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PAPER

Systematic Review of Augmented Reality Methodologies for High School Courses

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ABSTRACT

Augmented Reality (AR) is an emerging technology that holds vast potential for being used in pedagogy. The underlying technology of AR is becoming cheaper and ubiquitous every day as smartphones and tablets flood our markets. Numerous AR applications have been designed and developed for Android and IOS platforms to teach STEM subjects. The complexity and scope of such applications range from primary education to university education. While AR-based educational applications have been developed in both developed and developing countries, there is still a need for such applications in Kazakhstan. This systematic literature review looked at developed AR applications for teaching STEM subjects to high school children to develop a pathway for developing indigenous AR applications at the same scale. We identified a lack of standardized assessment tools for measuring success of AR studies. The results of the systematic literature suggest that developers from Kazakhstani will need to focus on reducing techno stress on children. Otherwise, the intended results may not be achieved as stress is counterproductive.

KEYWORDS

augmented reality, PRISMA guideline, systematic review, high school, education, Kazakhstan

1 INTRODUCTION

Middle school and high school play a crucial role in laying the foundation of scientific knowledge which serves as the basis for future careers in science-related subjects [1]. Unfortunately, many students tend to lose interest and motivation to study science during this period [2]. This decline in motivation can be attributed to various factors, including teaching methods, the nature of the topics, and lack of resources [3]. The tangible reasons i.e., teaching methodology, nature of the topic, and lack of resources can be tackled with the latest technology at our disposal. Improving the teaching style by making it more interesting, engaging, and

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learner-centric can greatly improve the students' learning ability [4]. Although textbooks play a crucial role in the learning process, they are cumbersome and lack contextual and inquiry-based learning opportunities [5]. Therefore, supplementing textbooks with interactive course material can enhance the teaching methodology of science teachers [6]. By incorporating mobile applications that utilize visualization, gamification, and problem-solving during classes, there is potential to increase student interest in STEM courses [7], [8].

Augmented Reality is a promising technology in this regard, and it has been explored by several researchers in studies conducted on various subjects [6], [9]–[13]. AR encompasses a wide spectrum of technologies that make use of images, videos, text, and computer-generated images (CGI) to project a virtual environment onto users' real world [14], [15]. This is achieved by seamlessly blending the elements of the two worlds in a computer simulated image that updates the virtual environment in real-time [16]–[18]. AR helps in understanding concepts and workings of scientific tools by simulating real-world scenarios in a virtual world layered over real world. Such learning is considered as better than real-world learning because AR can augment working principles as the user interacts [19]. Such augmentation is not possible with real world objects, as real-world equipment only demonstrates its working without showing the underlying principle. AR applications have the capacity to attach additional multimedia files with interactive objects that can be opened and viewed in real-time [11]. Multimedia files in AR can be instrumental in teaching unobservable concepts, demonstrating lab safety, and objectifying abstract concepts [20]. AR can utilize both 2D and 3D images to present detailed visualization of objects and the interactive nature of AR allows for user engagement and improved spatial ability [21], [22]. Subjects such as geometry, maths, chemistry, mechanics, anatomy, and astronomy require acute spatial awareness [23]–[26].

Augmented Reality has demonstrated its potential in enhancing long-term memory retention. Research conducted by Vincenzi *et al.* showed that content received through AR was better retained by students until much later compared to content received through video or paper [27]. This aspect of AR could be beneficial for students in building a repository of scientific facts and principles that are essential for examinations, laboratory work, and real-life applications. The immersive and interactive nature of AR provides a hands-on-experience, which can significantly improve students' motivation and interest in complex subjects [28]. Previous research shows that despite the novelty of AR systems, students prefer to learn through AR when given the choice. Students are also more likely to repeat the AR learning experiences and feel higher satisfaction [29]. A study conducted in Kazakhstan also showed an increase in students' attentiveness, interest, and creative thinking when taught a complex subject using AR technology [30]. Due to these reasons, researchers believe that AR will soon be adopted as a formal learning technology [31].

