	Jalaluddin et al. (2020) (Malaysia)	Marker	English	Achievement	ADDIE model, CTML theory	Primary school (45 students)
5.	Hussein et al. (2023) (Iraq)	Marker	English	Achievement, tendencies, and acceptance	Not mentioned	Primary school (58 students)
6.	Nordin et al. (2020) (Malaysia)	Marker	Robotics educational game	Interest, engagement	Agile model	Secondary school (4 students) and higher institution (7 students)
7.	Lin et al. (2023) (Taiwan)	Marker	Smart Industry	Knowledge and Understanding, Skills, Attitudes and Values, Enjoyment, Inspiration and Creativity, Behaviour and Progression	Generic Learning Outcome (GLO) model	Senior high school (62 students)
8.	Merino et al. (2022) (Chile)	Marker	Science	Experts' validation on AR apps and sequential analysis performed by pre-service teachers	Teaching Learning Sequence (TLS) model	Scientists, teachers, and pre-service teachers
9.	Blanca & Lucá (2020) (Mexico)	Marker	Mathematics	Achievement, motivation (ARCS)	Constructivism learning theory, ARCS Model	Secondary school (93 students from one private and two public schools)
10.	(Widyaningsih et al., 2023)	Marker	Physical Education	Learning and implementation	ADDIE model	28 physical education

	(Indonesia)			model		teachers
11.	Awang et al. (2019) (Malaysia)	Marker	Mathematics	Usability (ease of use, usefulness, self-efficacy, compatibility, using intention)	Not mentioned	Primary school (32 Linus students)
12.	Sun & Chen (2020) (Taiwan)	Marker	Mathematics	Achievement	Not mentioned	Primary school (60 students)
13.	Ozcakir & Cakiroglu (2021) (Turkey)	Marker	Mathematics	Need analysis and prototyping stage	Guides for Improving Spatial Ability with AR (GISAR)	1st iteration (2 teachers), 2nd iteration (66 middle school students), 3rd iteration (26 students)
14.	Lavicza et al. (2022) (Austria)	Markerless	Mathematics	Design aspects	Not mentioned	Not mentioned
15.	Sukardjo et al. (2023) (Indonesia)	Not mentioned	Engineering	Instructional design, material, media, and language	ADDIE model	Vocational High School (24 students)
16.	Richardo et al. (2023) (Indonesia)	Marker	Mathematics	Design evaluation and achievement	ADDIE model	4 expert validators, 4 mathematics teachers, Junior High School (18 students)
17.	Lu et al. (2021) (Hong Kong, China)	Marker	Chemistry	Student perceptions (Awareness, learning, understanding, and engagement)	Constructivism learning theory, GBL theory, CTML theory	Higher education (46 students)
18.	Yamtinah et al. (2023) (Indonesia)	Marker	Chemistry	Achievement, product quality	ADDIE model	3 Secondary schools (168 students)
19.	Arvola et al. (2021) (Sweden)	Marker	Outdoor activity	Usability, teacher and student experience, opportunities, and challenges	Not mentioned	Primary schools (13 teachers & 9 nonteachers for evaluating the apps and 6 pupils for

						semi-structured interviews)
20.	Najmi et al. (2023) (Saudi Arabia)	Marker	Dangers of electronic games addiction (DEGA)	Effectiveness (knowledge, awareness)	Experiential learning theory (design), CTML theory (design), Constructivism theory (learning awareness)	High School (75 students)
21.	Tanalol et al. (2021) (Malaysia)	Marker	Jawi	Learnability, acceptance	ADDIE model	Pusat Minda Lestari (10 pupils, age 5 to 6 years old)
22.	Muktiani et al. (2022) (Indonesia)	Markerless	Pencak Silat (Martial Art)	Design evaluation and achievement	APPED model	Junior High School (44 teachers)
23.	Nasir & Fakhruddin (2023) (Indonesia)	Marker	Physics	Design evaluation and achievement	ADDIE model	Senior High School (68 students)
24.	Khazali et al. (2023) (Malaysia)	Marker	English	Attention, relevance, confidence, satisfaction	ADDIE & ARCS models	Primary school (36 students)
25.	Sulisworo et al. (2021) (Indonesia)	Marker	Science	Behaviour, perception	Not mentioned	Junior High School (24 teachers)

