INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN PROGRESSIVE EDUCATION & DEVELOPMENT

OPEN ACCESS JOURNAL

Vol 13, Issue 1, (2024) E-ISSN: 2226-6348

Augmented Reality (AR) Technology in Biology and Life Science Education: A Systematic Literature Review (SLR)

Suhaida Subran, Siti Nur Diyana Mahmud

Faculty of Education, Universiti Kebangsaan Malaysia (UKM)

Email: suhaidasubran1710@gmail.com, diyana@ukm.edu.my

To Link this Article: http://dx.doi.org/10.6007/IJARPED/v13-i1/20455 DOI:10.6007/IJARPED/v13-i1/20455

Published Online: 27 January 2024

Abstract

Augmented Reality (AR) blends computer-generated images with real-world environments, enhancing education with positive outcomes, including improved academic performance, attitude, knowledge retention, comprehension, and motivation. Surprisingly, a systematic literature review addressing AR's role in biology and life sciences must be improved. This study investigates AR's background in biology education, prevalent fields and topics, benefits, and limitations. This research followed five essential stages: establishing guidelines, formulating research questions, systematic searching strategies using identification, screening, and feasibility criteria, utilizing Scopus, WOS, ERIC, and OpenAIRE for data, and quality assessment, data extraction, and analysis. As a result, the topic of the circulatory system in the anatomy field was prominently featured. Additionally, the affective domain demonstrated significant benefits with 56.3%, including positive attitude, fun learning, and improved motivation, followed by the improving cognitive domain with 32.4% and the psychomotor domain with 11.3%. Impressively, only eleven limitations were identified in contrast to seventy benefits in AR's application to biology education, such as technical problems, lack of content, and weak internet coverage.

Keywords: Augmented Reality, Biological Education, Life Sciences Education, Educational Technology, Ar Technology in Biology

Introduction

IR 4.0, the Fourth Industrial Revolution (IR 4.0), signifies a rapid and transformative development driven by digital technologies. This revolution encompasses advancements in the Internet of Things (IoT) and compels all sectors to adapt swiftly to the rapid evolution of technology and automation systems. Its impact extends beyond industry and agriculture, reaching into business, banking, and education. With the advent of IR 4.0, there is an escalating demand for computers and mobile devices, transcending age boundaries and significantly affecting the tech-savvy Alpha generation (Yapici & Karakoyun, 2021). This technological surge must be harnessed to its full potential, as it serves as a potent tool for enhancing educational quality through diverse applications (Ziden et al., 2022). The fusion of technology and education is a concept that has been introduced previously, particularly in 21st-century teaching and learning environments.

Augmented Reality (AR) technology seamlessly blends virtual objects, represented as computer-generated three-dimensional environments, with the real-world environment, delivering an immersive user experience (Altinpulluk, 2019; Das et al., 2017; Lo et al., 2021). AR empowers users to interact with virtual elements that appear integrated into their surroundings. AR has emerged as a dynamic field of study within the realm of education, drawing considerable research interest for its unique capacity to offer immersive and transformative learning experiences distinct from other technologies (Avila-Garzon et al., 2021). AR applications have proliferated across diverse learning domains, spanning mathematics, physical sciences, life sciences, and earth and space studies (Sırakaya & Sırakaya, 2022). Prior research extensively documents the advantages of AR in education, encompassing improved academic achievement and learning outcomes (Akçayır & Akçayır, 2017), improved motivation Altinpulluk (2019), enhanced visualization of abstract concepts Akçayır & Akçayır (2017) more engaging and enjoyable teaching practices (Nurhayati et al., 2022; Ramli et al., 2022), active student engagement (Akçayır & Akçayır, 2017; Wommer et al (2021), and reduced cognitive load (Bower et al., 2014).

Prior research has highlighted students' challenges in comprehending science concepts, particularly physics, chemistry, and biology, resulting in negative perceptions of science as a complex and daunting subject (Nordin & Ling, 2011). Students often view science as challenging to grasp, leading to low academic performance (Phang, Abu, Bilal Ali, & Salleh, 2014). Studies have shown that biology, in particular, poses challenges due to its abstract concepts, extensive content, and time-intensive learning requirements (Çimer, 2012). A prevailing issue contributing to these challenges is the absence of technology to support science education, causing students to experience stress and anxiety (Nachiappan, Muthaiah, & Suffian, 2017). Augmented Reality (AR) technology offers a promising solution, with documented benefits including reduced cognitive load, enhanced visualization of abstract concepts, improved motivation, and an engaging learning experience (Bower et al., 2014). While previous research has explored AR's potential in education, there remains a dearth of focus on its application in biological education. This study seeks to bridge this gap by investigating how AR can be effectively integrated into the teaching and learning of biology and life sciences. The central research question revolves around the utilization of AR in this context, with three primary focuses or objectives which are:

i. Identifying the biology field and topics that employ AR
ii. Elucidating the benefits of AR in biology education
iii. Examining the associated challenges and limitations of AR in Biology education

Methodology

Established guidelines (Mohamed Shaffril, Samsuddin, & Abu Samah, 2021)

A Systematic Literature Review (SLR) is a formal method employed to systematically gather, synthesize, and critically assess data on a particular topic in a transparent and replicable method (Higgins et al., 2011). This comprehensive process involves collecting and analyzing research studies from various sources, including articles, conference proceedings, books, and dissertations (Pati & Lorusso, 2018). Conducting an SLR encourages researchers to explore studies beyond their specific subjects and available networks, exposing them to extensive search methods based on predefined criteria (Robinson & Lowe, 2015). To ensure the quality and transparency of the SLR methodology, researchers should adhere to established guidelines, review protocols, or publication standards. In this study, guidelines from (Shaffril et al., 2021) were utilized, as they are compatible with various research areas and outline seven critical components of developing an SLR: (1) construction and validation of guidelines, (2) formulation of research questions, (3) systematic search strategies, (4) quality assessment, (5) data extraction, (6) data synthesis, and (7) data presentation. These guidelines enable researchers to plan essential aspects of SLR writing, produce transparent reviews, and serve as valuable references for future studies (Mengist, Soromessa, & Legese, 2020). Following established guidelines, researchers can formulate comprehensive research questions, strategically plan searches, select appropriate criteria, and rigorously assess article quality. Additionally, these guidelines incorporate an extensive systematic search strategy, complementing traditional methods with advanced techniques like phrase searches, truncation, wildcards, and field code functions.

Formulation of Research Questions

The research question formulation holds a pivotal significance in creating a Systematic Literature Review (SLR). The methodology used, the process of extracting and synthesizing data, must be able to answer the study's research questions. In this study, the research question is formed in two ways: ideas based on past studies (Pacheco et al., 2021). The articles studied are related to AR technology in Biology and life science education. The second way is to use the Research Question Development Tool (RQDT), which is a PICo pnemonic that involves P (problem or population), I (Interest), and Co (Context)(Lockwood, Munn, & Porritt, 2015). Based on this concept, the three main aspects to be studied are teaching and learning (Population), Augmented reality (Interest), and Biology or life sciences (context). This formula allows the author to produce the main research question in this paper: How is the use of Augmented reality in the teaching and learning of Biology and life sciences? There are three research questions to be studied, namely:

i. Which field and topic within Biology utilizes AR technology?
ii. What are the advantages of integrating AR into Biology Education?
iii. What are the constraints and challenges associated with the application of AR in Biology Education?

Systematic search strategy

As outlined by (Mohamed Shaffril et al., 2021), the systematic search strategy comprises three key phases: identification, screening, and eligibility. This approach empowers researchers to locate and synthesize pertinent research topics efficiently, culminating in the creation of well-structured and transparent Systematic Literature Reviews (SLRs).

Identification

For the systematic search, the study's research question, as established following Kitchenham & Charters (2007), focused on three primary keywords: "augmented reality," "Biology," and "education." The authors employed related terms, synonymous, and word variations sourced from platforms like thesaurus.com to broaden the scope and enhance the variety of keywords. Furthermore, the authors incorporated keywords derived from previous studies and recommendations provided by experts (Table 1). The amalgamation of these carefully curated keywords formed the basis for systematic search techniques, encompassing handpicking and advanced methods such as field code functions, phrase searches, wildcards, truncation, and Boolean operators (as detailed in Table 2). These techniques were applied across four databases: Scopus, Web of Science (WOS), Education Resources Information Centre (ERIC), and OPENaire. The utilization of multiple databases served to complement each other, minimizing potential research gaps. Given the absence of a comprehensive single database, diversifying the search across these platforms was essential (Xiao & Watson, 2019). The advanced search across Scopus and WOS yielded a promising pool of 745 articles with potential relevance for inclusion in the construction of the Systematic Literature Review (SLR).

