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Augmented Reality in Learning Settings: A Systematic Analysis of its Benefits and Avenues for Future Studies

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Abstract:

Despite its increasing use in various settings, Augmented Reality (AR) technology is still often considered experimental, partly due to a lack of clear understanding of the benefits of using AR. This study systematically reviews research on the use of AR in learning settings. Our analysis of 93 relevant articles offers 21 benefits related to the learning gains and outcomes of using AR. Our study shows that the positive effects of using AR on learners' motivation and joy have been well-studied, whereas the effects on independent learning, concentration, spontaneous learning, critical thinking, and practical skills have not yet been examined in detail. Beyond classifying and discussing the benefits of using AR in learning settings, we elaborate avenues for future studies. We specifically point to the importance of conducting long-term studies to determine the value of using AR in learning beyond the initial novelty and exploring the integration of AR with other technologies.

Keywords: Augmented Reality (AR), Trends of AR, Learning, Education, Systematic Literature Review, Information Systems (IS).

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1 Introduction

Augmented Reality (AR) allows individuals to see the real world with virtual objects overlaid upon, or composited with, their real environment (Azuma, 1997). Virtual objects are computer-generated virtual imagery information that exists in nature or effect but not formally or actually (Milgram & Kishino, 1994).

Over the last couple of years, AR applications have been introduced into many learning scenarios to offer an innovative educational method for helping learners advance critical capacity and a greater understanding of underlying concepts (Bower et al., 2014; Sural, 2018). Learners often need to understand complex or abstract notions, such as three-dimensional models and audiovisual items (Liarokapis & Anderson, 2010). Augmented Reality (AR) can address these needs and play an essential role in providing learners with a virtual overlay of the real world (Bower et al., 2014), thus enhancing learning (Akçayır & Akçayır, 2017) and giving enjoyable prospects to practice (Bressler & Bodzin, 2013). AR can entice and motivate learners by discovering and monitoring resources from diverse perspectives (Lee, 2012). Since using AR offers a multitude of potentials for learning settings, it can be expected to have a more efficient effect through broader user adoption (Lee, 2012).

AR-based applications for learning settings are becoming increasingly available, with even low-cost smartphones supporting AR content visualization (Booton et al., 2021; Pedaste et al., 2020). Although the number of downloads of AR applications in educational settings exceeds millions, many academic studies on the use of AR in learning settings are carried out as experiments with large effect sizes with a focus on specific effects (Kljun et al., 2020). Many existing studies present limited or fragmented evidence, leaving educators uncertain about why AR should be implemented in their teaching practices (Kerawalla et al., 2006; Wu et al., 2013). Although these studies have identified several benefits associated with the use of AR in learning settings (Chu et al., 2019; Nadeem et al., 2020), there is currently no comprehensive and coherent classification of these benefits. Thus, there is a need for an overview that can contribute to a better understanding of the overall role of the AR artefact in education and assist educators in making informed decisions about their implementation in specific educational scenarios (Diegmann et al., 2015).

Our study provides a structured literature review of the benefits of using AR in learning settings. We consolidate evidence from 93 articles and classify them into six types of learning, building on Fink's taxonomy of significant learning (Fink, 2013). Beyond previous research focusing on some chosen benefits of using AR in specific learning settings, our study provides a comprehensive overview of all the benefits of using AR, which allows us to identify well-established categories and those that warrant further research. Highlighting well-established beneficial areas and areas that seem promising but have not been studied in detail yet allows us to indicate opportunities for future research. Next, this study identifies where and how AR is applicable when designing a learning-centered system by organizing validated benefits of using AR in a comprehensive taxonomy. The classification provides crucial suggestions for practitioners on decisions related to implementing AR as a learning tool.

The remainder of this article is organized as follows. Section 2 provides the context for our study and details its purpose. Section 3 gives an overview of the methodology adopted for the study. Section 4 details the survey findings based on descriptive data (years of publication, sample groups, educational level, research methods, data collections, AR types and devices, and limitations) and the benefits of reviewed papers. Before presenting conclusions, section 5 concludes the critical findings from the review, discusses the related scientific and practical implications, and indicates potential future research.

