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EXPLORING THE EVOLUTION OF AR TECHNOLOGIES: A COMPREHENSIVE REVIEW OF RECENT LITERATURE (2019-2023)

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ABSTRACT

This research is motivated by the need to provide a comprehensive and up-to-date understanding of the state-of-the-art in AR (AR) technologies. The last five years (2019-2023) have witnessed unprecedented growth in AR applications in education fields. Thirty out of 191 published Social Science Citation Index articles from 2019 to 2023 were reviewed with a coding scheme. The findings reveal that the science subject predominates among the various subjects discussed, with 80% of researchers opting to conduct experiments inside the classroom, demonstrating a fourfold preference over those conducted outside. The mobile platform emerges as the most widely discussed platform, capturing the attention of 47% of researchers. Examining the roles of AR, teaching agents hold the highest percentage at 81.3%, followed by motivational agents at 15.6% and peer agents at 3.1%. Furthermore, the role of a teacher as a facilitator stands out as the most prevalent among the various teacher roles discussed. In terms of research methods, experimental and quantitative approaches are prominent, each accounting for 33.3%. The study delves into the user performance aspect, indicating that users demonstrate higher efficiency and quality in designing materials using AR material design systems compared to traditional synthetic systems. Notably, a significant portion of research is conducted in the middle of secondary school settings (33.3%), with a predominant research duration falling between 2 weeks to 1 month (36.7%). In terms of data collection, the pre-test and post-test method prevails, constituting 74.4% of cases. The positive impact of AR implementation is evident in increased understanding, self-efficacy, and favorable attitudes. This abstract provides a concise summary of key trends and findings, contributing valuable insights to the ongoing discourse on AR in education.

Keywords: AR, Teacher Role, Quantitative, Qualitative

INTRODUCTION

AR (AR) is the process of integrating digital information with a user's real-time environment (Hwang et al., 2023; Weng et al., 2020). Unlike Virtual Reality (VR), which creates a completely artificial environment, AR allows users to experience the real world with added digital elements. The primary advantage of AR is its ability to blend digital and three-dimensional components with an individual's perception of the real world(Ciloglu & Ustun, 2023; Ibáñez et al., 2020). AR presents visual elements, sound, and other sensory information

to the user through devices like smartphones or glasses, overlaying the information onto the device to create an interwoven experience where digital information alters the user's perception of the real world (Cai et al., 2021; Christopoulos et al., 2022).

Currently, there are five main types of AR technology:

- Projection-based: This type of AR uses visual markers to create an interactive experience. The most common markers used are two-dimensional images and textbooks, which can be easily replaced or augmented with digital information.
- Recognition-based: Also known as markerless AR, this approach uses object recognition to create a virtual experience. The augmented image replaces the original image either partially or fully.
- Location-based: This type of AR uses GPS coordinates to determine the user's location and provides relevant information about the surrounding environment. It is useful for generating experiences in complex elements that require a specific location.
- Outlining: Outlining-based AR focuses on creating virtual boundaries or outlines of real-world objects, allowing users to visualize and interact with the environment in new ways.
- Superimposition-based: This type of AR uses object recognition to create the virtual experience. The augmented image replaces the original image either partially or fully.

In education, the transformative potential of technology has long been recognized. Over the last five years (2019-2023), AR has emerged as a powerful tool with the capacity to revolutionize the educational landscape (Fidan & Tuncel, 2019; Zimmerman et al., 2023). As the integration of AR into educational practices gains momentum, it becomes imperative to delve into the wealth of knowledge generated during this period, comprehensively reviewing articles that implement AR in educational settings. This review is motivated by a multifaceted rationale that encapsulates the dynamic nature of educational technology and the evolving needs of modern learners.