Table 1
list of keywords used

Augmented reality	Biology	Education
Interactive learning environment	Life science	Study
AR	Natural science	learning
Educational technology		teaching

Table 2
Search strings used in selected databases

Database		*String*
i.	Scopus	TITLE-ABS-KEY (("augmented reality" OR "interactive learning environment" OR "educational technology") AND ("Biology" OR "life science" OR "natural science") AND ("education" OR "study" OR "learning" OR "teaching"))
ii.	WOS	TS= (("augmented reality" OR "interactive learning environment" OR "educational technology") AND ("Biology" OR "life science" OR "natural science") AND ("education" OR "study" OR "learning" OR "teaching"))
iii.	Others like ERIC and OPENaire	AR in Biology Education

Screening

The second step in the systematic search strategy is the screening process, where the author applies specific acceptance and rejection criteria. This filtering can be automated using data retrieval tools. The criteria include selecting articles published between 2019 and 2023, focusing exclusively on journal articles with empirical data, and considering articles only in English. The choice of English as the primary language for inclusion is practical, as it aligns with the predominant language of academic publications and avoids issues related to translation, confusion, and additional costs (Linares-Espinós et al., 2018). By applying these criteria, 626 articles that did not meet the established standards were excluded from consideration. Lastly, the 119 articles will undergo further evaluation in the subsequent phase of the review process.

Table 3
Criteria for Article Selection and Rejection

Criteria	Acceptance criteria	Rejection criteria
Year of publication	2019- January 2023	Before 2019 and after January 2023
Language	English	Other than English
Types of documents	Journal article with empirical data	Reviews of articles, chapters in books, proceedings

Eligibility

In the systematic search strategy, the eligibility phase is the third step. During this phase, the author manually reviews the remaining articles by examining their titles and abstracts, aligning them with pre-established acceptance and rejection criteria. After this review, 90 articles were excluded from the list for various reasons, including topics unrelated to Augmented reality, content outside the scope of life sciences (e.g., biomolecules or biochemistry), duplicate articles, and unavailability. Lastly, This leaves only 29 articles that will undergo further quality assessment in the next phase of the study.

Quality appraisal

After the eligibility phase in the systematic search strategy, the next crucial step is quality appraisal to mitigate bias in the selected articles. This step involves applying a standardized tool or checklist. In this study, the Mixed-Method Appraisal Tool (MMAT), developed by (Pace et al., 2012), was employed. MMAT's versatility allows it to evaluate five study design types: qualitative, randomized, non-randomized, quantitative descriptive, and mixed studies (Hong et al., 2018) . Each article undergoes a two-step evaluation process: initial screening questions and a comprehensive assessment based on five criteria tailored to the study's design. MMAT encompasses 25 criteria, and appraisers must indicate "Yes," "No," or "Can't tell" for each. An article must meet at least three criteria for inclusion in the Systematic Literature Review (SLR). This stringent quality assessment involves two independent experts who collaboratively determine the article's status, following guidelines (Charrois, 2015). This rigorous process ensures the credibility of selected articles for the SLR.

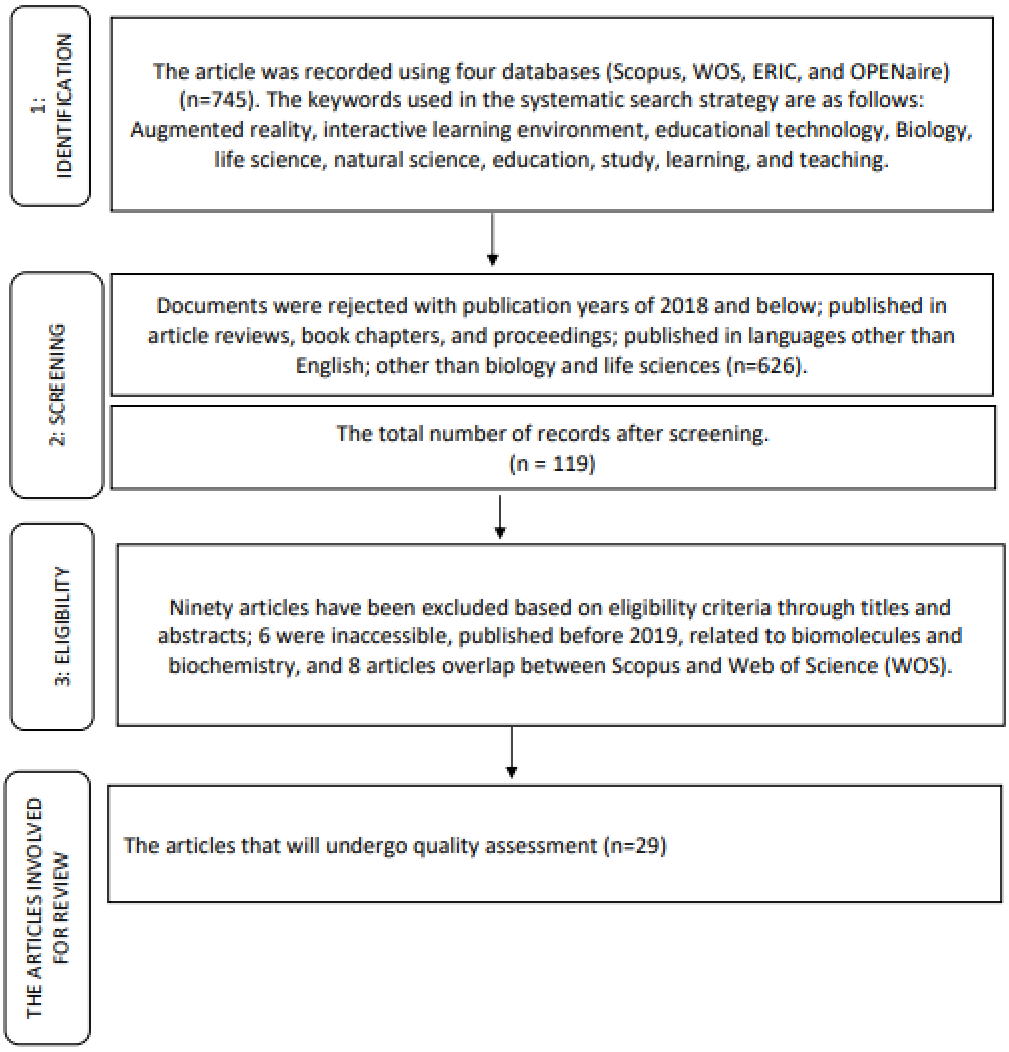

Figure 1: Flowchart in the article searching process

Data Extraction and Data Analysis

The research question guides data extraction from the chosen article. The extracted data should directly address the research query and then undergo analysis. This study employs qualitative synthesis, specifically thematic analysis. The thematic analysis involves identifying recurring themes in collected data and is suitable for various study designs, whether qualitative, quantitative, or mixed (Flemming et al., 2019). This study uses a thematic deductive analysis approach, where the authors predefined themes before data synthesis.

Table 4
Criteria used to determine methodology and analysis for selected articles

Research design	Assessment criteria
Qualitative	QA1-Is the qualitative approach appropriate to answer the research question? QA2- Are the qualitative data collection methods adequate to address the research question? QA3- Are the findings adequately derived from the data? QA4- Is the interpretation of results sufficiently substantiated by data? QA5- Is there coherence between qualitative data sources, collection, analysis, and interpretation?
Quantitative randomized controlled trials	QA1- Is randomization appropriately performed? QA2-Are the groups comparable at baseline? QA3- Are there complete outcome data? QA4- Are outcome assessors blinded to the intervention provided? QA5- Did the participants adhere to the assigned intervention?
Quantitative non randomized	QA1- Are the participants representative of the target population? QA2- Are measurements appropriate regarding both the outcome and intervention (or exposure)? QA3- Are there complete outcome data? QA4- Are the confounders accounted for in the design and analysis? QA5- During the study period, is the intervention administered (or exposure occurred) as intended?
Quantitative descriptive	QA1- Is the sampling strategy relevant to address the research question? QA2- Is the sample representative of the target population? QA3-Are the measurements appropriate? QA4- Is the risk of nonresponse bias low? QA5- Is the statistical analysis appropriate to answer the research question?
Mixed method	QA1- Is there an adequate rationale for using a mixed methods design to address the research question? QA2- Are the different components of the study effectively integrated to answer the research question? QA3- Are the outputs of the integration of qualitative and quantitative components adequately interpreted? QA4-Are divergences and inconsistencies between quantitative and qualitative results adequately addressed? QA5- Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?