2 Background

In the 1960s, Ivan Sutherland (1968) created a prototype that enabled viewing 3D graphics employing holographic projection. During the 70s and 80s, research organizations, NASA, the aviation industry, and other industry centers advance wearable devices, including digital displays and 3D graphics with AR. It was not until the early 1990s that Caudell and Mizell (1992) coined the term “augmented reality” in aviation. They developed an experimental AR system to help workers wiring harnesses. Since the 1990s, attention to AR, virtual reality, 3D technology, and mobile technology has increased in computer science (Azuma et al., 2001; Van Krevelen & Poelman, 2010).

A plethora of studies in computer science and learning utilize AR to support beneficial aspects such as learning gain (Chu et al., 2019; Conley et al., 2020; Fonseca et al., 2014; Nadeem et al., 2020) and motivation (Chu et al., 2019; Fonseca et al., 2014; Koo et al., 2019; Moorhouse et al., 2019; Nadeem et al., 2020; Tobar-Muñoz et al., 2017). AR offers the possibility of learner participation (Cai et al., 2020; Lu & Liu, 2015; Sáez-López et al., 2020) through collaborative learning areas using interactive 3D content in learning environments (Chen et al., 2020; Küçük et al., 2016; Tobar-Muñoz et al., 2017). Compared to traditional teaching approaches, AR offers more interesting (Abdusselam & Karal, 2020; Hung et al., 2017; Moorhouse et al., 2019; Sáez-López et al., 2020) and engaging activities (Abdusselam & Karal, 2020; Lorusso et al., 2018; Pombo & Marques, 2019) and also seems to influence positively on learner's intentions to participate in learning subjects (Huang & Liaw, 2014). Within AR settings, the augmentation of learning content in real-world situations can support students in creating abstract content and improving their confidence (Abdusselam & Karal, 2020; Al-Imamy, 2019; Chin et al., 2019; Cubillo et al., 2015).

The above discussion shows that while AR research in different learning areas has incredibly advanced, the usage of AR is still far from widespread in education (Silva et al., 2019). In addition, "further research is needed to identify the effectiveness and advantages of AR applications for addressing the special needs of students" (Bacca Acosta et al., 2014) since the capability of AR in learning applications is just now being investigated (Chen & Tsai, 2012). Then, due to the higher availability of head-mounted displays for AR (Madeira et al., 2021) and mobile technology (Suhail, 2019), it is crucial to examine previous research (Davies et al., 2010) to identify the current insights into the benefits of AR in learning settings.

Palmarini, Erkoyuncu, Roy, and Torabmostaedi (2018) also point out the necessity for associating AR technologies and their applications more systematically. Consequently, this systematic review aims to enhance the literature by identifying the benefits of using AR in learning settings and providing directions for future research.

3 Methodology

This study conducted a systematic literature review (SLR) of all studies on the advantages and benefits of AR in learning. We followed the protocol by Kitchenham et al. (2009). We used Fink's (2013) taxonomy of significant learning to classify the benefits. This study is an extended version of a systematic literature review (SLR) on the advantages and benefits of AR in learning settings published in (Mohammadhossein et al., 2022). We employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist to guarantee a sufficient standard design.

3.1 Search Methods

To discover relevant papers, we used the ISI Web of Science. We conducted a database search from January 2012 to December 2021. The inclusion timespan is based on the NMC Horizon reports (Johnson et al., 2012), which predicted that AR technology would be widespread in K-12 education within 4–5 years after 2011. Two researchers discussed keywords and synonyms. A third researcher reviewed the method to reduce the likelihood of biases or unintentional errors. The following search string was used: "Augmented reality" AND ("train" OR "learn" OR "educate").

3.2 Search Outcomes

The ISI Web of Science keyword research resulted in thousand two hundred and ten (n = 1210) articles. They were downloaded as an Excel sheet and checked to ensure no duplicated or irrelevant articles were added to the database. Forty-three (n = 43) duplicates were detected. After removing the duplicates, 1167 papers were screened according to the criteria outlined in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion criteria	Exclusion criteria
Published between January 2012 and December 2021.	Studies outside these dates or times.
The article must involve AR as a primary component.	Studies about VR and MR did not focus on AR.
Studies relating specifically to the formal education context, training, and learning outcomes.	Papers based on weak analysis, books, online sites, and grey literature (reports, magazines, etc.).
Academic papers were available in full text.	Papers without any beneficial aspect for learning or training.