- Technological Advancements in Education:
  The rapid evolution of technology has redefined traditional pedagogical approaches. AR, with its ability to overlay digital content onto the physical world, presents an innovative avenue for enhancing educational experiences. Understanding how recent technological advancements in AR have been harnessed for educational purposes is essential for educators, researchers, and policymakers alike.
- Pedagogical Innovation and Learning Outcomes:
  The integration of AR in education goes beyond mere technological novelty; it represents a paradigm shift in pedagogy. The literature from 2019 to 2023 likely encapsulates a myriad of AR applications designed to enhance learning outcomes, engage students, and foster critical thinking skills. Examining these implementations allows us to discern effective strategies and best practices for incorporating AR into diverse educational contexts.
- Addressing Educational Challenges:
  Education faces a spectrum of challenges, ranging from accessibility and inclusivity to individualized learning needs. AR can address some of these challenges by providing interactive and personalized learning experiences. A review of recent articles can shed light on how AR has been leveraged to overcome educational barriers and create more equitable learning environments.
- Impact on Student Motivation and Engagement:
  One of the key factors driving the interest in AR within education is its potential to enhance student motivation and engagement. The dynamic and interactive nature of AR content can captivate learners, making the educational process more enjoyable and

meaningful. Investigating recent literature allows us to gauge the real-world impact of AR on student motivation and engagement.

- Future Directions and Educational Policy Implications:
  As AR continues to permeate educational settings, understanding the current state of research is instrumental in shaping future directions. This review aims to identify gaps in knowledge, highlight emerging trends, and inform educational policies to ensure that the integration of AR aligns with broader educational goals and objectives.

This systematical review aims to review the AR articles within the education domain from 2019 to 2023 to harness the full potential of technological advancements for the betterment of education. By synthesizing and analyzing the wealth of knowledge generated during this period, this review seeks to contribute to the ongoing dialogue on the intersection of AR and education, providing insights that will inform future research, instructional practices, and educational policies.

RESEARCH METHOD

In this review paper, we searched for published SSCI articles in the database using search terms such as AR, AR, and learning within 2019 to 2023. This review adopted the four phases of analytical protocol of the PRISMA guidelines including identification, screening, eligibility, and included studies (Moher et al., 2009). The document type was *article*, the category of article was then limited to *education and educational research and education scientific disciplines,* and we selected only *open access articles*. First, we compiled a list with all articles, which matched our search term and category and returned with 191articles.

Two educational technology experts were invited to identify and eliminate irrelevant articles among the 191 articles to meet the purpose of this analysis. To this end, 30 articles successfully met the screening criteria, necessitating them to be composed in English and specifically focused on the application of AR to support learning.

Subsequently, the identified articles underwent additional coding, wherein the coding criteria encompassed the study's primary focus, research location, platform type, participant count, AR application roles, teacher involvement, research methodology, group design format, educational level, intervention duration, and details related to data collection, analysis, and research findings.

RESULT AND DISCUSSION

Article's focus

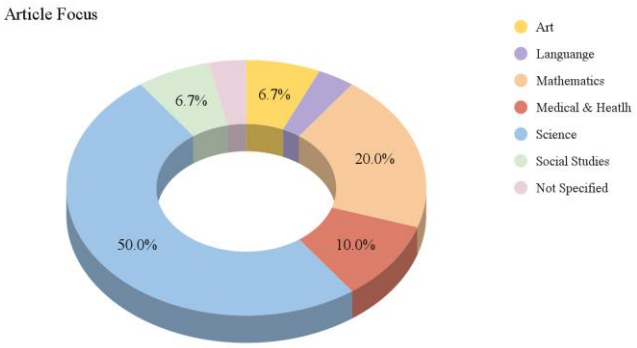
Based on the article's focus pie chart (Table 1), it can be stated that the science subject has the highest number compared to other subjects, constituting 50%. This is followed by the mathematics subject at 20%, with Medical and Health following closely at 10%. Meanwhile, the art and social studies subjects are equal, each accounting for 6.7%. The language category makes up only 3.3%.

However, there is one journal categorized as "not specified," indicating that the journal does not clearly discuss the focus of the research. The journal title is "The Effect of AR Technology on the Performance of University Students." It does not provide enough detailed information to determine the specific field or discipline that is the focus of the research.