Source: (Hong et al., 2018)

Table 5
Result of quality assessment

No	Study	Research design	QA1	QA2	QA3	QA4	QA5	Number of criteria fulfilled	Inclusion in the review
1	Weng et al. 2020a	QN (NR)	/	/	/	C	/	4/5	/
2	Erbas and Demirer 2019	MX	/	/	/	/	/	5/5	/
3	Fuchsova and Korenova 2019	MX	/	/	X	/	/	4/5	/
4	Khalifah Mustami et al. 2019	QN (DC)	/	/	/	C	/	4/5	/
5	Celik, Guven, and Cakir 2020	MX	/	/	/	X	/	4/5	/
6	Petrov and Atanasova 2020	QN (NR)	/	/	/	C	/	4/5	/
7	Yang & Tsai 2021	QN (NR)	/	/	/	C	/	4/5	/
8	Dehghani et al. 2023	QN (R)	/	/	/	C	/	4/5	/
9	Gnidovec et al. 2020	QN (NR)	/	/	/	C	/	4/5	/
10	Wommer et al. 2021	QL	/	/	/	/	/	5/5	/
11	Gregorcic & Torkar 2022	QN (NR)	/	/	/	C	/	4/5	/
12	Nurhayati et al. 2022	QN (NR)	/	/	/	C	/	3/5	/
13	Al-Muqbil 2022	QN (NR)	/	/	/	C	/	4/5	/
14	Delgado-Rodríguez et al. 2023	MX	/	/	/	/	/	5/5	/
15	Maraza-Quispe et al. 2023	QN (R)	/	X	/	C	/	3/5	/
16	Sarnat et al. 2019	QL	/	/	/	/	/	5/5	/
17	Lo et al. 2021	MX	/	/	/	/	/	5/5	/
18	Kozcu Cakir et al. 2020	MX	/	/	/	/	/	5/5	/
19	Damopolii et al. 2022	QN (NR)	/	/	/	C	/	4/5	/
20	Ramli et al. 2022	QL	/	/	/	/	/	5/5	/
21	Stojšić et al. 2022	QN (NR)	/	/	/	C	/	4/5	/
22	Lam et al. 2023	QN (NR)	X	/	/	C	/	3/5	/
23	Yildirim 2020	MX	/	/	/	/	/	5/5	/
24	Yildirim 2021	MX	/	/	/	/	/	5/5	/
25	Yapici & Karakoyun 2021	MX	/	/	/	/	/	5/5	/

No	Study	Research design	QA1	QA2	QA3	QA4	QA5	Number of criteria fulfilled	Inclusion in the review
26	Sontay & Karamustafaoglu 2021	QL	/	/	/	/	/	5/5	/
27	Sivri & Eroglu 2022	QN (NR)	/	/	/	C	/	5/5	/
28	Ziden et al. 2022	MX	/	/	/	/	/	5/5	/
29	Omurtak & Zeybeck 2022	MX	/	/	/	/	/	5/5	/

QA: *Quality appraisal*; QN (NR): Quantitative nonrandomized; QN (R): Quantitative randomized controlled trials; QN (DC): Quantitative descriptive; QL: Qualitative; MX: Mixed method

Result

Background of the selected studies

Out of the 29 articles included in the Systematic Literature Review (SLR) study, seven were conducted in Turkey Erbas & Demirer (2019); Cakir et al (2020); Omurtak & Zeybek (2022); Yıldırım (2021); Sontay & Karamustafaoglu (2021); Yapici & Karakoyun (2021); Yildirim (2020), five in Indonesia Damopolii et al (2022); Erwinsah et al (2019); Mustami et al (2019); Nurhayati et al (2022); Weng et al (2020a), three in Malaysia (Lam, Lim, & Tan, 2023; Ramli et al., 2022; Ziden et al., 2022), two in Slovenia Gnidovec et al (2020); Gregorcic & Torkar (2022), two in Taiwan Yang & Tsai (2021), and one each in Saudi Arabia, Brazil, Bulgaria, Fiji, Iran, Istanbul, Serbia, Slovakia, and Spain. Additionally, three studies did not specify their location.

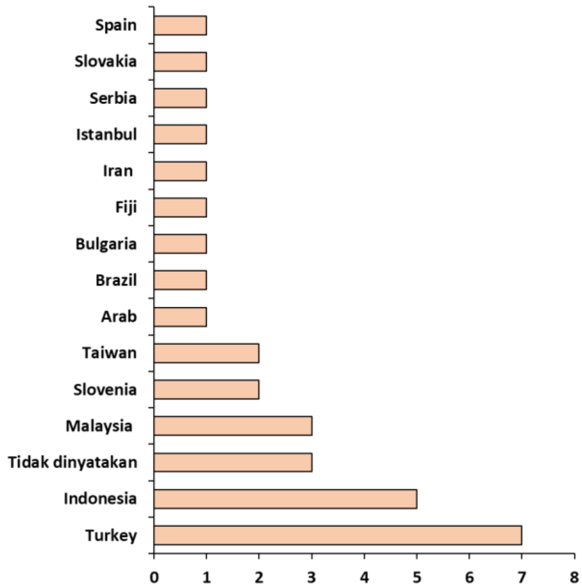

Figure 2: Countries where the studies were conducted

From the 29 selected articles, a diverse array of research designs was identified. Among them, 11 studies adopted quantitative non-randomized research designs (Al-Muqbil, 2022; Damopolii et al., 2022; Gnidovec et al., 2020; Gregorcic & Torkar, 2022; Lam et al., 2023; Nurhayati et al., 2022; Petrov & Atanasova, 2020; Sivri & Eroglu, 2022; Stojšić, Ostojić, &

Vol. 13, No. 1, 2024, E-ISSN: 2226-6348 © 2024

Stanisavljević, 2022; Weng et al., 2020a; Yang & Tsai, 2021). An equal number of studies, 11 in total, utilized mixed-method research designs (Celik et al., 2020; Delgado-Rodríguez, Carrascal Domínguez, & Garcia-Fandino, 2023; Erbas & Demirer, 2019; Fuchsova & Korenova, 2019; Kozcu Cakir et al., 2020; Lo et al., 2021; Omurtak & Zeybek, 2022; Serdar Yıldırım, 2021; Yapici & Karakoyun, 2021; Yildirim, 2020; Ziden et al., 2022). Additionally, four qualitative studies were included (Ramli et al., 2022; Sarnat et al., 2019; Gökhan Sontay & Karamustafaoglu, 2021; Wommer et al., 2021), along with two quantitative control randomized (Dehghani, Mohammadhasani, Hoseinzade Ghalevandi, & Azimi, 2023; Maraza-Quispe et al., 2023) and one study employing a quantitative descriptive research design (Mustami et al., 2019).

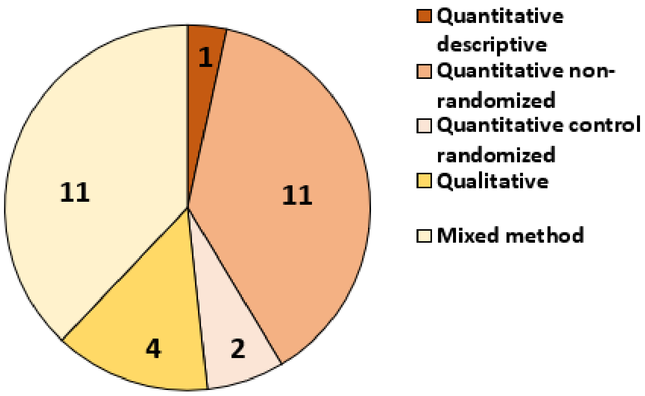

Figure 3: Research design of selected studies

Between 2019 and January 2023, 31 articles met the inclusion criteria. These were distributed across the years as follows: six articles in 2019 (Erbas & Demirer, 2019; Erwinsah et al., 2019; Fuchsova & Korenova, 2019; Khalifah Mustami et al., 2019; Sarnat et al., 2019; Weng et al., 2020a), seven articles in 2020 (Arslan, Kofoğlu, & Dargut, 2020; Celik et al., 2020; Dehghani et al., 2023; Gnidovec et al., 2020; Petrov & Atanasova, 2020; Yang & Tsai, 2021; Yildirim, 2020), six articles in 2021 (Kozcu Cakir et al., 2020; Lo et al., 2021; Serdar Yıldırım, 2021; Gokhan Sontay & Karamustafaoğlu, 2021; Wommer et al., 2021; Yapici & Karakoyun, 2021), nine articles in 2022 (Al-Muqbil, 2022; Damopolii et al., 2022; Gregorcic & Torkar, 2022; Nurhayati et al., 2022; Omurtak & Zeybek, 2022; Ramli et al., 2022; Sivri & Eroglu, 2022; Stojšić et al., 2022; Ziden et al., 2022), and three studies until January 2023 (Delgado-Rodríguez et al., 2023; Lam et al., 2023; Maraza-Quispe et al., 2023).