While early implementations of AR technology required specialized equipment to create 3D virtual environments, recent advancements have made it possible to use multimedia devices such as TVs, computers, tablets, and smartphones to create AR experiences [32]. The portability and accessibility of smartphones, in particular, make them ideal for creating AR textbook supplementary materials. However, despite the potential benefits of AR for improving science education in middle and high schools, there is a lack of understanding regarding the most effective methodologies for implementing AR in the classroom. While previous studies have demonstrated the benefits of AR for enhancing long-term memory retention, motivation, and interest in complex subjects, further research is needed to design and implement AR-based teaching materials. By addressing this research gap, we can better understand how AR can be leveraged to improve science education during the crucial middle and high school years and potentially reverse the decline in student interest and motivation in STEM subjects. This systematic review aims to explore previous research on the use of AR in high school environments and its impact on student learning and motivation, including a prospective study of an AR application designed to teach STEM to high school students in Kazakhstan. Specifically, this study will examine the methodologies used to implement AR for teaching science subjects to secondary and high school students.

2 METHODOLOGY

The articles related to AR applications in high school education for teaching science were retrieved from two databases. SCOPUS and Web of Science (WoS). The databases were searched for articles published in the field between 2013 and 2022. The search queries used for each database are given in Table 1. The search was limited to studies published in the field of education. Citavi and Excel were used to remove duplicates and sort articles. After removing duplicates and systematic reviews 153 articles were screened based on their titles and abstracts. The selection process followed the PRISMA guidelines and is illustrated in Figure 1. Two reviewers independently applied the inclusion and exclusion criteria (Table 2) to the list of articles to avoid publication bias. To limit the scope of the study, conference papers were excluded. The rationale for excluding conference papers is that this study focuses on the high school students and college education, as STEM subjects are typically taught at the high school or college level in Kazakhstan. In Kazakhstan, high school usually comprises grades 7 through 11, and college starts after the completion of grade 9. It is during this time that students start exploring and developing their interests in STEM fields. Therefore, by focusing on high school and college students, this study aims to explore the potential impact of AR technology on student learning and motivation during this critical period of STEM education. Any disagreements were resolved by consulting a third reviewer. A total of 112 articles were eliminated from the study based on the population criteria (less than 3rd grade and more than 10th grade). Only studies with students ranging from 4th to 10th grades were selected for this review. Ultimately, 41 articles were identified as highly relevant to our study. After a thorough examination of the full-texts 13 studies were excluded as they were found to be irrelevant. The data from the selected articles were independently extracted into Excel worksheets by two researchers. All the authors participated in data analysis and data synthesis through discussions and write-ups.