The prevalence of science subjects in AR research can be attributed to the potential of AR technology in assisting students with comprehending abstract and complex concepts or unobservable phenomena within the science curriculum. This technology also enhances the explanation of scientific content by superimposing virtual objects over real items or environments in a multidimensional approach (Xu et al., 2022).

Table 1. Article Focus

No.	Subject	Number of Journals
1	Art	2
2	Language	1
3	Mathematics	6
5	Medical & Health	3
6	Science	15
7	Social Studies	2
8	Not specified	1
	Total	**30**



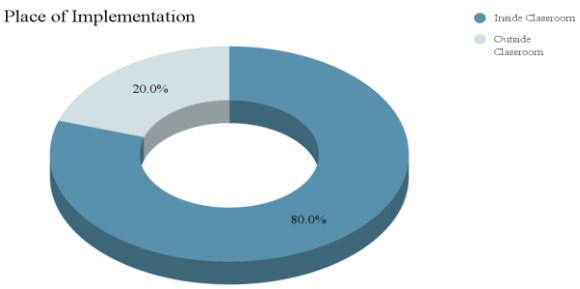
Place of Implementation

Among the 30 journals, 24 conducted research inside the classroom, while the remaining 6 were carried out outside the classroom (Table 2). Stated differently, a total of 80% of researchers opted to conduct experiments or observations and collect data inside the classroom, which is four times more than those conducted outside the classroom, accounting for 20%. One journal reported that the research was conducted outside the classroom, specifically in a museum. The rationale behind this choice was to provide a more immersive and vibrant museum experience. Other researchers were motivated to explore collaborative family involvement in child education, necessitating the experimentation to be conducted outside the classroom.

Conversely, numerous journals delved into the impact of learning technologies, particularly AR, within the classroom. As a result, teachers found themselves compelled to elucidate subjects collaboratively with technology to students, specifically within the classroom.

Table 2. Place of Implementation

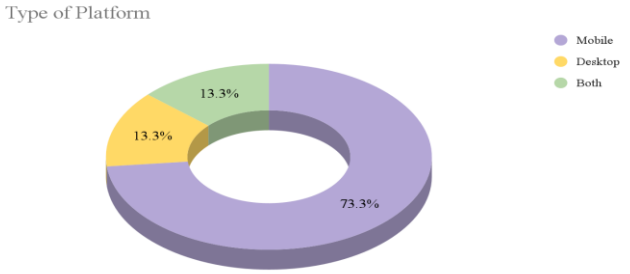
No.	Category	Number of Journals
1	Inside Classroom	24
2	Outside Classroom	6
3	Both (Inside & Outside Classroom)	0
4	Not Specified	0
	Total	**30**



Type of Platform

Table 3. Type of Platform

No	Category	Number of Journals
1	Desktop	4
2	Mobile	22
3	Both (Desktop & Mobile)	4
4	Not Mentioned	0
	Total	**30**



There are two types of platforms being used: desktop and mobile. According to four journals, the platform predominantly used is desktop, constituting 13.3% of the 30 journals (Table 3). The most widely discussed platform is the mobile platform, with 22 out of 30 journals, accounting for 73.3%. Four journals discuss both desktop and mobile platforms used in the experiments. From the data above, it is evident that mobile platforms have the highest percentage, indicating that the majority of experiments discussed in the journals utilized the mobile platform due to its proximity and accessibility to users.

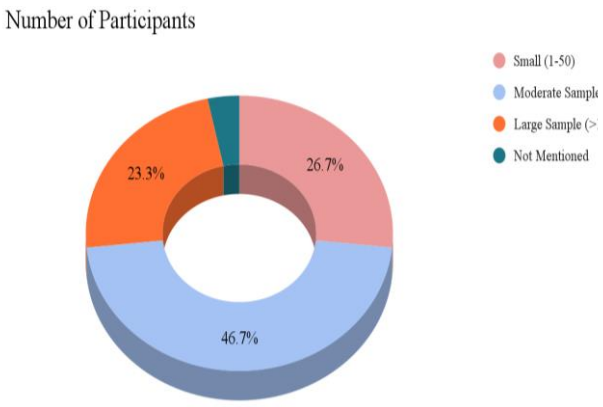
Mobile application platform is a suite of software tools used for designing, creating, and maintaining mobile applications. Mobile devices offer several advantages in education (Goundar, 2011), including accessibility anywhere at any time, user engagement with the mobile application, interactive learning experiences, affordability, and long battery life, making them suitable for a school. Mobile devices have shown improvements in healthcare professionals, enhancing various efficiencies (Ventola, 2014).