The screening procedure rejected five hundred and ninety-eight (n = 598) research papers based on Table 1 exclusion and inclusion criteria unrelated to our research subject. The full text was retrieved to review relevant and eligible articles. The review carefully set the inclusion criteria to ensure an effective selection process. Other publication formats were excluded to safeguard the quality and effectiveness of the review. Further research papers (n = 144) were excluded for various other reasons (e.g., they were magazine articles and or reports). Subsequently, the remaining articles (n = 425) were read carefully. As a result, an additional three hundred (n = 332) papers were excluded, as they were unrelated to the research questions, of low quality, or not substantial for this study. Based on the PRISMA statement, Figure 1 describes the methodology used to conduct this systematic review, including the reasons for excluding full-text articles. PRISMA is a “preferred reporting item for systematic literature review and meta-analysis” (Moher et al., 2009).

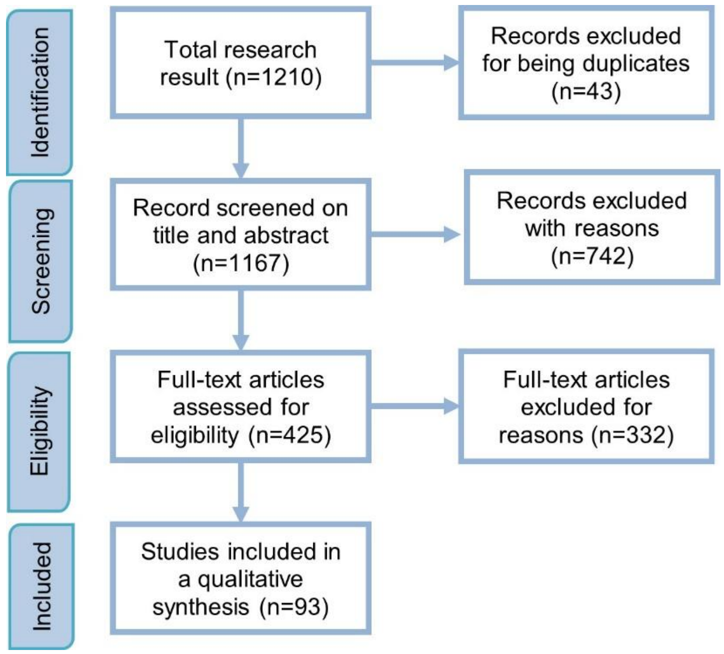

Figure 1. PRISMA Flow Diagram Describing the Selection Process

3.3 Quality Appraisal

A critical appraisal procedure was implemented based on the guidance of Kitchenham (2004) to ensure the quality of the SLR. We assessed the quality of each article with the help of the below quality checklists and ranked them as low, medium, or high (Nidhra et al., 2013).

- QA1: Is the area of the research paper relevant to our research?
- QA2: Do the research topics include the benefits and limitations of AR study in learning?
- QA3: Are there accurate details on the research methodology?
- QA4: Are the results of the research relevant to our study?
- QA5: Is the study approach validated?

Pre-defined answers were settled to each question – if it met the quality criterion (weight of 1), partially met the quality criterion (weight of 0.5), or did not meet the quality criterion (weight of 0). Each study was categorized into a high-quality group for an overall score above 3 and a low-quality group for an overall score below 1. Any overall score between 3 and 1 was categorized in the medium-quality group. According to the quality criteria, 45 articles were classified as high-quality studies, 48 were of medium quality, and 50 were ignored, while they had low-quality scores. The selected papers were added to an EndNoteX9 bibliography and reference management system, downloaded from the database, archived, and categorized to create a singular Excel sheet to study their systematic characteristics.

3.4 Data Extraction and Analysis

After ensuring the quality assessment criteria, the selected articles were carefully read, and metadata on the studies was extracted. Okoli (2015) states that data extraction is significant and relevant to the research topic. The content of the primary studies was downloaded, carefully reviewed, summarized, and synthesized in a singular Excel sheet. For each chosen study, basic information was obtained for references: authors' names, titles of papers, publication year, and publisher. We extracted data from these articles based on seven key items, including the research purpose, study design (methodology), types of AR technology, types of AR devices used, participant characteristics (such as age and educational level), reported benefits of AR, and reported limitations of AR research.