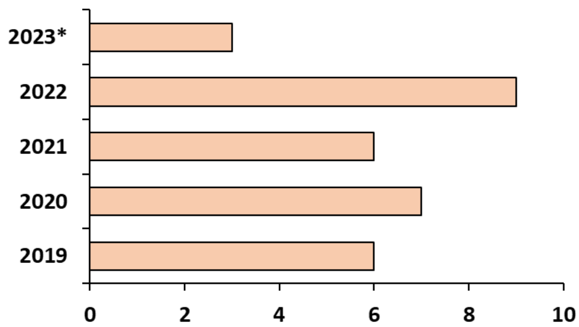

Figure 4: Publication years of selected studies until January 2023 (*)

Furthermore, the selected articles were published in various journals, with two articles each in the following journals: International Journal of Information and Education Technology (Maraza-Quispe et al., 2023; Nurhayati et al., 2022), Journal of Science, Environment and Health Education (Omurtak & Zeybek, 2022; Serdar Yıldırım, 2021), Malaysian Journal of Online Education Technology (Gokhan Sontay & Karamustafaoğlu, 2021; Yapici & Karakoyun, 2021), TEM Journal (Damopolii et al., 2022; Lam et al., 2023), and one article each in Advances in Physiology Education (Gregorcic & Torkar, 2022), Eurasia Journal of Mathematics, Science and Technology Education (Ziden et al., 2022), European Journal of Contemporary Education (Fuchsova & Korenova, 2019), Interactive Learning Environments (Dehghani et al., 2023), International Journal of Cognitive Research in Science, Engineering and Education (Stojšić et al., 2022), International Journal of Contemporary Educational Research (Sivri & Eroglu, 2022), International Journal of Curriculum and Instruction (Al-Muqbil, 2022), International Journal of Emerging Technologies in Learning (Ramli et al., 2022), International Journal of Technology Enhanced Learning (Mustami et al., 2019), International Journal of Technology in Education (Kozcu Cakir et al., 2020), Journal of Insect Systematics and Diversity (Sarnat et al., 2019), Journal of Computer Assisted Learning Erbas & Demirer (2019), Journal of Computational Research Weng et al (2020a), Journal of New Approaches in Educational Research (Delgado-Rodríguez et al (2023), Journal of Physics Erwinsah et al (2019), Journal of Science Education and Technology (Gnidovec et al., 2020), Turkish Journal of Science Education Arslan et al (2020), Journal Sustainability (Lo et al., 2021), MDPI Journal Petrov & Atanasova (2020), Learning Technology Research (Celik et al., 2020), Science & Technology Education Research (Wommer et al., 2021), Journal of Internet Technology Yang & Tsai (2021), and Jornal Curriculum and Technology (Al-Muqbil, 2022).

The Identified Themes

This study employed inductive thematic analysis to extract themes from 29 articles, addressing the primary research question: How is the use of Augmented reality in the teaching and learning of Biology and life sciences? Three themes emerged: (1) The field and topic in Biology where AR technology applied, (2) the advantages of integrating AR into Biology Education, and (3)what are the constraints and challenges associated with integrating AR in Biology Education. The following section elaborates on these themes based on insights from 29 selected articles.

Research question 1: In which fields and topics of Biology is AR technology applied?

Studies have shown that AR technology is utilized in various domains within Biology. Among these domains, topics related to the circulatory system are the most prevalent. Based on an analysis of 29 articles, it was observed that the field of anatomy had the highest representation, accounting for 43.24 percent (16 out of 37 topics), followed by cell biology, encompassing knowledge about animal cells, plant cells, and organelles, at 18.92 percent (7 out of 37 topics). Entomology, which deals with insects and physiology concerning the functions of living organisms' systems, constituted 8.11 percent (3 out of 37 topics). Conversely, the least explored areas in the application of AR were biotechnology (related to food technology), virology (about bacteria and viruses), and taxonomic classifications of organisms, each accounting for 2.70 percent (1 out of 37 topics). Notably, three articles needed to specify their particular focus.

In this study, the field of anatomy demonstrated the highest integration of AR technology, accounting for 43.24% compared to other fields. Anatomy, a scientific discipline that investigates the structures, organs, and systems within organisms, encompasses a wide range of topics, including the circulatory, endocrine, digestive, excretion, support and movement systems, and respiratory systems. Two notable studies exemplify the impact of AR in the field of anatomy. Firstly, the study Gregorcic & Torkar (2022) employed a structure-behavioral-functional (SBF) model integrated with AR to facilitate students' comprehension of complex circulatory systems. This study showed significant improvements in students' knowledge of the circulatory system.

Similarly, Cakir et al (2020) integrated Mobile Augmented Reality (MAR) applications into the 5E model for Biology instruction, explicitly focusing on the nervous system and coordination. This innovative approach made laboratory learning sessions more engaging, particularly in brain surgery, where students benefited from a deeper understanding and close examination of brain organs through MAR technology. Furthermore, studies of Mustami et al (2019), which concentrated on the digestive and excretion systems, highlighted the effectiveness of integrating AR into biology textbooks. This integration significantly enhanced students' mean achievement scores, underscoring the potential of AR to elevate learning outcomes in these critical areas of Biology.

Cell biology, or cytology, represents this study's second-highest field of AR utilization, accounting for 18.92%. Cytology is a specialized branch of Biology that explores cells' structure, functions, and characteristics. A noteworthy study by (Delgado-Rodríguez et al., 2023) employed AR technology to investigate cell mitotic division, providing valuable insights into this fundamental cellular process. Additionally, Lam et al (2023) developed an AR-based gaming application to study animal and plant cells, further enhancing the exploration of cell biology concepts. While many studies have primarily concentrated on topics such as the circulatory system, there are also studies exploring multiple topics simultaneously. For instance, the study conducted by Cakir et al (2020) employed the Mobile Augmented Reality (MAR) application to facilitate understanding of anatomy, covering diverse anatomical regions like the heart, brain, kidneys, and eyes. This result demonstrates the versatility of AR technology in addressing various anatomical systems in Biology education.

Table 6
Topics and fields in Biology that have used AR technology

No.	Study	Topic	Number of topics covered	Field
1	Weng et al., 2020a	Food Biotechnology	1	Biotechnology
2	Erbas & Demirer, 2019	Cell	1	Cytology
3	Fuchsova & Korenova, 2019	Neural anatomy and endocrine system	1	Anatomy
4	Khalifah Mustami et al., 2019	Digestive and excretion system	2	Anatomy
5	Celik et al., 2020	Blood circulatory system	1	Anatomy
6	Petrov & Atanasova, 2020	Blood circulatory system	1	Anatomy
7	Yang & Tsai, 2021	Insect	1	Entomology