3.1 Type of Augmented Reality Technology

Through SLR, 22 articles focused on developing marker-based AR applications in education. An animated 3D object appears on the smartphone screen when the AR camera is aimed at target markers (Suprapto et al., 2020). For example, students use a physics pocketbook as a marker to learn planetary motion (Suprapto et al., 2021). Yamtinah et al. (2023) also developed a marker-based AR to test the effectiveness of AR media based on a tetrahedral chemical representation.

The marker-based type has been used extensively to collect participant data in education, as evidenced by the significant proportion of 17 review studies (68%). Statistical analysis indicates that the marker-based type remains reliable due to its ability to track images with high precision, thereby augmenting 3D models during the learning process.

Although other AR techniques exist, marker-based AR remains widely used in education because it creates simple, static experiences with low complexity and fewer technical issues. Other AR types, such as those in Devagiri et al. (2022) and Aggarwal & Singhal (2019), are rarely used due to higher complexity or implementation challenges.

Furthermore, markerless AR eliminates the need for physical image markers; only two studies, or 8% of those reviewed, used markerless AR. Although limited, markerless AR offers flexible applications, does not require specific images, and provides better support for dynamic learning and visualization in education.

3.2 Target Subject in Education Using Augmented Reality Technology

Search findings from 2019 to 2023 using SLR found 16 studies. These studies showed that AR technology is widely used in Science, Technology, Engineering, and Mathematics (STEM) education (64%). Studies on physics (Nasir & Fakhruddin, 2023; Suprapto et al., 2020, 2021), science (Merino et al., 2022), mathematics (Lavicza et al., 2022; Ozcakir & Cakiroglu, 2021; Richardo et al., 2023), engineering (Sukardjo et al., 2023), and chemistry (Yamtinah et al., 2023) focus on designing and developing product quality assurance based on expert evaluation and validation. These account for 36% of the overall studies. Only five studies have focused on AR technology development for language subjects (Hussein et al., 2023; Jalaluddin et al., 2020; Khazali et al., 2023; Tanalol et al., 2021; Uiphanit et al., 2020). Most studies focus on the effectiveness of AR usage in learning (60%), while 40% address factors such as motivation, learnability, acceptance, and other related aspects.

However, only two studies evaluated usability aspects (Arvola et al., 2021; Awang et al., 2019), making up 8% of the reviewed papers. Evaluating AR application usability is vital to ensure the learning process runs smoothly without technical issues and fulfils learning objectives. Most studies focus on AR effectiveness, with less attention to usability when assessing student achievement and related factors. Therefore, usability evaluation is necessary in each study to achieve consistent outcomes.

3.3 Theory and Model Applied in Design, Development, and Evaluation

The theories and models used in the studies are stated in the design and development of the applications. Most studies applied the instructional design (ID) of the ADDIE model for AR application development, while six papers did not mention any ID models that were used. There is also little discussion on other theories and models used in the development, such as the Cognitive Theory of Multimedia Learning (CTML) (Jalaluddin et al., 2020; Lu et al., 2021; Najmi et al., 2023), constructivist learning theory (Blanca & Lucá, 2020; Lu et al., 2021; Najmi et al., 2023), and others.

example, the ARCS model evaluates motivation, encompassing attention, relevance, confidence, and satisfaction (Suprapto et al., 2020; Widyaningsih et al., 2023), as does the Technology Acceptance Model (TAM) (Suprapto et al., 2021). Nevertheless, the evaluation model is not widely linked to studies, as most focus on effectiveness evaluation.