A content analysis (Berelson, 1952) was conducted to identify the benefits of using AR in learning settings. The technique entails the systematic, replicable compression of a large text into a smaller number of content categories using explicit encoding rules (Berelson, 1952). Analyzing the content of papers and grouping them according to their shared characteristics allows content analysis to identify research trends. Because pre-developed forms can inappropriately orient researchers during coding and can be misleading for the intended goal (Akçayır & Akçayır, 2017), no pre-made template was utilized to assess the benefits.

Tesch's (1990) eight steps were utilized to code the data openly. The eight steps are: (1) get a sense of the entire; (2) select one document and consider its underlying meaning, then jot down your thoughts in the margin; (3) make a list of all topics, group similar topics, and create columns to distinguish between major, unique, and unused topics; (4) code the information; (5) choose the most descriptive terminology for your topics and categorize them; (6) determine the final abbreviation for each classification and alphabetize the codes; (7) gather by final code and conduct preliminary analysis; (8) recode if required.

3.5 Use of Fink's Taxonomy

To encourage and evaluate more lasting and meaningful learning experiences, or significant learning, Fink (2003b) enlarged Bloom's taxonomy (1956) and put equal emphasis on topics outside of content mastery and application. Fink also addressed topics that were left out of Bloom's taxonomy. Although Bloom's taxonomy is well-established and widely used, it primarily focuses on the cognitive domain when compared to Fink's (2013) taxonomy links experiential learning and learner-centered teaching with significant learning experiences (Rodriguez, 2018). According to Fink, certain learning types, including "learning how to learn, leadership and interpersonal skills, ethics, communication skills, character tolerance, and the ability to change," cannot be categorized according to the established taxonomy (2003b). Fink's (2003a) model of substantial learning expands on Bloom's taxonomy while providing a fresh perspective on the planning and assessment of educational activities. Before moving on to the next level, a student should be proficient at any level, according to Bloom (1956). Fink argued that learning is bidirectional rather than hierarchical, as in Bloom's taxonomy, and that improvement in one category aids pupils in improving in every other category. For instructors to concentrate on skills other than course content, Fink, like Bloom, intended to incorporate higher-order learning into his particular taxonomy (Fink, 2003b). Fink's taxonomy provides a model for course design that can be easily applied to new and existing courses (Fink, 2003a, 2003b).

We used Fink's (2013) taxonomy of significant learning to structure and organize the body of knowledge and study the relationships among concepts (Szopinski et al., 2019). It is not easy to keep an overview of various individually mentioned and studied benefits without a coherent categorization. Although we examined various taxonomies, we found that the Fink (2013) taxonomy and how it works seemed most beneficial since it gives us a comprehensive and complete picture of learning. We used and applied this taxonomy in AR, demonstrated how valuable and useful it is, and provided a comprehensive overview of the benefits of using AR in learning settings.

The following list briefly describes each of the six categories of Fink's taxonomy.

- Learning how to learn happens when students' skills support them to become better and more well-organized learners. It comprises learning how to be a better and more active student, to be involved in inquiry and understand more about a specific subject or area, and efficiently become self-directed learners (Manalo, 2006).
- Foundational knowledge includes remembering and understanding information and concepts. These concepts are required for the achievement of more advanced types of learning.
- The application involves learning how to perform and complete intellectual, physical, or social tasks. Critical, creative, and practical thinking are involved in this type of learning.

- Integration includes making relationships between concepts and the different realms of everyday life or any combination. Integration offers intellectual power to learners (Fink, 2013).
- The human dimension relates to students learning something significant about themselves and others. Learning about the human dimension allows students to realize who they are and what they want to become (Manalo, 2006).
- Caring includes altering feelings, interests, or values because of the learning. It includes caring more about something or caring in another way.