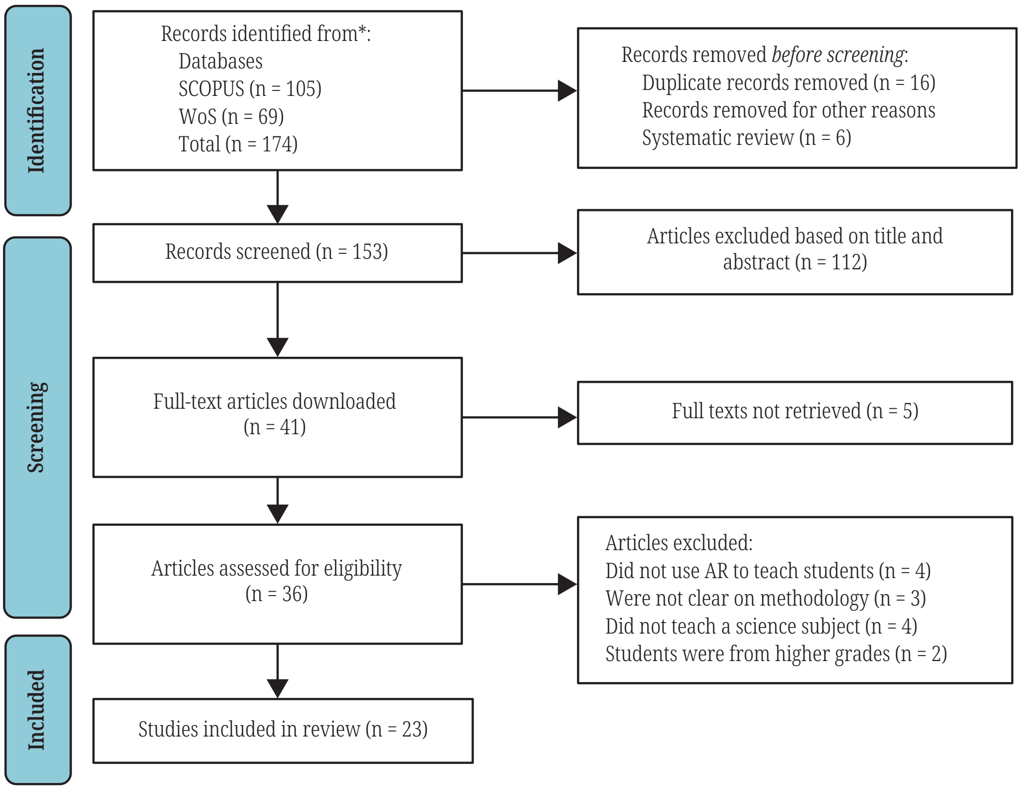

Fig. 1. PRISMA guideline flowchart

Table 1. Search queries used on SCOPUS and WoS

Keywords Used	Database	Date	No. of Articles
(TITLE-ABS-KEY (augmented AND reality) AND TITLE-ABS-KEY (teach* AND science) AND NOT TITLE-ABS-KEY (language)) AND PUBYEAR > 2010 AND PUBYEAR < 2022 AND PUBYEAR > 2010 AND PUBYEAR < 2022 AND (LIMIT-TO (PUBSTAGE, “final”)) AND (LIMIT-TO (DOCTYPE, “ar”)) AND (LIMIT-TO (SRCTYPE, “j”)) AND (EXCLUDE (SUBJAREA, “ENGI”) OR EXCLUDE (SUBJAREA, “HEAL”) OR EXCLUDE (SUBJAREA, “ENER”)) AND (LIMIT-TO (LANGUAGE, “English”))	SCOPUS	25/5	105
Augmented reality (Abstract) and **teach science** (All Fields) and **Education Educational Research** or **Education Scientific Disciplines** (Web of Science Categories) and **Engineering** (Exclude – Research Areas) and **Computer Science** or **Radiology Nuclear Medicine Medical Imaging** (Exclude – Research Areas) and **Review Articles** (Exclude – Document Types) and **Early Access** or **Book Chapters** or **Proceedings Papers** or **Editorial Materials** (Exclude – Document Types) and **Education Educational Research** or **Education Scientific Disciplines** (Web of Science Categories) and **Education Educational Research** or **Education Scientific Disciplines** (Web of Science Categories) and **2021** or **2020** or **2019** or **2018** or **2017** or **2016** or **2015** or **2014** or **2012** (Publication Years) and **Social Sciences Citation Index (SSCI)** (Web of Science Index))	WoS	25/5	69

Table 2. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Research done in a classroom	university students
high school or college students	engineering students
android apps	ESL
	language learning
	conference papers

3 RESULTS AND DISCUSSION

The number of studies utilizing AR for teaching STEM subjects to high school students has shown an increase over the years. While there were fewer studies prior to 2015, the number of studies steadily increased in the following years, with the highest number of studies published in 2017. The number of studies declined slightly in 2018 and 2019, with three studies published each year. However, despite the impact of COVID-19 on educational institutes worldwide, the second-highest number of studies was published in 2020. The trend in the number of studies published each year is not entirely clear, but the data suggests a sustained interest in the subject. Figure 2 provides a clear illustration of the trends in the number of studies published over the years.