As observed, one of the benefits of mobile applications is that users can engage with the application. Consequently, most experiments discussed in the journals aim to increase user engagement with the application.

Number of Participants

Table 4. Number of Participants

No.	Size	Number of Journals
1	Small (1-50)	8
2	Moderate Sample (51-100)	14
3	Large Sample (>100)	7
4.	Not Mentioned	1
	Total	**30**



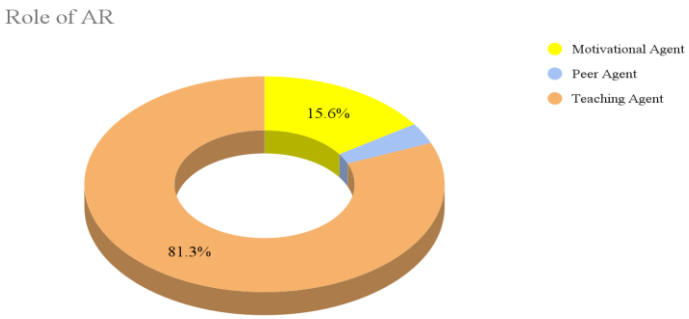
The participants in the 30 journals were diverse, categorized into four groups: a small sample consisting of 1 to 50 participants, a moderate sample consisting of 51 to 100 participants, a large sample with more than 100 participants, and journals not specifying the number of participants. Among the 30 journals, the majority of researchers conducted experiments with 51 to 100 participants, classified as moderate samples (Table 4). The second-highest number involved experiments or data collection within small groups, followed closely by large samples with only a one-journal difference. One journal did not mention the number of participants in their research. In percentage terms, 47% of researchers used moderate samples, while 27% used small samples, 23% used large samples, and 3% did not mention participant numbers.

According to Saunders and Townsend (2016), the number of participants may vary according to the research's purpose. In alignment with this, Onwuegbuzie and Leech (2007) stated that the data's quantity should be sufficient; it should neither be too small nor too large for proper data analysis. Therefore, the number of participants in these journals is designed adequately to meet the research requirements and gather accurate data (Adamson et al., 2007).

Role of AR

Table 5. Role of AR

No.	Category	Number of Journals
1	Motivational Agent	5
2	Peer Agent	1
3	Teachable Agent	0
4	Teaching Agent	26
5	Not Mentioned	0
	Total	**30**



There are 4 roles of AR used in the articles which are motivational agent, peer agent, teaching agent, and teachable agent (Table 5):

1. Teaching agents play the role of human teachers and can present instructions, illustrate examples, ask questions, and provide immediate feedback.
2. Peer agents serve as learning mates for students to encourage peer-to-peer interactions.
3. Motivational agents serve as companions to students and encourage positive behavior and learning.
4. Students can teach teachable agents to facilitate gradual learning. In this approach, the agent acts as a novice and asks students to guide them along a learning route.