4 Findings

4.1 Descriptive Data

Figure 2 shows that the number of research publications among the selected studies has significantly increased since 2012. One likely explanation for this growth is that AR is more broadly available to the general public due to the advances in mobile technology and the rise of mobile device owners. Of the 93 selected studies, only 22 were published between 2012 and 2016, while 71 were published between 2017 and 2021. Interestingly, 42 studies were published in 2020 and 2021, which could imply that a similar level of growth will continue in 2021 and after. According to these results, AR in learning is an emerging topic, and the research on AR in education is in the initial phase (Bacca Acosta et al., 2014; Chen et al., 2017; Wu et al., 2013). As forecasted by Horizon, AR will be a promising technology in overtime (Arvidson et al., 2006).

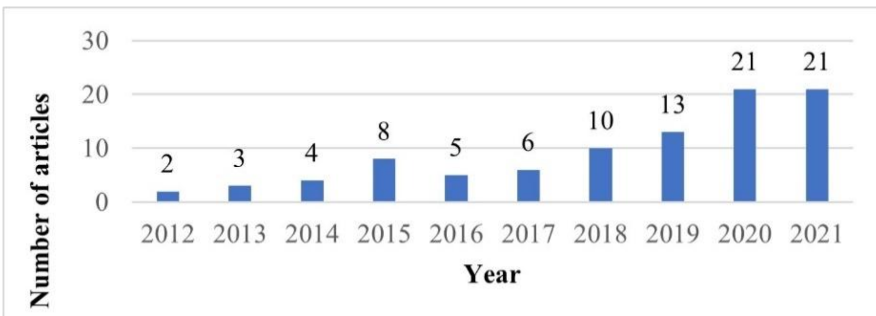

Figure 2. Number of Publications on AR in Education per Year in the Study Period

The most frequent research method is quantitative design, making up 48%, followed by 27% using mixed design, 17% using qualitative design, and 8% of articles not mentioning any specific research method; similarly, in the analysis performed by (Quintero, Baldiris, Rubira, Cerón, and Velez (2019) and Arici, Yildirim, Caliklar, and Yilmaz (2019) between 2013 and 2018, the quantitative method also gained the highest number of whole work. Since the potential of AR technologies in learning is being researched, and researchers aim to identify the effect of AR use on student achievement or in assessing student views on AR, quantitative studies are frequently used (Sırakaya et al., 2020). On the contrary, according to Bacca Acosta et al. (2014), between 2003 and 2013, most of the studies used a mixed evaluation design for AR studies. It might be because there have been more AR studies since 2015, while the Bacca study took place between 2003 and 2013. The most popular research design among quantitative methods was the experimental design, consistent with Sırakaya and Alsancak Sirakaya's (2020) study.

Regarding the "Type of AR," we used the classification of Wojciechowski and Cellary (2013), which introduces three types of AR: marker-based, marker-less, and location-based. Marker-based AR needs the identification or registration of a marker or object to bring up digital information; marker-less AR is based on the recognition of the object's forms; and location-based AR overlays information based on the geographical location of the operator. Marker-based AR was used in most of the articles (69%). Location-based AR (15%) and markerless AR (11%) rarely apply in studies. Five percent of studies did not mention the type of AR.

A mobile device (smartphone or tablet) was typically used as an AR device. This is possibly based on the widespread availability of these mobile technologies worldwide. Chen (2017) also found similar results in his study and confirmed that mobile technologies are mainly used for AR technology. Computers and webcams (laptops) were the second most popular applied devices. There were also 3D glasses (Petrov & Atanasova, 2020), Microsoft HoloLens (Condino et al., 2021; Schez-Sobrino et al., 2020), and a Head-mounted display (HMD) (Hung et al., 2017) used in the articles for applying AR systems, such as guitar learning system (Keebler et al., 2014), AR Circuit system (Matcha & Rambli, 2016), ARFlora system (Chang et al., 2016), MagAR (Abdusselam & Karal, 2020), MagicBook (Schneider et al., 2020) and Holo-BLSD (Strada et al., 2019).

According to the findings, mobile applications and marker-based materials on paper were the popular types of AR use, which could have come along with the spread of mobile devices. These results align with previous studies which found that these types of AR are easy to use and practical to develop (Arici et al., 2019).