Fig. 2. Selected publications according to year

Table 3. Systematic review results using PRISMA guidelines

Author, Year	Methodology				Remarks	Reference
	Sample Size	Control	Instruments	Assessment Style		
Baran, Yecan et al. 2020	30	No	Questionnaire survey	Subjective assessment	No control group No assessment of academic achievement or learning No "technology adaptation time" provided	[33]
Bressler, Bodzin et al. 2019	202	No	Survey	Subjective assessment	The group efforts rather than individual effort in learning via AR may not provide the exact measure of AR's potential in teaching science No "technology adaptation time" provided	[34]
Cai, Chiang et al. 2020	38	Yes	Researcher-prepared quiz and questionnaire	Pre-test, post-test, and delayed post-test	Got the students acquainted with AR by introducing a pre-experiment AR game to reduce the distraction from newness of technology	[35]
Chang, Hwang 2018	111	Yes	Learning motivation questionnaire, Critical thinking tendency questionnaire	Pre-test, post-test analysis	Only 5 students were from each group for post-activity interview. No "technology adaptation time" provided	[36]
Chen, Chou et al. 2016	71	No	Instructional Materials Motivation Survey (IMMS)	Pre-test, post-test analysis	Both groups learnt with some form of AR. No "technology adaptation time" provided	[37]
Chen, Liu 2020	104	Yes	Post-instructional interviews	Pre-test, post-test, and delayed post-test	Both groups learnt with some form of AR. No "technology adaptation time" provided	[38]
Fidan, Tuncel 2019	91	Yes	Semi-structured interviews	Pre-test, post-test analysis	Two experimental and one control. In table the comparison between control and AR group is included and PBL is excluded. Also systematically reviewed AR studies on physics till 2018 Acquainted the students with AR apps before starting the experiment	[39]
Giasiranis, Sofos 2017	42	Yes	Intermediate Flow questionnaire, final Flow questionnaire	Subjective assessment	No instructions were provided using AR. Familiarity with the underlying technologies may interfere with the true assessment score using AR	[40]
Gnidovec, Zemlja et al. 2020	51	Yes	Technology Acceptance Questionnaire	Pre-test, post-test, and delayed post-test	Students were not given time to familiarize themselves with AR technology even though they had never used the technology before	
Hsiao, Chang et al. 2016	884	Yes	Researcher-prepared questionnaire	Pre-test, post-test analysis	The study had a very complex methodology compared to other studies. Comparing 5 different groups at the same time. No "technology adaptation time" provided	[41]
Huang, Lin 2017	104	Yes	Researcher-prepared questionnaire	Pre-test, post-test analysis	SkyView is an advanced and feature-loaded app. Additional time should have been given to experimental group to familiarise themselves with the working of the app	[42]

Kamarainen, Metcalf et al. 2013	71	No	Interviews and questionnaire	Subjective Assessment	The classes were taught by different teachers. No "technology adaptation time" provided	[43]
Karagozlu, 2018	147	Yes	Semi-structured interview form	Pre-test, post-test analysis	Teachers were given training in using the app before the beginning of the experiment. No "technology adaptation time" provided to students	[44]
Kirikkaya, Başgül 2019	120	Yes	Solar System and Beyond Success Test. (SSBST) Students' Motivation Scale for Science Teaching	Pre-test, post-test analysis	Control group and experimental group belonged to different schools. Therefore, there may be a wide gap in the instructions' value. No "technology adaptation time" provided	[45]
Lin, Chen et al. 2015	76	Yes	Observations and focus group interviews	Pre-test, post-test analysis	No control group was set for lower performing students. No "technology adaptation time" provided	[46]
Önal, Önal 2021	51	Yes	Interview	Pre-test, post-test analysis	Students were trained in using AR technology before the actual experiment using examples similar to the experimental material	[47]
Sahin, Yilmaz 2020	100	Yes	Attitude towards AR Activities Scale	Pre-test, post-test analysis	Students' average grade in the previous science class were taken as the pre-test results. More recent results would be better for the study. No "technology adaptation time" provided.	[11]
Say, Pan 2017	53	Yes	Open-ended interviews	Pre-test, post-test analysis	Control and experimental group taught in different buildings. No "technology adaptation time" provided.	[48]
Tarng, Ou et al. 2013	60	Yes	Researcher-prepared questionnaire survey	Pre-test, post-test analysis	Between group comparison was not done. No "technology adaptation time" provided.	[49]
Toledo-Morales, Sanchez-Garcia 2018	49	Yes	Researcher-prepared questionnaire	Pre-test, post-test analysis	The experimental group had higher grades in pre-test and post-test, the significance of the score difference was not checked. No "technology adaptation time" provided.	[50]
Turan, Atila 2021	3	No	Interviews	Pre-test, post-test analysis	Sample size is extremely small. No "technology adaptation time" provided.	[51]
Wan, Sun et al. 2018	59	Yes	Researcher-prepared questionnaire	Pre-test, post-test, and delayed post-test	There is a lack of information regarding the instructor for each class. No "technology adaptation time" provided.	[52]
Weng, Otanga et al. 2020 – E	68	Yes	Survey	Pre-test, post-test analysis	Sample was not randomized No "technology adaptation time" provided.	[6]