No.	Study	Topic	Number of topics covered	Field
8	Dehghani et al., 2023	Blood circulatory system	1	Anatomy
9	Gnidovec et al., 2020	Blood circulatory system	1	Anatomy, physiology
10	Wommer et al., 2021	Morphology and insect taxonomy	2	Entomology, taxonomy
11	Gregorcic & Torkar, 2022	Blood circulatory system	1	Anatomy, physiology
12	Nurhayati et al., 2022	Environmental pollution	1	Ecology
13	Al-Muqbil, 2022	Bacteria and viruses	2	Virology
14	Delgado-Rodríguez et al., 2023	Cell and cell division	1	Cytology
15	Maraza-Quispe et al., 2023	Cell	1	Cytology
16	Sarnat et al., 2019	Insect	1	Entomology
17	Lo et al., 2021	Plant and environment	1	Ecology
18	Kozcu Cakir et al., 2020	Anatomy and function of heart, brain, kidney and eyes	2	Anatomy, physiology
19	Damopolii et al., 2022	Coordination system	1	Anatomy
20	Ramli et al., 2022	Reproduction, animal growth (chicken and frog)	1	Anatomy
21	Stojšić et al., 2022	Not specified	-	Not specified
22	Lam et al., 2023	Animal and plant cell	1	Cytology
23	Yildirim, 2020	Animal and plant cell structures, organells	1	Cytology
24	Serdar Yıldırım, 2021	System in the human body	1	Anatomy
25	Yapici & Karakoyun, 2021	Not specified	-	Not specified
26	Gökhan Sontay & Karamustafaoglu, 2021	Support and movement systems, respiration system, and blood circulatory system	3	Anatomy
27	Sivri & Eroglu, 2022	Support and movement systems	2	Anatomy
28	Ziden et al., 2022	Human digestive system	1	Anatomy
29	Omurtak & Zeybek, 2022	Not specified	-	Not specified
	Total			33

Table 7
Fields in Biology that have used AR technology

Field	Number	Percentage (%)
Anatomy	16	43.24
Biotechnology	1	2.70
Ecology	2	5.41
Entomology	3	8.11
Physiology	3	8.11
Cytology	7	18.92
Taxonomy	1	2.70
Virology	1	2.70
Not specified	3	8.11
Total	37	100.00

Research question 2: What are the advantages of integrating AR into Biology Education?

The data extracted from 29 articles revealed a total of 71 benefits associated with the use of AR in Biology Education. These advantages have been categorized into three distinct domains: the cognitive, the affective, and the psychomotor domains. The cognitive domain, which pertains to intellectual aspects, draws from the framework of Bloom's taxonomy, initially developed by educational psychologist Dr. Benjamin Bloom in 1956. Bloom's taxonomy classifies learning into two primary domains: the cognitive domain, which encompasses knowledge acquisition, and the affective domain, which encompasses the development and transformation of emotions, feelings, and attitudes. Additionally, the psychomotor domain, introduced by Simpson in 1966, focuses on physical development and skills acquisition. This domain complements Bloom's taxonomy and provides a comprehensive framework for understanding the diverse benefits of incorporating AR technology into Biology Education (Nafiati, 2021).

The affective domain exhibited the highest prevalence among the recorded benefits, accounting for 56% (40 out of 71) of the total advantages associated with AR in Biology Education. This domain primarily encompasses changes in attitudes, behaviors, and emotional appreciation. Within the affective domain, several benefits were identified in this study, including a positive shift in learning attitudes, increased motivation, and providing an enjoyable and engaging learning experience through AR technology. For instance, a study conducted in Turkey Omurtak & Zeybek (2022) aimed to assess AR applications' impact on academic achievement and motivation in Biology teaching. While the study did not find a significant difference in student motivation based on the Motivation Questionnaire for Biology Lessons test, interviews with students revealed that using AR made the teaching and learning process more enjoyable and engaging and infused a sense of excitement and joy. These findings align with other studies, such as the one by (Yapici & Karakoyun, 2021), which also utilized AR in Biology education. These studies consistently showed that AR usage heightened students' enthusiasm for learning and made the educational experience more captivating.

Furthermore, this study identified 23 benefits (32.4%) associated with the cognitive domain, emphasizing academic achievement, knowledge retention, and enhanced comprehension. For instance, a study conducted by Yildirim (2020), which centered on using

AR to explore the structures of animal and plant cells and their organelles, demonstrated that AR technology significantly elevated students' academic achievement. Similarly, the study (Omurtak & Zeybek, 2022) yielded consistent outcomes, revealing a notable difference in mean academic achievement levels between pre- and post-examinations following the incorporation of AR into the teaching and learning process. These findings underscore the positive impact of AR on cognitive aspects of Biology Education.

The psychomotor domain, encompassing aspects related to physical changes in students, such as active participation in classes, revisiting learning content, self-directed learning, and the stimulation of creativity, constituted the domain with the lowest representation, accounting for 11.3% (8 out of 71) of the identified benefits. For instance, a study by Fuchsova & Korenova (2019) involved 61 prospective primary school teachers in a study focusing on visualizations of the anatomy of the nervous and endocrine systems using AR technology. The results indicated improvements in motivation, enhanced collaborative abilities among students, and highlighted the students' creative potential. Although the psychomotor domain had a smaller percentage of benefits, it nonetheless demonstrated the positive impact of AR in fostering physical and creative engagement in Biology Education.

Table 8
Benefits of the use of AR in Biological Education

Study (Year)	Cognitive domain	Affective domain			Psychomotor domain
		PA	FL	M	
Weng et al., 2020a	/	/	/		
Erbas & Demirer, 2019		/		/	
Fuchsova & Korenova, 2019	/			/	/
Khalifah Mustami et al., 2019			/		/
Celik et al., 2020	/		/		
Petrov & Atanasova, 2020	/				
Yang & Tsai, 2021	/	/		/	
Dehghani et al., 2023	/				
Gnidovec et al., 2020	/				
Wommer et al., 2021	/	/		/	/
Gregorcic & Torkar, 2022	/				
Nurhayati et al., 2022	/		/	/	
Al-Muqbil, 2022	/				/
Delgado-Rodríguez et al., 2023	/			/	
Maraza-Quispe et al., 2023	/			/	
Sarnat et al., 2019					
Lo et al., 2021		/	/		
Kozcu Cakir et al., 2020	/	/	/		/
Damopolii et al., 2022	/	/	/		
Ramli et al., 2022	/	/	/		/
Stojšić et al., 2022		/			
Lam et al., 2023		/		/	
Yildirim, 2020	/		/	/	
Serdar Yıldırım, 2021	/		/		
Yapici & Karakoyun, 2021	/	/	/		/
Gokhan Sontay & Karamustafaoğlu, 2021	/	/	/		
Sivri & Eroglu, 2022	/	/		/	
Ziden et al., 2022	/		/	/	
Omurtak & Zeybek, 2022	/	/	/	/	/
Total	23	14	14	12	7
Total by domain	23	40			8
Percentage (%)	32.4%	56.3%			11.3%
Total	71				

PA: Positive attitude; FL: Fun learning; M: Motivation

Research question 3: What are the constraints and challenges associated with the application of AR in Biology Education?

In the analysis of the 29 articles included in this Systematic Literature Review (SLR), a significant majority, comprising 23 articles (79%), did not provide information regarding the limitations, challenges, or disadvantages associated with the use of Augmented Reality (AR) in Biology Education. However, six articles (21%) acknowledged and reported various limitations related to AR in Biological education. The study revealed that technical challenges, accounting for 64% of the reported limitations, primarily encompassed issues related to tools, weak internet coverage Fuchsova & Korenova (2019), long application startup time Omurtak & Zeybek (2022), lack of content Lam et al (2023), and complex download requirements (Ziden et al., 2022). Other than that, it has been recorded that financial and behavioral factors comprise 18% of each category. Financial challenges include the high cost of producing AR content for use in the teaching and learning process (Petrov & Atanasova, 2020; Yapici & Karakoyun, 2021). Then another 18% revealed that using AR in biology education can make the student passive and phone addicted (Yapici & Karakoyun, 2021). These findings highlight the need for educators and researchers to address and overcome these challenges when incorporating AR technology into Biology Education.

Table 9
Limitations and challenges of using AR in Biology Education

Study	Challenge	Category		
		Technical	Finance	Behavioral factor
Fuchsova & Korenova, 2019	Lack of content	/		
	Technical problem	/		
	Weak internet coverage	/		
Omurtak & Zeybek, 2022	Long app startup load time	/		
Petrov & Atanasova, 2020	High cost		/	
Lam et al., 2023	Lack of content	/		
Ziden et al., 2022	Complex download requirement	/		
Yapici & Karakoyun, 2021	Students become passive			/
	Phone addiction			/
	High cost		/	
	Technical problems	/		
Total		7	2	2
Percentage by domain (%)		64	18	18

Discussion

This Systematic Literature Review (SLR) endeavors to investigate the utilization of Augmented Reality (AR) technology in Biology and life sciences education in studies conducted from 2019 to January 2023. It offers up-to-date insights into the landscape of Biological education involving AR, encompassing the covered topics, the advantages associated with AR implementation, and the limitations and challenges encountered in its use.