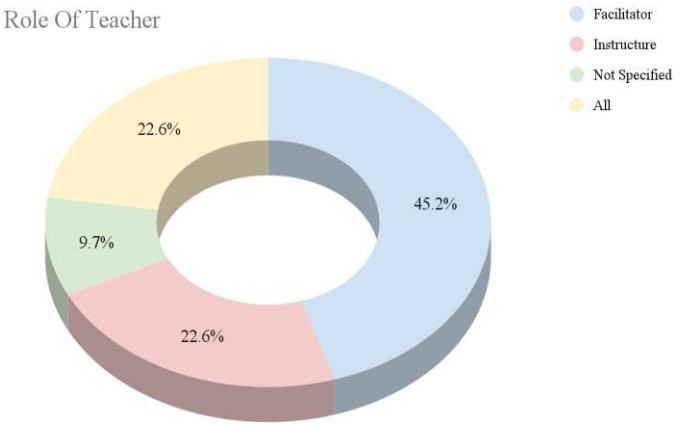
From 30 articles, the highest role of AR is as teaching agent 81,3 % followed by motivational agent 15,6 % and peer agent 3,1 %. None of the articles use AR as a teachable agent. Actually, there are 30 articles discussed, but there are 2 articles that used AR as motivational and teaching agent. From the data above, we can see that teaching agents have the highest percentage because this approach is more knowledgeable than others. In the stead of

actual teachers, teaching agents can give directions, give examples, ask questions and give immediate feedback (Dwivedi et al., 2019; Kulik & Fletcher, 2016).

Role of Teacher

Table 6. Role of Teacher

No.	Category	Number of Journals
1	Assessor	0
2	Facilitator	14
3	Instructor	7
4	All (Assessor + Facilitator + Instructor)	3
4	Not Specified	7
	Total	**31**



Based on the Role of Teacher's pie chart (Table 6), it can be stated that the role of a teacher as a facilitator has the highest number among others. The second rank is shared by the roles of "instructor" and "not specified." Three journals explicitly mentioned the roles of teachers as assessors, instructors, and facilitators. The teachers are described as designers of learning using AR, guiding and motivating students throughout the class, and providing feedback to students, ultimately reporting their performance assessments after utilizing AR in their studies.

Seven journals fall under the category of "not specified," signifying that these journals do not clearly discuss the role of the teacher or that some research wasn't conducted in a school setting. The role of the teacher as a facilitator is the most frequently found in the journals we reviewed. A facilitator of learning is a teacher who promotes assistance, guidance, and ensures support to the students in their learning process. In the 21st century, the learning process must be based on student-centered learning (Ujlakyné Szucs, 2009). According to Johnson and McElroy (2010), teachers no longer function as lecturers or, in our terms, dictators, but as facilitators of learning. For example, students learn by doing, and teachers act as coaches, assisting their students when necessary. Students learn to use inquiry methods and collaborate with others.

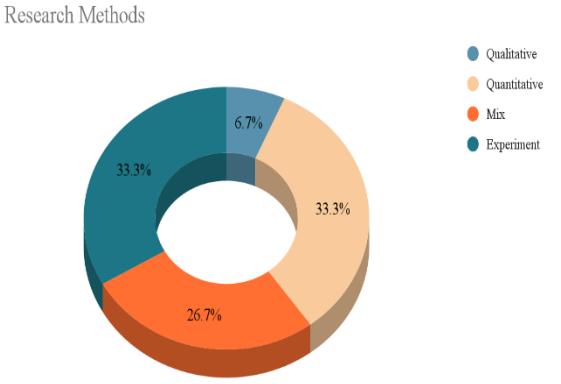
Times have changed, and teachers should be aware of the demands of the 21st century. Nowadays, students do not lack information; they can browse the internet, access 24-hour cable news, use mobile phones for instant access to excessive amounts of information, and utilize advanced technology such as AR. This implies that teachers no longer function as the sole source of information for students, as in teacher-centered learning.

Research Method

Table 7. Research Method

No.	Category	Number of

		Journals
1	Qualitative	2
2	Quantitative	10
3	Mixed (Qualitative & Quantitative)	8
4	Experiment	10
Total		**30**