3.4 Summary of Findings and Suggestions for Future Studies

This study examined techniques used to develop AR applications in education settings. While earlier research explored the effectiveness of integrating AR into teaching and learning, they did not specifically focus on development methods. We found that most AR applications in schools rely on marker-based techniques rather than markerless or other approaches. For marker-based systems, the digital layer aligns with the real environment when the AR camera targets a 2D image or QR code. In contrast, virtual objects can be placed anywhere without moving physical objects, which is known as a markerless technique or superimposition-based method, where the original view of an object is partially or fully replaced with a new view. Our study indicates that both markerless and object recognition techniques are user-friendly and easy to implement. The proposed methods do not require images as targets, making them effective tools for teaching and learning both inside and outside the classroom.

This study conducted a thorough examination of the approaches employed in developing augmented reality applications for education, with a particular focus on techniques that do not rely on markers and those that recognize objects. However, further research is needed to confirm the development process, particularly regarding technical difficulties. Our findings indicate that the majority of educational augmented reality applications are developed using marker-based methods. Future research could explore the development of AR applications that utilize markerless and object recognition techniques to enhance visualization.

From a policy perspective, using AR technology in educational settings supports the global goal of providing quality, inclusive, and equitable education, as outlined in Sustainable Development Goal 4 (United Nations Statistics Division, 2020). In Malaysia, this approach aligns with the Malaysia Education Blueprint (Pelan Pembangunan Pendidikan Malaysia, PPPM 2013–2025), which emphasizes the importance of 21st-century education, technological advancement, and integrating technology to promote higher-order thinking skills. Teaching resources that incorporate AR, especially those using markerless and object recognition techniques, can help achieve policy goals by fostering interactive, student-centered learning and equipping students with essential digital skills for the future. essential digital skills for the future.

Therefore, developing AR applications in education using markerless and object recognition techniques has great potential as an effective technology-assisted teaching tool both inside and outside the classroom. To maximize its impact, future studies should not only focus on technical development but also consider policy frameworks and educational reforms that support the meaningful integration of emerging technologies in teaching and learning.

4. Conclusion

In summary, most studies chosen for analysis focused on developing marker-based augmented reality applications. More than half of the studies were related to STEM subjects, primarily aimed at visualizing abstract concepts. There is a lack of research specifically exploring the development of AR applications using markerless and other techniques. Markerless and 3D object recognition methods do not rely on image targets; instead, they detect real 3D objects as targets. AR applications should incorporate markerless and 3D recognition techniques to enhance the AR learning process. AR is continually advancing, offering researchers an opportunity to explore this technology more thoroughly, shifting from static to dynamic applications. The potential of AR technology in education, particularly when employing techniques beyond marker-based approaches, is highly promising and warrants further investigation in this field.

Acknowledgments

No funding was received upon completion of the study. We would like to express our gratitude to everyone who participated directly and indirectly in the completion of this manuscript. We would like to thank the reviewers for their constructive feedback.

Disclosure Statements

Generative AI tools, such as Grammarly Pro, were used for language editing and improving the clarity of the manuscript. All intellectual content, research design, and data analysis were conducted solely by the authors. The authors declare that no false data, references, or conclusions were generated by AI.

References

Aggarwal, R., & Singhal, A. (2019). Augmented Reality and its effect on our life. *Proceedings of the 9th International Conference On Cloud Computing, Data Science and Engineering, Confluence 2019*, 510–515. https://doi.org/10.1109/CONFLUENCE.2019.8776989

AlNajdi, S. M. (2022). The effectiveness of using augmented reality (AR) to enhance student performance: using quick response (QR) codes in student textbooks in the Saudi education system. *Educational Technology Research and Development*, *70*(3), 1105–1124. https://doi.org/10.1007/s11423-022-10100-4

Arulanand, N., RameshBabu, A., & Rajesh, P. K. (2020). Enriched learning experience using augmented reality framework in engineering education. *Procedia Computer Science*, *172*(2019), 937–942. https://doi.org/10.1016/j.procs.2020.05.135

Arvola, M., Fuchs, I. E., Nyman, I., Szczepanski, A., Arvola, M., Fuchs, I. E., Nyman, I., Szczepanski, A., & Arvola, C. M. (2021). Mobile Augmented Reality and Outdoor Education Mobile Augmented Reality and Outdoor Education. *Built Environment*, *47*(2), 223–242. https://doi.org/https://doi.org/10.2148/benv.47.2.223