Between 2019 and January 2023, the prevalence of Augmented Reality (AR) technology in Biology Education experienced its most significant growth in 2022. This surge can be attributed to the digital revolution and the impact of the COVID-19 pandemic, which necessitated a shift towards technology-driven teaching and learning methods when face-to-face education became challenging. The adoption of these technologies reflects a paradigm shift in teaching methods to align with the preferences and needs of contemporary students. Technology integration offers novel opportunities for information acquisition, enhances creativity, and facilitates meaningful learning experiences for students, as indicated by (Shanks et al., 2017). Furthermore, the current generation of students is intimately familiar with mobile phones, and studies like the one conducted by Ewais et al (2019) highlight the gradual integration of mobile devices into everyday life. This trend extends to younger generations, with mobile devices being increasingly utilized for AR applications in educational settings. Notably, this study found that 72% (21 out of 39) of the included articles employed mobile devices, such as phones equipped with code-scanning capabilities or AR markers, in AR applications for Biological education.

Based on the systematic literature review conducted on 29 articles, it was discovered that 33 different topics have utilized Augmented Reality (AR) applications. Notably, the field of anatomy emerged as the primary user of AR technology. Anatomy pertains to the scientific study of the structure of organs that constitute the organism's system. It is a captivating field of science that can attract students. However, it is known to be quite challenging to comprehend, as noted by Assaraf (2018), leading to potential misunderstandings and difficulties in grasping system-related science in humans, as mentioned by Selvi & Yakisan, (2004) , ultimately rendering the learning process in this domain complex and intricate (Gregorcic & Torkar, 2022). The research findings highlighted that the circulatory system was the most prevalent topic employing AR technology in biology. The circulatory system is an intricate network involving various levels of cellular organization. This system comprises diverse types of cells that combine to form tissues, and these tissues, in turn, combine to create various organs such as arteries, veins, capillaries, and the heart, each with its distinct functions. Subsequently, these different organs collectively form the circulatory system, which performs various vital functions like the transportation of oxygen, hormones, carbon dioxide, nutrients, and more. The application of AR technologies, such as the behavioral function of SBF Structure in the study conducted by Gnidovec et al (2020) was beneficial in helping students understand the intricacies of the circulatory system. This technology, in turn, contributed to an enhanced comprehension of human heart anatomy, physiology, and the effects of adrenaline on the circulatory system among students. AR allows students to visualize and comprehend abstract concepts, as noted by Erbas & Demirer (2019), by presenting educational content with 3D images that bridge the gap between the natural world and the virtual one (Al-Muqbil, 2022).

A study of 29 articles investigating the use of Augmented Reality (AR) in biology education revealed several benefits, categorized into three domains: cognitive, affective, and psychomotor. In the cognitive domain alone, a total of 23 benefits were identified. Students who employed AR technology demonstrated improved academic performance in various aspects of biology education. They exhibited better comprehension of insect-related knowledge and natural science (Yang & Tsai, 2021). Additionally, their understanding of complex topics like the heart, blood capillaries, and cardiac activity was enhanced, as evidenced by (Petrov & Atanasova, 2020). AR also contributed to heightened comprehension and analysis skills, aligned with Bloom's taxonomy, according to findings from (Weng et al., 2020a).

Furthermore, AR was associated with increased critical thinking skills (Damopolii et al., 2022). Moreover, students noted their ability to successfully answer questions related to cells and organelles in postgraduate tests, signifying meaningful learning. This trend was consistent with other studies (Abdullah et al., 2022; Sırakaya & Sırakaya, 2022). However, the study (Erbas & Demirer, 2019) produced contrasting results. Their research did not reveal a significant difference in academic achievement among the groups involved in the study. This disparity might be attributed to the use of AR primarily as a tool for demonstration, possibly due to suboptimal instructional planning and an emphasis on technology rather than the content of the learning materials.

The study revealed that the affective domain accounted for the highest percentage of benefits at 56.3%, encompassing 40 out of the total 71 benefits identified. Augmented Reality (AR) has injected a sense of fun and excitement into the learning of biology, as evidenced by studies conducted by (Celik et al., 2020; Mustami et al., 2019; Weng et al., 2020b). This technology has increased student motivation (Erbas & Demirer, 2019; Maraza-Quispe et al., 2023; Yang & Tsai, 2021). Furthermore, these findings are consistent with studies conducted by (Chen, 2019), highlighting AR's ability to captivate students and enhance their motivation to learn. AR allows students to visualize and comprehend abstract and invisible concepts, which can be challenging with traditional teaching methods. This technology-heightened motivation positively impacts the teaching and learning of biology, ultimately contributing to improved academic achievement.

The study also identified the advantages of Augmented Reality (AR) in the psychomotor domain. AR enables students to engage in self-directed learning and repetition (Fuchsova & Korenova, 2019; Yapici & Karakoyun, 2021). This flexibility allows teaching and learning to occur independently of time and location. Furthermore, AR encourages active participation and engagement (Wommer et al., 2021; Yapici & Karakoyun, 2021) fostering active and interactive learning experiences (Ramli et al., 2022). For example, (Wommer et al., 2021) used AR applications in an educational game called "Insect GO" to help students understand insect morphology, taxonomy, and life cycle. The study involved 21 students aged 11 to 15 years old. It commenced with a hands-on activity in which students had to choose appropriate lenses to capture insect pictures using their mobile phones before proceeding to the next step. This approach illustrates the benefits of AR in the psychomotor domain, where students actively engage in activities and acquire knowledge through hands-on experiences.

In Biology education, there have been advantages and limitations associated with the application of Augmented Reality (AR). While there are approximately 70 benefits of using AR, only eleven limitations and challenges have been identified. These findings align with a systematic literature review (SLR) conducted by (Avila-Garzon et al., 2021), which indicated a limited number of issues in implementing AR in education. Although the limitations may seem small, they serve as valuable guidance for teachers and AR software designers in Biology education, helping them address and overcome the identified challenges.

Limitations and Recommendations of Future Studies

This study has several limitations, including restrictions on the databases used in systematic search strategies. The study employed a systematic search strategy that utilized truncation, Boolean operators, and phrase searches primarily for two primary databases, namely Scopus and Web of Science (WOS). A manual hand-picking method was also used for the ERIC and OpenAIRE databases. Furthermore, the articles retrieved were also constrained by the specific keywords listed in Table 1. Moreover, this study focused exclusively on biology-related content, specifically within the field of life sciences. The following section outlines recommendations for future studies based on the identified issues and gaps.

i. This systematic literature review (SLR) study found that most studies focus on the anatomical field of the human circulatory system. In the future, studies should also explore other topics, such as the process of homeostasis in the human body.
ii. The field of study can also be extended to areas involving plants, namely botany, such as leaf structures and processes that occur in leaves, such as photosynthesis and transpiration.
iii. The results indicated that Augmented Reality (AR) positively impacted academic achievement within the cognitive domain. However, there is controversy because there are studies that present opposing findings. Therefore, future studies should focus on related factors.

Conclusion

This study aims to comprehend and address the research question, "How is Augmented Reality used in the teaching and learning of Biology and life sciences?" A systematic search strategy was employed, involving identification, screening, and eligibility criteria across four data repositories: Scopus, Web of Science (WOS), OpenAIRE, and ERIC, spanning from 2019 to January 2023. Following the qualification process based on title and abstract review, the article quality assessment was carried out using the Mixed Method Appraisal Tool (MMAT), with the participation of two experts in teaching and learning Biology, each possessing over ten years of teaching experience. Ultimately, 29 articles were included in this systematic literature review (SLR). The study addressed three primary questions: the areas and domains of Biology that have implemented Augmented Reality, the advantages of Augmented Reality in biology education, and the challenges or limitations encountered. Presented below are the key findings of this study

i. There was a notable rise in AR studies in Biology and Life Sciences education, particularly in 2022, accounting for 9 out of 29 studies, representing 31% of the total studies conducted from 2019 to January 2023.
ii. Most studies were conducted in Turkey, totaling 7 out of 29, accounting for 24%.
iii. The mixed method and non-random quantitative designs had 11 studies, while the descriptive quantitative design included only one study.
iv. Topics related to the circulatory system and the field of anatomy are the most prominent areas that make extensive use of Augmented Reality (AR).
v. There are numerous benefits and positive impacts of Augmented Reality (AR) in Biology education, encompassing three domains. The affective domain exhibited the highest percentage, followed by the cognitive and psychomotor domains.
vi. There were eleven challenges identified among the 29 articles studied. This number is significantly smaller when compared to the 70 benefits of Augmented Reality (AR) in Biology.