Out of the 23 selected studies, 22 utilized quantitative analysis as their primary methodology of choice (Table 3). Qualitative assessment was also conducted, but it served as a supplementary approach to the quantitative methodology and was not included in the analysis. The study by Baran *et al.* was the only study that employed qualitative analysis [33]. The predominant use of quantitative analysis suggests that researchers dealing with innovative teaching methodologies prefer measurable progress over intuitive progress. Furthermore, a notable advantage of quantitative methodology is its reproducibility and in limited dependence on space and time [53]. This implies that studies conducted across geographical but in similar developing contexts and within a short period of time apart can be objectively compared. Consequently, it becomes easier to validate or challenge the results by different or the same researchers. Another advantage of using quantitative analysis is the ability to generalize results. Further, results obtained from quantitative analysis are easily visualized and interpreted. However, in the context of pedagogy, it is important to consider the ease of use of innovative technologies. The introduction of innovative technology may induce stress in both students and teachers due to the learning curve associated with the newer technology being used for teaching and learning a particular subject [54]. The additional stress can potentially hinder the learning process. Therefore, qualitative data should be given, as much weightage as quantitative data, and it is an area that requires further attention and exploration.

The research methodology employed by the majority of the identified studies was focused on middle school education. The grade breakdown data reveals that the most commonly investigated grade by the researchers was 7th grade (see Figure 3). Out of the 23 studies, 7 studies involved subjects from 7th grade. The lowest grade within K-12 system that was included in the study was grade 4. The bar graph illustrating the distribution of studied grades exhibits a bell-shaped distribution skewed to the left. Only one study utilized a mixed population of grade 7 and grade 8 students. The popularity of grade 7 could be attributed to both the perceived ease of using AR technology and the fact that students at this grade level begin to encounter challenging concepts in STEM subjects. Further, they are at the threshold of learning core concepts in each subject. Grade 7 represents a convergence of some of these core concepts albeit its relative ease.

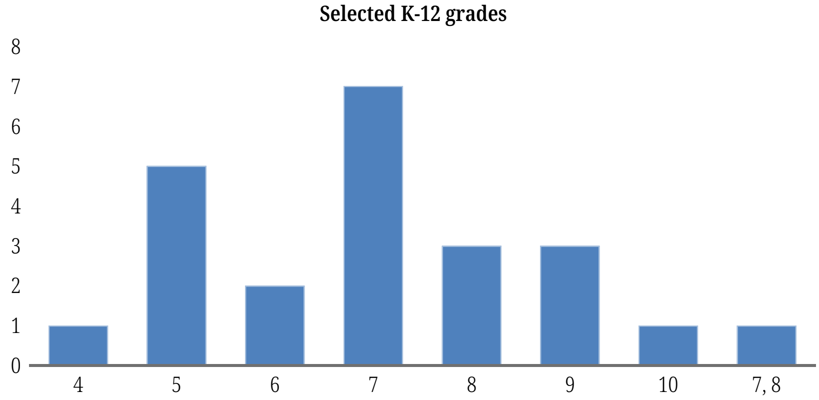

Fig. 3. The frequency of selected grades

Among the studies, the most popular device utilized was tablet, which were used by 10 studies (Figure 4). The second most popular device was smartphones, employed by 6 studies. One study allowed the use of either device. Computers were the least commonly used device. The preference for tablets and smartphones can be attributed to their mobility and the presence of various useful sensors such as gyroscopes and accelerometers. The goal of AR technology is to engage students with the scientific phenomenon in an interactive way, and the use of tablets and smartphones aligns well with this goal. Tablets and smartphones are also quite powerful devices, and their computing power rivals PCs [55]. Hence the combination of their computing capabilities and mobility make these devices highly suitable for teaching with AR technology. The preference for tablets over smartphones may be attributed to the larger screen size of tablets. The larger screen size is perceived to provide a more immersive learning experience.