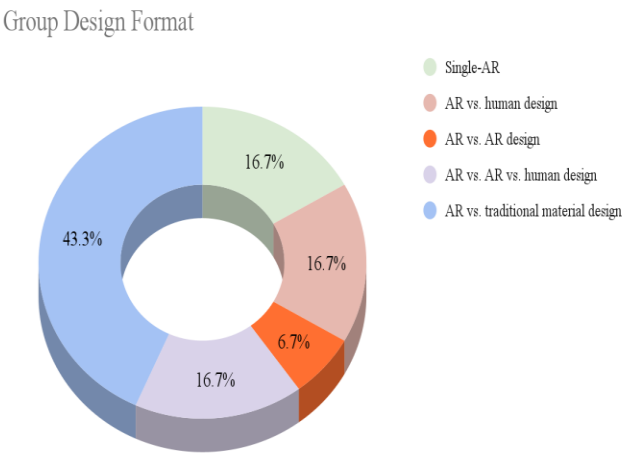


The tactics, procedures, or techniques used in the gathering of data or evidence for analysis in an effort to find new knowledge or develop a deeper comprehension of a subject are known as research methods. Based on the given percentages (Table 7), the research method used in these articles was predominantly experimental (33,3%) and quantitative (33.3%), followed by Mixed quantitative and qualitative (26.7%) and qualitative (6.7%). The choice of research method depends on the nature of the research question, the type of data needed and the resources available to the researchers. An experimental research design helps researchers execute their research objectives with more clarity and transparency.

Group Design Format

Table 8. Group Design Format

No.	Category	Number of Journals
1	Single-AR	5
2	AR vs. human design	7
3	AR vs. AR design	4
4	AR vs. AR vs. human design	0
5	AR vs. traditional material design	14
Total		**30**



From the Table 8, it might represent some kind of design format. Each category seems to indicate the preference or effectiveness of a particular design format approach. The table appears to contain assessments for different design formats, particularly related to AR and traditional material design.
Here's the breakdown of the meaning for each entry:

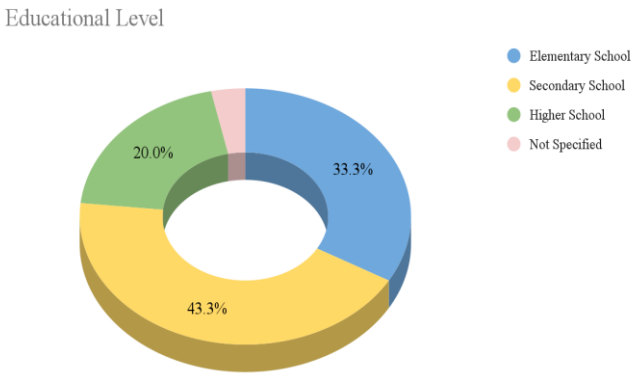
1. Single-AR = 5, may indicate a preference or effectiveness of a design involving the use of AR.
2. AR vs. human design = 7, it might suggest a preference or effectiveness of a design involving AR compared to a design involving humans.
3. AR vs. AR design = 4, could reflect a comparison between two different AR designs.
4. AR vs. traditional material design = 14, may indicate a preference or effectiveness of a design involving AR compared to a traditional design.

The use of AR in material design offers several advantages over traditional material design systems. According to a study, users perform better in terms of efficiency and quality of designed materials in AR material design systems compared to traditional synthetic systems. AR is supplementing or replacing traditional manuals and training methods at an ever-faster pace.

Educational Level

Table 9. Educational Level

No.	Category	Number of Journals
1	Preschool	0
2	Elementary School	10
3	Secondary School	13
4	Higher Education	6
5	Not Specified	1
	Total	**30**



Based on the educational level pie chart (Table 9), it can be stated that most of the research is done in the middle of secondary school by 33,3% (13 journals). Followed by elementary school by 25,6% (10 journals), higher education by 15,4% (6 journals), and not specified by 3,3%. There is no AR research in kindergarten.

Secondary school students are at an age where they are beginning to develop their critical thinking skills and problem-solving abilities. This makes them ideal candidates for research projects that involve complex technology like AR. Many secondary school students are interested in technology and are eager to learn about new innovations. This makes them highly motivated to participate in AR research projects. Students in elementary and middle school have difficulty understanding complex abstract concepts. For example, the abstractness of basic astronomy concepts prevents students from understanding the material and negatively affects their attitudes toward the classes. In order to overcome these difficulties, visuals in the classroom should be used.