Awang, K., Nor, S., Shamsuddin, W., Ismail, I., & Rawi, N. A. (2019). The usability analysis of using augmented reality for linus students. *Indonesian Journal of Electrical Engineering and Computer Science*, *13*(1), 58–64. https://doi.org/10.11591/ijeecs.v13.i1.pp58-64

Blanca, M., & Luc á, M. (2020). Impact of augmented reality technology on academic achievement and motivation of students from public and private Mexican schools . A case study in a middle-school geometry course �n. *Computers and Education*, *145*(May 2019), 1–9. https://doi.org/10.1016/j.compedu.2019.103734

Devagiri, J. S., Paheding, S., Niyaz, Q., Yang, X., & Smith, S. (2022). Augmented Reality and Artificial Intelligence in industry: Trends, tools, and future challenges. *Expert Systems* *with Applications*, *207*(July), 118002. https://doi.org/10.1016/j.eswa.2022.118002

Dreimane, S., & Daniela, L. (2021). Educational Potential of Augmented Reality Mobile Applications for Learning the Anatomy of the Human Body. *Technology, Knowledge and Learning*, *26*(4), 763–788. https://doi.org/10.1007/s10758-020-09461-7

Fidan, M., & Tuncel, M. (2019). Integrating augmented reality into problem based learning: The effects on learning achievement and attitude in physics education. *Computers and Education*, *142*(July), 103635. https://doi.org/10.1016/j.compedu.2019.103635

Hussein, H. A., Ali, M. H., Al-Hashimi, M., Majeed, N. T., Hameed, Q. A., & Ismael, R. D. (2023). The Effect of Web Augmented Reality on Primary Pupils' Achievement in English. *Applied System Innovation*, *6*(1), 1–20. https://doi.org/10.3390/asi6010018

Iglesia, G., & Iglesia, J. G. (2023). Augmented Reality Limitations. *Anuario Electrónico de Estudios En Comunicación Social "Disertaciones,"* *16*(1), 1–18. https://doi.org/https://doi.org/10.12804/revistas.urosario.edu.co/disertaciones/a.11991

Jalaluddin, I., Ismail, L., & Darmi, R. (2020). Developing Vocabulary Knowledge among Low Achievers : Mobile Augmented Reality (MAR) Practicality. *International Journal of Information and Education Technology*, *10*(11), 813–819. https://doi.org/10.18178/ijiet.2020.10.11.1463

Khazali, N. A., Ismail, I., Sakamat, N., Zain, N. H. M., Noh, N. A. M., & Ishak, N. H. (2023). Smart pictorial dictionary via mobile augmented reality. *Bulletin of Electrical Engineering and Informatics*, *12*(2), 1019–1028. https://doi.org/10.11591/eei.v12i2.4009

Lavicza, Z., Weinhandl, R., Prodromou, T., An, B., Lieban, D., Hohenwarter, M., Fenyvesi, K., Brownell, C., & Manuel, J. (2022). Developing and Evaluating Educational Innovations for STEAM Education in Rapidly Changing Digital Technology Environments. *Sustainability (Switzerland)*, *14*(12), 1–15. https://doi.org/https://doi.org/10.3390/su14127237

Lavrentieva, O. O., Arkhypov, I. O., Kuchma, O. I., & Uchitel, A. D. (2020). Use of simulators together with virtual and augmented reality in the system of welders' vocational training: Past, present, and future. *CEUR Workshop Proceedings*, *2547*, 201–216.