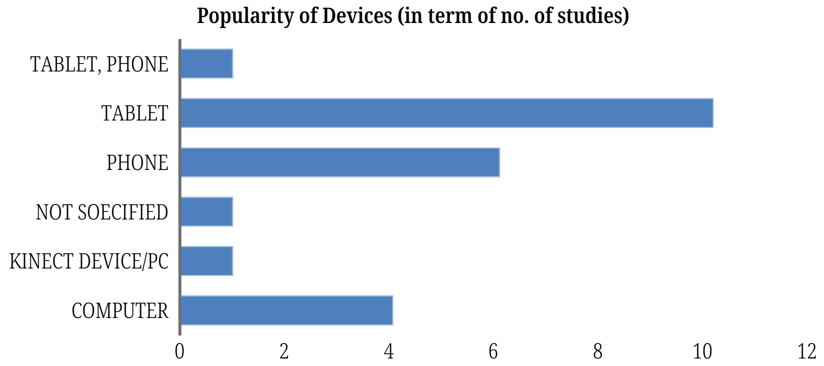

Fig. 4. Frequency of AR devices

There were two prominent geographical hotspots in AR studies, with seven studies originating from Turkey and an equal number of studies from Taiwan (Figure 5). Interestingly, these hotspots emerged even though the literature also identified other developed countries, with the exception of Brunei. This concentration of studies in specific regions raises concerns about generalizability of results to other developed nations.

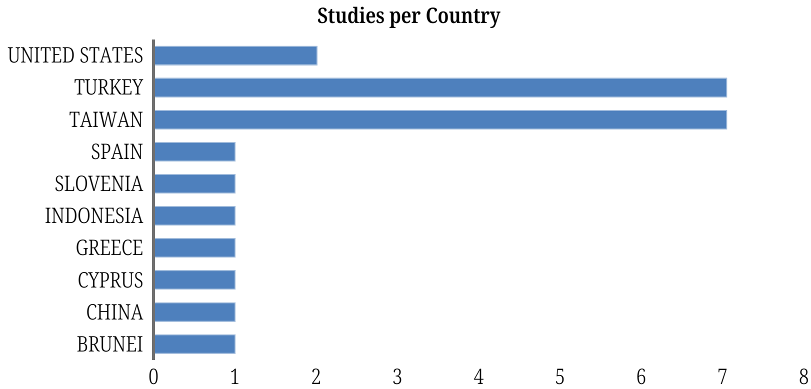

Fig. 5. Studies done in each country

The limited usage of AR in STEM subjects' pedagogy in countries other than Turkey and Taiwan warrants further investigation in a separate study. The current findings show that results obtained from these studies may not be applicable for formulating reliable policies across the rest of the developed world. It is crucial to conduct studies in other developed countries, as their results would be more easily replicable in similar contexts. Further, the exclusive focus on the developed world raises concern regarding the feasibility of implementing AR in the developing world. Developing nations are in need of high standard STEM education, however, the cost of AR technology may pose a barrier to research and implementation in these regions. Conducting AR studies in the developing nations would provide be a better assessment of feasibility of the feasibility of implementing AR technology for teaching STEM subjects at school level. Further, there is a noticeable absence of studies on 'AR as a tool for teaching STEM subjects' at school level in Kazakhstan. None of the studies identified in this review met the inclusion criteria for Kazakhstan, as the identified studies focused on the university level. Therefore, there is a significant gap that needs to be addressed.

The methodology employed for selecting the study population exhibited bias towards male population in some studies. The mean female representation in the samples was found to be 43%, which significantly deviates from the average male-to-female population ratio. This disparity can be attributed to the uneven sample selection with respect to gender by certain researchers. For instance, one study had only 33% [33] females in the sample, another study had 32% [11] females, and yet another study included only 21% females [6]. Considering that females have nearly equal representation in high school science subjects, it is important for the study samples to accurately reflect this gender balance [56]. Two of the identified studies belong to Turkey and one from Indonesia. However, the rest of the samples selected in studies conducted in Turkey had either equal or slightly higher representation of females in the study sample. Therefore, these studies fall out of the general trend of sample selection. Population selection is a crucial aspect of the methodology, and it should aim to replicate the real-world scenarios as closely as possible. Therefore, it is suggested that future studies strive to select an even ratio of male to female participants to ensure a more representative sample.

4 CONCLUSION

The primary focus of this literature review was to examine the methodologies used in previous research on the use of AR in pedagogy. Our findings revealed that the majority of the previous studies placed a strong emphasis on quantitative data analysis, while the utilization of qualitative data as the primary source of analysis is extremely low. Although quantitative data allows for the measurement of performance differences, It is important to also prioritize the inclusion of qualitative data in future research to access factors such as techno stress and other subjective experiences. Additional measures such as having the same instructor for the entire study population, to provide a more comprehensive analysis of the impact of AR in pedagogy.

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