Table 2. Limitation Distribution Summary

Limitations	No. of articles	Percentage of articles
Small sample size	32	34%
Apps limitation to a small number of courses	17	18%
Limited generalizability	15	16%
Time limitation	14	15%
Technical problems	11	12%
Smartphone operating system limitation	6	6%
Long time for development	5	5%
Real-world experiment limitation	6	6%
High price	4	4%
Self-reported study	4	4%
Lack of Familiarity with new technology	3	3%
Lack of a comparison group or a focus group	2	2%
Novelty factor	2	2%
Problems with research methods	6	6%

The limits of AR development studies were sample size limitation, application limitation to the small number of courses, limited generalization, time limitation, technical problems, operating system limitation, and other limitations mentioned in Table 2. This table presents the percentages of the top fourteen limitations in reviewing the articles. The other ones were cited once between studies. According to Suárez-Warden, Rodriguez, Hendrichs, García-Lumbreras, and Mendívil (2015), “estimation of a minimum acceptable sample size becomes imperative to avoid explorations based on intuition and limited available data.” Most studies also mention that the limited sample size does not represent the population (Keebler et al., 2014; Schneider et al., 2020). Moreover, in most of the studies, the varieties of areas for exploration were not as abundant as what would be experienced in realistic situations, and it would have a direct impact on the result in different domains (Chanlin & Chan, 2018; Tobar-Muñoz et al., 2017; Xiao et al., 2020). Mobile phone limitations for developing AR applications, time duration for AR implementation, and the high equipment price (Petrov & Atanasova, 2020) were also the main restrictions for AR developments.

4.2 Benefits of AR in Learning Settings

This article focuses on the benefits related to AR learning outcomes as they are directly linked to obtaining a learning gain. As an outcome of the data analysis, twenty-one benefits related to AR learning gains and outcomes were identified.

- Memory retention: Improved capabilities related to remembering learning content
- Cognitive load: Reduced cognitive load
- Understanding of abstract concepts: The improved visualization makes it easier to grasp complex facts

- Imagination and creativity: Using AR allows for new ways of approaching and solving problems
- Critical thinking: Using AR helps to identify critical issues
- Practical skills: Using AR allows one to train practical skills in new ways
- Learning activity and outdoor experience: Increased opportunities for new learning activities
- Participation (cooperation): Increased participation
- Team collaboration: Improved ways of working together as a team
- Team interaction: Improved team interaction
- Engagement: Increased learner engagement
- Motivation: Increased motivation to learn
- Joy and interest: Increased joy and interest when learning
- Perceived learning attitude: Improved attitude toward the learning experience and the learning content
- Confidence: Increased learner confidence in terms of the learning experience
- Satisfaction: Increased learner satisfaction in terms of the learning experience
- Attention: More awareness and alertness toward the learning objective
- Self-efficiency and self-regulation: Improved learned
- Independent learning: Increased learner ability to learn independently
- Concentration: Increased focus of the learner
- Spontaneous learning: Increased opportunities to learn spontaneously

Increased motivation, joy, and interest are the most frequently mentioned categories among these benefits. Understanding and remembering the concepts (Chang et al., 2016; Chin & Wang, 2021; Hung et al., 2017), critical and practical thinking (Chen et al., 2020; Faridi et al., 2021), creativity (Sáez-López et al., 2020; Yilmaz & Goktas, 2017), interaction with people, and concepts (Hung et al., 2017; Iordache et al., 2012) are essential to achieving learning performance.

In 80 percent of the reviewed papers, authors reported that AR had increased their learning gains, and those other benefits, such as motivation, engagement, and participation, can positively affect learning outcomes. As a result, these benefits should be classified in a way that shows how using AR in a learning setting can enhance student learning performance. Therefore, the benefits should be categorized in a way that helps to evaluate student performance and enhance student learning outcomes.

Using Fink's taxonomy (2013) of significant learning, the identified benefits are categorized into six categories to evaluate their potential and connect to a learner's learning performance, namely: (a) Learning how to learn, (b) Foundational knowledge, (c) Applications, (d) Integration, (e) Human dimension, and (f) Caring. According to Fink (2003a), any type of learning that involves one or more of the above learning categories can be considered significant. Significant learning takes place when these distinct categories come together and intersect within a learning environment. This intersection of perspectives and dimensions fosters a holistic and profound learning experience, enhancing the overall quality and depth of the educational process. Fink (2013) argues that improving one category helps develop other categories as the taxonomy is not hierarchical, but 'relational and interactive', enabling learning to be synergistic.