Lin, J. L., Su, F. Y., Lin, C. Y., & Hsiao, K. H. (2023). Developing an Integrated Teaching Module for the Topic of Smart Industry in the Museum. *International Journal of Information and Education Technology*, *13*(5), 806–812. https://doi.org/10.18178/ijiet.2023.13.5.1871

Lu, A., Wong, C. S. K., Cheung, R. Y. H., Im, T. S. W., King, I., & Pegrum, M. A. (2021). Supporting Flipped and Gamified Learning With Augmented Reality in Higher Education. *Frontiers in Education*, *6*(April), 1–11. https://doi.org/10.3389/feduc.2021.623745

Merino, C., Iturbe-sarunic, C., Miller, B. G., Parent, C. E., Phillips, J. G., Pino, S., Garrido, J. M., Arenas, A., & Zamora, J. (2022). Snailed It ! Inside the Shell : Using Augmented Reality as a Window Into Biodiversity. *Frontiers in Education*, *7*(July), 1–13. https://doi.org/10.3389/feduc.2022.933436

Mohamed Shaffril, H. A., Samah, A. A., Samsuddin, S. F., & Ali, Z. (2019). Mirror-mirror on the wall, what climate change adaptation strategies are practiced by the Asian's fishermen of all? *Journal of Cleaner Production*, *232*, 104–117. https://doi.org/10.1016/j.jclepro.2019.05.262

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ (Online)*, *339*(7716), 332–336. https://doi.org/10.1136/bmj.b2535

Muktiani, N. R., Rahayu, S., & Ardiyanto, H. (2022). Augmented reality mobile app-based multimedia learning of Pencak Silat to enhance the junior high school students ' learning outcomes. *Cakrawala Pendidikan: Jurnal Ilmiah Pendidikan*, *41*(2), 553–568. https://doi.org/https://doi.org/10.21831/cp.v41i2.49217

Nadzri, A. Y. N. M., Ayub, A. F. M., & Zulkifli, N. N. (2023). The Effect of Using Augmented Reality Module in Learning Geometry on Mathematics Performance among Primary Students. *International Journal of Information and Education Technology*, *13*(9), 1478–1486. https://doi.org/10.18178/ijiet.2023.13.9.1952

Najmi, A. H., Alhalafawy, W. S., & Tawfiq Zaki, M. Z. (2023). Developing a Sustainable Environment Based on Augmented Reality to Educate Adolescents about the Dangers of Electronic Gaming Addiction. *Sustainability (Switzerland)*, *15*(4), 1–22. https://doi.org/10.3390/su15043185

Nasir, M., & Fakhruddin, Z. (2023). Design and Analysis of Multimedia Mobile Learning Based on Augmented Reality to Improve Achievement in Physics Learning. *International Journal of Information and Education Technology*, *13*(6), 993–1000. https://doi.org/10.18178/ijiet.2023.13.6.1897

Nordin, N. A. A., Majid, N. A. A., & Zainal, N. F. A. (2020). Mobile augmented reality using 3d ruler in a robotic educational module to promote stem learning. *Bulletin of Electrical Engineering and Informatics*, *9*(6), 2499–2506. https://doi.org/10.11591/eei.v9i6.2235

Ozcakir, B., & Cakiroglu, E. (2021). An Augmented Reality Learning Toolkit for Fostering Spatial Ability in Mathematics Lesson : Design and Development. *European Journal of Science and Mathematics Education*, *9*(4), 145–167. https://doi.org/https://doi.org/10.30935/scimath/11204

Richardo, R., Wijaya, A., Rochmadi, T., Abdullah, A. A., Nurkhamid, Astuti, A. W., & Hidayah, K. N. (2023). Ethnomathematics Augmented Reality: Android-Based Learning Multimedia to Improve Creative Thinking Skills on Geometry. *International Journal of Information and Education Technology*, *13*(4), 731–737. https://doi.org/10.18178/ijiet.2023.13.4.1860

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*(June), 100136. https://doi.org/10.1016/j.dajour.2022.100136

Shakirova, N., Al Said, N., & Konyushenko, S. (2020). The Use of Virtual Reality in Geo-Education. *International Journal of Emerging Technologies in Learning*, *15*(20), 59–70. https://doi.org/10.3991/ijet.v15i20.15433

Shewail, A. S., Elsayed, N. A., & Zayed, H. H. (2023). Survey of indoor tracking systems using augmented reality. *IAES International Journal of Artificial Intelligence*, *12*(1), 402–414. https://doi.org/10.11591/ijai.v12.i1.pp402-414