Reference

Abdullah, N., Baskaran, V. L., Mustafa, Z., Ali, S. R., & Zaini, S. H. (2022). Augmented Reality: The Effect in Students' Achievement, Satisfaction and Interest in Science Education. *International Journal of Learning, Teaching and Educational Research*, *21*(5), 326–350. https://doi.org/10.26803/ijlter.21.5.17

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

Al-Muqbil, N. S. M. (2022). Impact of Teaching a Proposed Unit on Successful Intelligence and Augmented Reality in Biology on Lateral Thinking and Science Fiction among High School Students in Al-Saih City, Saudi Arabia. *Journal of Curriculum and Teaching*, *11*(8), 63–78. https://doi.org/10.5430/jct.v11n8p63

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

Arslan, R., Kofoğlu, M., & Dargut, C. (2020). Development of augmented reality application for biology education. *Journal of Turkish Science Education*, *17*(1), 62–72. https://doi.org/10.36681/tused.2020.13

Avila-Garzon, C., Bacca-Acosta, J., Kinshuk, , Duarte, J., & Betancourt, J. (2021). Augmented Reality in Education: An Overview of Twenty-Five Years of Research. *Contemporary Educational Technology*, *13*(3), ep302. https://doi.org/10.30935/cedtech/10865

Bower, M., Howe, C., McCredie, N., Robinson, A., & Grover, D. (2014). Augmented Reality in education - cases, places and potentials. *Educational Media International*, Vol. 51, pp. 1–15. https://doi.org/10.1080/09523987.2014.889400

Celik, C., Guven, G., & Cakir, N. K. (2020). Integration of mobile augmented reality (Mar) applications into biology laboratory: Anatomic structure of the heart. *Research in Learning Technology*, *28*. https://doi.org/10.25304/rlt.v28.2355

Charrois, T. L. (2015). *Systematic Reviews: What Do You Need to Know to Get Started? 68*(2), 144–148.

Chen, Y. C. (2019). Effect of Mobile Augmented Reality on Learning Performance, Motivation, and Math Anxiety in a Math Course. *Journal of Educational Computing Research*, *57*(7), 1695–1722. https://doi.org/10.1177/0735633119854036

Çimer, A. (2012). What makes biology learning difficult and effective: Students' views. *Educational Research and Reviews*, *7*(3), 61–71. https://doi.org/10.5897/ERR11.205

Damopolii, I., Paiki, F. F., & Nunaki, J. H. (2022). The Development of Comic Book as Marker of Augmented Reality to Raise Students' Critical Thinking. *TEM Journal*, *11*(1), 348–355. https://doi.org/10.18421/TEM111-44

Das, P., Zhu, M., McLaughlin, L., Bilgrami, Z., & Milanaik, R. L. (2017, June 1). Augmented reality video games: New possibilities and implications for children and adolescents. *Multimodal Technologies and Interaction*, Vol. 1. MDPI AG. https://doi.org/10.3390/mti1020008

Dehghani, M., Mohammadhasani, N., Hoseinzade Ghalevandi, M., & Azimi, E. (2023). Applying AR-based infographics to enhance learning of the heart and cardiac cycle in biology class. *Interactive Learning Environments*, *31*(1), 185–200. https://doi.org/10.1080/10494820.2020.1765394

Delgado-Rodríguez, S., Carrascal Domínguez, S., & Garcia-Fandino, R. (2023). Design, Development and Validation of an Educational Methodology Using Immersive Augmented Reality for STEAM Education. *Journal of New Approaches in Educational Research*, *12*(1), 19. https://doi.org/10.7821/naer.2023.1.1250

Erbas, C., & Demirer, V. (2019). The effects of augmented reality on students' academic achievement and motivation in a biology course. *Journal of Computer Assisted Learning*, *35*(3), 450–458. https://doi.org/10.1111/jcal.12350

Erwinsah, R., Aria, M., & Yusup, Y. (2019). Application of augmented reality technology in biological learning. *Journal of Physics: Conference Series*, *1402*(6). IOP Publishing Ltd. https://doi.org/10.1088/1742-6596/1402/6/066090

Ewais, A., Troyer, D. O., Abu Arra, M., & Roma, M. (2019). A Study on Female Students' Attitude Towards the Use of Augmented Reality to Learn Atoms and Molecules Reactions in Palestinian Schools. In *Augmented reality, visual reality, and computer graphic* (pp. 295–309). Italy.

Flemming, K., Booth, A., Garside, R., Tunçalp, Ö., & Noyes, J. (2019). Qualitative evidence synthesis for complex interventions and guideline development: clarification of the purpose, designs and relevant methods. *BMJ Global Health*, *4*(Suppl 1), e000882. https://doi.org/10.1136/bmjgh-2018-000882

Fuchsova, M., & Korenova, L. (2019). Visualisation in basic science and engineering education of future primary school teachers in human biology education using augmented reality. *European Journal of Contemporary Education*, *8*(1), 92–102. https://doi.org/10.13187/ejced.2019.1.92

Gnidovec, T., Žemlja, M., Dolenec, A., & Torkar, G. (2020). Using Augmented Reality and the Structure–Behavior–Function Model to Teach Lower Secondary School Students about the Human Circulatory System. *Journal of Science Education and Technology*, *29*(6), 774–784. https://doi.org/10.1007/s10956-020-09850-8

Gregorcic, T., & Torkar, G. (2022). Using the structure-behavior-function model in conjunction with augmented reality helps students understand the complexity of the circulatory system. *Advances in Physiology Education*, *46*(3), 367–374. https://doi.org/10.1152/ADVAN.00015.2022

Higgins, J. P. T., Altman, D. G., Gøtzsche, P. C., Jüni, P., Moher, D., Oxman, A. D., … Sterne, J. A. C. (2011). The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. *BMJ (Online)*, *343*(7829). https://doi.org/10.1136/bmj.d5928

Hong, Q. N., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., … Pluye, P. (2018). The Mixed Methods Appraisal Tool (MMAT) version 2018 for information professionals and researchers. *Education for Information*, *34*(4), 285–291. https://doi.org/10.3233/EFI-180221

Mustami, K. M., Syamsudduha, S., Ismail, I. M., & Mustami, M. (2019). Validity, practicality, and effectiveness development of biology textbooks integrated with augmented reality on high school students. In *Int. J. Technology Enhanced Learning* (Vol. 11).

Kitchenham, B., & Charters, S. (2007). *Guidelines for performing Systematic Literature Reviews in Software Engineering*. Retrieved from https://www.researchgate.net/publication/302924724

Kozcu Cakir, N., Guven, G., & Celik, C. (2020). Integration of Mobile Augmented Reality (MAR) Applications into the 5E Learning Model in Biology Teaching. *International Journal of Technology in Education*, *4*(1), 93. https://doi.org/10.46328/ijte.82

Lam, M. C., Lim, S. M., & Tan, S. Y. (2023). User Evaluation on a Mobile Augmented Reality Game-based Application as a Learning Tool for Biology. *TEM Journal*, *12*(1), 550–557. https://doi.org/10.18421/TEM121-65

Linares-Espinós, E., Hernández, V., Domínguez-Escrig, J. L., Fernández-Pello, S., Hevia, V., Mayor, J., … Ribal, M. J. (2018, October 1). Methodology of a systematic review. *Actas Urologicas Espanolas*, Vol. 42, pp. 499–506. Elsevier Ltd. https://doi.org/10.1016/j.acuro.2018.01.010

Lo, J. H., Lai, Y. F., & Hsu, T. L. (2021). The study of ar-based learning for natural science inquiry activities in taiwan's elementary school from the perspective of sustainable development. *Sustainability (Switzerland)*, *13*(11). https://doi.org/10.3390/su13116283

Lockwood, C., Munn, Z., & Porritt, K. (2015). Qualitative research synthesis: Methodological guidance for systematic reviewers utilizing meta-aggregation. *International Journal of Evidence-Based Healthcare*, *13*(3), 179–187. https://doi.org/10.1097/XEB.0000000000000062

Maraza-Quispe, B., Alejandro-Oviedo, O. M., Llanos-Talavera, K. S., Choquehuanca-Quispe, W., Choquehuayta-Palomino, S. A., & Caytuiro-Silva, N. E. (2023). Towards the Development of Emotions through the Use of Augmented Reality for the Improvement of Teaching-Learning Processes. *International Journal of Information and Education Technology*, *13*(1), 56–63. https://doi.org/10.18178/ijiet.2023.13.1.1780

Mengist, W., Soromessa, T., & Legese, G. (2020, February 1). Method for conducting systematic literature review and meta-analysis for environmental science research. *Science of the Total Environment*, Vol. 702. Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2019.134581

Shaffril, M. H. A., Samsuddin, S. F., & Abu Samah, A. (2021). The ABC of systematic literature review: the basic methodological guidance for beginners. *Quality and Quantity*, *55*(4), 1319–1346. https://doi.org/10.1007/s11135-020-01059-6

Nachiappan, S., Muthaiah, L., & Suffian, S. (2017). Analisis sikap murid terhadap mata pelajaran Sains di Sekolah Jenis Kebangsaan (Tamil). *Jurnal Pendidikan Sains & Matematik Malaysia*, *7*(2), 85–105.