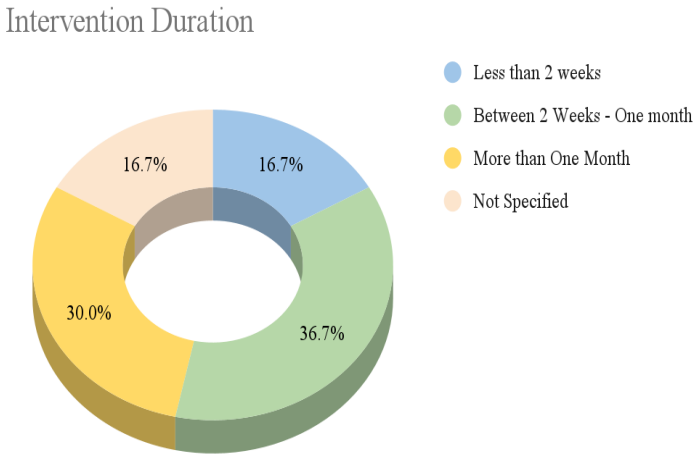
Intervention Duration

Based on the intervention duration pie chart (Table 10), it can be stated that the duration of most research is between 2 weeks to 1 month with a percentage of 36,7% (11 journals). The research that takes more than 1 month is 30% (9 journals). Meanwhile, the research that took less than 2 weeks and not specified has 16,7% (5 journals).

The intervention duration in AR research can vary depending on the specific study and the targeted outcomes. Factors such as the research question, the population being studied, and the specific interventions being tested can all influence the duration of the intervention.

Table 10. Intervention Duration

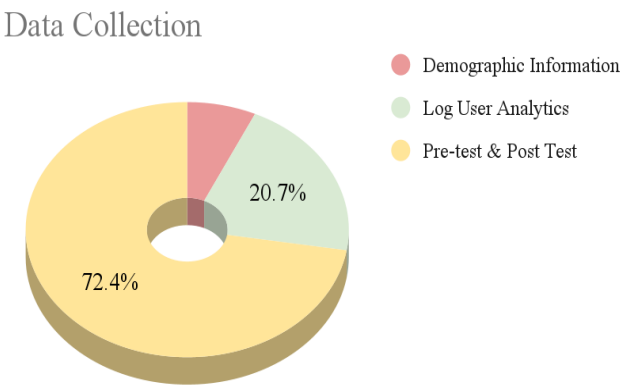
No.	Category	Number of Journals
1	Less than 2 Weeks	5
2	Between 2 Weeks - One Month	11
3	More than One Month	9
5	Not Specified	5
	Total	**30**



Data Collection

Table 11. Data Collection

No.	Category	Number of Journals
1	Demographic Information	2
2	Log User Analytics	6
3	Pre-test & Post Test	22
	Total	**30**

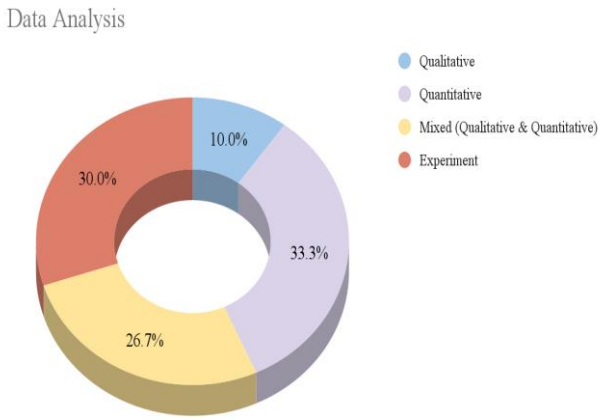


Based on the data collection pie chart (Table 11), it can be stated that most data collection is held with pre-test & pro-test by 74,4%. Followed by log users by 20,7%, and 6,9% demographic. Pre- and post-testing has the advantage of comparing results before and after an intervention, which can assist in determining how the program affected changes in participants' stated attitudes, knowledge, and behaviors. The potential for participants to recall or learn from the pre-test, however, is a serious drawback of this design, particularly if there is a short interval between the pre- and post-tests.