Sukardjo, M., Khasanah, U., Rahmat, S. T., Khaerudin, & Setiawan, B. (2023). Virtual Laboratory Design for Learning Electro-Pneumatic Practices in Vocational High Schools. *European Journal of Educational Research*, *12*(2), 719–737. https://doi.org/10.12973/eu-jer.12.2.719

Sulisworo, D., Drusmin, R., Kusumaningtyas, D. A., Handayani, T., Wahyuningsih, W., Jufriansah, A., Khusnani, A., & Prasetyo, E. (2021). The Science Teachers ' Optimism Response to the Use of Marker-Based Augmented Reality in the Global Warming Issue. *Education Research International*, *2021*, 1–9. https://doi.org/https://doi.org/10.1155/2021/7264230

Sun, K. T., & Chen, M. H. (2020). Utilizing MAR for Remedial Teaching of Compound-Cube-Surface Area at Elementary School in Taiwan. *International Journal of Information and Communication Technology Education*, *16*(2), 18–35. https://doi.org/10.4018/IJICTE.2020040102

Suprapto, N., Ibisono, H. S., & Mubarok, H. (2021). The Use of Physics Pocketbook Based on Augmented Reality on Planetary Motion to Improve Students' Learning Achievement. *Journal of Technology and Science Education*, *11*(2), 526–540. https://doi.org/https://doi.org/10.3926/jotse.1167 It

Suprapto, N., Nandyansah, W., & Mubarok, H. (2020). An Evaluation of the " PicsAR " Research Project : An Augmented Reality in Physics Learning. *International Journal of Emerging Technology in Learning*, *15*(10), 113–125.

Tanalol, S. H., Nizam, D. N. M., Haslinda, Z., Sani, A., & Baharum, A. (2021). Jawi using multi-maker augmented reality. *Bulletin of Electrical Engineering and Informatics*, *10*(5), 2892–2898. https://doi.org/10.11591/eei.v10i5.2464

Uiphanit, T., Unekontee, J., Wattanaprapa, N., & Rakbumrung, W. (2020). Using Augmented Reality (AR) for Enhancing Chinese Vocabulary Learning. *International Journal of Emerging Technology in Learning*, *15*(17), 268–276. https://doi.org/https://doi.org/10.3991/ijet.v15i17.15161

United Nations Statistics Division. (2020). Global indicator framework for the Sustainable Development Goals and targets of the 2030 Agenda for Sustainable Development. *Work of the Statistical Commission Pertaining to the 2030 Agenda for Sustainable Development*, 1–21. https://unstats.un.org/sdgs/indicators/Global Indicator Framework after 2019 refinement_Eng.pdf%0Ahttps://unstats.un.org/sdgs/indicators/Global Indicator Framework_A.RES.71.313 Annex.pdf

Wen, Y. (2021). Augmented reality enhanced cognitive engagement: designing classroom-based collaborative learning activities for young language learners. *Educational Technology Research and Development*, *69*(2), 843–860. https://doi.org/10.1007/s11423-020-09893-z

Widyaningsih, H., Julianti, E., Setiawan, I., Asmawi, M., & Nuraini, S. (2023). Physical Education Learning Design with Augmented Reality for Special Needs Students. *International Journal of Human Movement and Sports Sciences*, *11*(5), 1070–1078. https://doi.org/10.13189/saj.2023.110515

Yamtinah, S., Vh, E. S., Saputro, S., Retno, S., & Ariani, D. (2023). Augmented reality learning media based on tetrahedral chemical representation : How effective in learning process ? *EURASIA Journal of Mathematics, Science and Technology Education*, *19*(8), 1–16. https://doi.org/https://doi.org/10.29333/ejmste/13436

Zuben, A. Von, & Viana, F. A. C. (2022). Generative adversarial networks for extrapolation of corrosion in automobile images. *Expert Systems with Applications*, *213*(PA), 118849. https://doi.org/10.1016/j.eswa.2022.118849

Copyright Disclaimer