Nafiati, D. A. (2021). Revisi taksonomi Bloom: Kognitif, afektif, dan psikomotorik. *Humanika*, *21*(2), 151–172. https://doi.org/10.21831/hum.v21i2.29252

Nordin, A., & Ling, H. (2011). *Hubungan Sikap Terhadap Mata Pelajaran Sains Dengan Penguasaan Konsep Asas Sains*.

Nurhayati, Rusdi, & Isfaeni, H. (2022). The Application of Mobile Augmented Reality to Improve Learning Outcomes in Senior High Schools. *International Journal of Information and Education Technology*, *12*(7), 691–695. https://doi.org/10.18178/ijiet.2022.12.7.1672

Omurtak, E., & Zeybek, G. (2022). The Effect of Augmented Reality Applications in Biology Lesson on Academic Achievement and Motivation. *Journal of Education in Science, Environment and Health*. https://doi.org/10.21891/jeseh.1059283

Pace, R., Pluye, P., Bartlett, G., Macaulay, A. C., Salsberg, J., Jagosh, J., & Seller, R. (2012). Testing the reliability and efficiency of the pilot Mixed Methods Appraisal Tool (MMAT) for systematic mixed studies review. *International Journal of Nursing Studies*, *49*(1), 47–53. https://doi.org/10.1016/j.ijnurstu.2011.07.002

Pacheco, M. P., Pereira, S. M., & Rego, I. E. (2021). Seismic preparedness of families with children: Measures and dynamics. *International Journal of Psychology*, *56*(1), 30–39. https://doi.org/10.1002/ijop.12694

Pati, D., & Lorusso, L. N. (2018). How to Write a Systematic Review of the Literature. *Health Environments Research and Design Journal*, *11*(1), 15–30. https://doi.org/10.1177/1937586717747384

Petrov, P. D., & Atanasova, T. V. (2020). The Effect of augmented reality on students' learning performance in stem education. *Information (Switzerland)*, *11*(4). https://doi.org/10.3390/INFO11040209

Phang, F. A., Abu, M. S., Bilal Ali, M., & Salleh, S. (2014). *Sains Humanika*. *2*(4), 63–71. Retrieved from www.sainshumanika.utm.my

Ramli, R. Z., Sahari, N., Noor, S. F. M., Noor, M. M., Majid, N. A. A., Dahlan, H. A., & Wahab, A. N. A. (2022). Assessing Usability of Learning Experience Prototype. *International Journal of Emerging Technologies in Learning*, *17*(9), 20–36. https://doi.org/10.3991/ijet.v17i09.29955

Robinson, P., & Lowe, J. (2015). Literature reviews vs systematic reviews. *Australian and New Zealand Journal of Public Health*, Vol. 39, p. 103. Wiley-Blackwell. https://doi.org/10.1111/1753-6405.12393

Sarnat, E. M., Hita Garcia, F., Dudley, K., Liu, C., Fischer, G., & Economo, E. P. (2019). Ready Species One: Exploring the Use of Augmented Reality to Enhance Systematic Biology with a Revision of Fijian Strumigenys (Hymenoptera: Formicidae). *Insect Systematics and Diversity*, *3*(5), 1–43. https://doi.org/10.1093/isd/ixz005

Selvi, M., & Yakisan, mehmet. (2004). *Misconceptions about enzymes in university students*.

Serdar Yıldırım, F. (2021). Effectiveness of augmented reality implementation methods in teaching Science to middle school students. *International Journal of Curriculum and Instruction*, *13*(2), 1024–1038.

Shanks, J. D., Izumi, B., Sun, C., Martin, A., & Shanks, C. B. (2017). Teaching undergraduate students to visualize and communicate Public Health data with infographics. *Frontiers in Public Health*, *5*(NOV). https://doi.org/10.3389/fpubh.2017.00315

Sivri, Ş. N., & Eroglu, E. (2022). The Impact of Using Model and Augmented Reality Technology on Students' Science Achievement, Motivation, and Interest Levels. *International Journal of Contemporary Educational Research*. https://doi.org/10.33200/ijcer.1123204

Sırakaya, M., & Sırakaya, D. A. (2022). A case study: what attracts teachers to augmented reality. *Participatory Educational Research*, *9*(6), 192–205. https://doi.org/10.17275/per.22.135.9.6

Sontay, Gökhan, & Karamustafaoglu, O. (2021). Science teaching with augmented reality applications: students views about "Systems in our body" unit*. *Malaysian Online Journal of Educational Technology*, *9*(3), 13–23. https://doi.org/10.52380/mojet.2021.9.3.218

Sontay, Gokhan, & Karamustafaoğlu, O. (2021). Students' Views on the use of Augmented Reality Technology in Teaching Science. *European Journal of Educational Sciences*, *8*(4), 1–14. https://doi.org/10.19044/ejes.v8no4a1

Stojšić, I., Ostojić, N., & Stanisavljević, J. (2022). Students' Acceptance of Mobile Augmented Reality Applications in Primary and Secondary Biology Education. *International Journal* *of Cognitive Research in Science, Engineering and Education*, *10*(3), 129–138. https://doi.org/10.23947/2334-8496-2022-10-3-129-138

Weng, C., Otanga, S., Christianto, S. M., & Chu, R. J. C. (2020a). Enhancing Students' Biology Learning by Using Augmented Reality as a Learning Supplement. *Journal of Educational Computing Research*, *58*(4), 747–770. https://doi.org/10.1177/0735633119884213

Weng, C., Otanga, S., Christianto, S. M., & Chu, R. J. C. (2020b). Enhancing Students' Biology Learning by Using Augmented Reality as a Learning Supplement. *Journal of Educational Computing Research*, *58*(4), 747–770. https://doi.org/10.1177/0735633119884213

Wommer, F. G. B., Sepel, L. M. N., & Loreto, E. L. S. (2021). Insects GO: a gaming activity for entomology teaching in middle school. *Research in Science and Technological Education*. https://doi.org/10.1080/02635143.2021.1921724

Xiao, Y., & Watson, M. (2019, March 1). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research*, Vol. 39, pp. 93–112. SAGE Publications Inc. https://doi.org/10.1177/0739456X17723971

Yang, S. Y., & Tsai, C. H. (2021). Deep motivation or surface strategy: effects of authentic technologies on scientific learning outcomes and study approaches. *Journal of Internet Technology*, *21*(6), 1835–1844. https://doi.org/10.3966/160792642020112106024

Yapici, İ. Ü., & Karakoyun, F. (2021). USING AUGMENTED REALITY IN BIOLOGY TEACHING. *Malaysian Online Journal of Educational Technology*, *9*(3), 40–51. https://doi.org/10.52380/mojet.2021.9.3.286

Yildirim, F. S. (2020). The Effect Of The Augmented Reality Applications In Science Class On Students' Cognitive And Emotional Learning. *Journal of Education in Science, Environment and Health*. https://doi.org/10.21891/jeseh.751023

Ziden, A. A., Ziden, A. A. A., & Ifedayo, A. E. (2022). Effectiveness of Augmented Reality (AR) on Students' Achievement and Motivation in Learning Science. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(4). https://doi.org/10.29333/ejmste/11923