Data Analysis

Table 12. Data Analysis

No.	Category	Number of Journals
1	Qualitative	3
2	Quantitative	10
3	Mixed (Qualitative & Quantitative)	8
4	Experiment	9
	Total	**30**

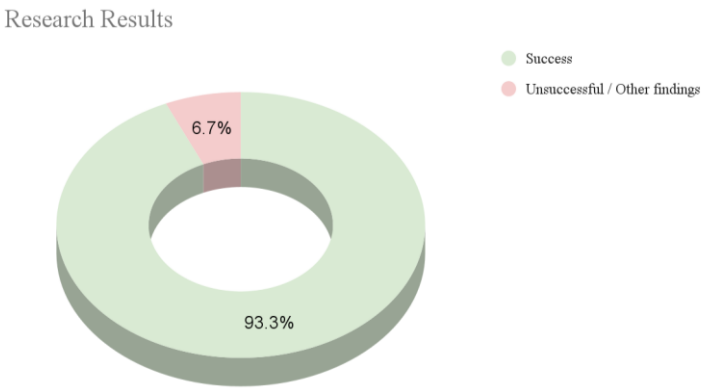


Based on the pie chart (Table 12), researchers analyze research data mostly using quantitative methods. Quantitative is the process of collecting numerical data that can be sorted, measured, or categorized through statistical analysis. This method facilitates the identification of patterns or relationships and enables the formulation of generalizations. This type of research is useful for finding out how much, how many, how often, or to what extent. But overall there is no high percentage gap with other types of data analysis except qualitative research. The researcher used T-test to compare several groups to get the data of the research results**.**

Research Results

Table 13. Research Results

No.	Results	Number of Journals
1	Success	28
2	Unsuccessful/Other findings	2
	Total	**30**



In general, 30 studies related to the use of AR provided positive results in increasing understanding, self-efficacy and attitudes (Table 13). AR can support learning because it can construct knowledge through active, independent and practical supportive learning, but there were 2 studies that showed insignificant results in increasing learning motivation. Failure in implementing AR can be caused by the high level of technological complexity which can discourage participants. Thus, the teacher's role as a facilitator is still needed in learning that uses AR.

There are other findings related to gender which have a small influence on technology use. Several references state that gender differences can influence the use of technology due to unequal access.

CONCLUSION

From 30 research articles on AR, it can be concluded that there are two challenges in AR research. The first challenge is from the technical side. There are various things that can influence research, including: device requirements (RAM, Memory, Camera, Processor), internet network, application stability. The second challenge is from the pedagogical side, which can be in the form of learning instructions, the role of the teacher, the role of students and learning conditions. Meanwhile, challenges related to the validity of research revolve around the number of respondents and the research time being too short.

Another challenge that may arise is related to teachers' and students' perceptions of learning using AR. In some schools where the level of mastery of technology is low, it may cause difficulties and stress in the learning process using AR. So, students can be demotivated in learning. Apart from that, most AR is still used as a means to display material in a more interesting way (projection based) while there is not much use of other AR models, such as Superimposition-based. Apart from that, the development of AR still revolves around its role as a teaching agent. AR is rarely used as a peer agent and motivational agent, let alone as a teachable agent.

Therefore, based on the results of the analysis carried out, several things are proposed as future studies, including:

1. Combining AR (AR) and AI (artificial intelligence) to create more realistic, engaging and personalized AR applications that can adapt to users and environments. AI can be used to recognize objects, faces, gestures, or scenes in the real world and offer related information or feedback to users. So, the role of AR is not only as a teaching agent, but can also be used as a peer agent, motivational agent and teachable agent.
2. Developing AR not only in science subjects, but also in other subjects. So that learning becomes more engaging and meaningful.
3. Developing learning using AR not only on one type of AR (Projection-based) but also on 4 other types (recognition-based, location based, outlining and superimposition-based).
4. AR research can be carried out in contrast to two regions that have a gap in use of technology. So that the effects can be known more completely.

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