Table 3 provides an overview of the benefits of using AR classified into Fink's categories of significant learning. A (+) indicates an increase or improvement (through AR), while a (-) indicates a decrease.

Table 3. Classifying the Benefits of Using AR into Fink's Taxonomy of Significant Learning

Taxonomy	Description of AR benefits	Benefits of using AR	Sample reference	Mentions
Foundational Knowledge	Through AR, learners can acquire information when needed and comprehend and visualize concepts. Using AR effectively improves students' knowledge retention and reduces their cognitive load to retain it.	Memory retention (+)	(Faridi et al., 2021)	12
		Cognitive load (-)	(Wen, 2019)	11
		Understanding of abstract concepts (+)	(Singh et al., 2019)	10
Application	AR encourages creativity and imagination, the ability to practice critical thinking, and the improvment of considerable motor skills through outdoor activities.	Imagination and creativity (+)	(Chang, Hu, et al., 2020)	5
		Critical thinking (+)	(Chen et al., 2020)	2
		Practical skills (+)	(Faridi et al., 2021)	2
		Learning activity and outdoor experience (+)	(Chin et al., 2019)	5
Integration	Activities involving collaboration and cooperation in an AR environment allow connections between people, viewing creations from multiple perspectives; creating simulations allows users to understand entire dynamic relationships.	Participation (co-operation) (+)	(Chanlin & Chan, 2018)	11
		Team collaboration (+)	(Wen, 2019)	8
Human Dimension	Interactions with others can provide insights into social and personal factors.	Team interaction (+)	(Küçük et al., 2014)	18
Caring	AR increases a learner's motivation and interest in a subject. In addition, increased engagement, a positive attitude towards learning, development of confidence, and overall satisfaction contribute to a sense of caring.	Engagement (+)	(Nadeem et al., 2020)	23
		Motivation (+)	(Mumtaz et al., 2017)	44
		Joy (+)	(Ozdamli and Hursen 2017)	42
		Perceived learning attitude (+)	(Cai et al., 2020)	18
		Confidence (+)	(Ibáñez et al. 2014)	13
		Satisfaction (+)	(Xiao et al., 2020)	14
Learning How to Learn	Using AR increases students' attention and concentration to become self-regulated and independent learners. It increases the student's interest in inquiry-based learning. This results in more effective and spontaneous learning.	Attention (+)	(López-García et al. 2019)	10
		Self-efficiency and self-regulation (+)	(Koo et al., 2019)	9
		Independent learning (+)	(Kamarainen et al. 2013)	2
		Concentration (+)	(Chang, Chen, et al., 2020)	2
		Spontaneous learning (+)	(Chang, Hu, et al., 2020)	2

Although our research focus was on the benefits of using AR, we noted that studies also mentioned some challenges associated with AR, which we want to mention briefly: Complex AR technology might overwhelm the learners (Alzahrani, 2020) as well as technical problems (Akçayır & Akçayır, 2017) and the cost of the devices (Echeverría et al., 2012). According to Herpich et al. (2014), being a novel technology, that includes several senses, can sometimes be very complex, especially for those who do not have technological abilities, such as children. In a few studies, AR systems were perceived to be more difficult to use than physical or desktop-based options (Radu, 2014).

5 Discussion

In the following, we will summarize our findings and embed them into extending the body of knowledge of using AR in learning settings. We then discuss our research's theoretical and practical implications and reveal applicable themes for research and practice that would benefit from further research.

5.1 Summary of Findings

With this study, we could build on previous studies on the state of the art of using AR in learning settings and extend the body of knowledge of using AR, specifically contributing a comprehensive and coherent overview of benefits related to AR learning gains and outcomes.

Our data shows that the number of published studies related to AR has been steadily increasing since 2012. In line with previous studies (Arici et al., 2019; Li et al., 2017; Quintero et al., 2019), we found that quantitative and experimental designs were the most preferred research methods, whereas questionnaires as well as pre-tests and post-tests, were the most common data collection methods. Our results also show that the articles mainly focused on mobile devices for using AR since mobile technologies have an advantage in cost and benefit (Goff et al., 2018) and that mobile applications and marker-based AR were the popular types, which can be linked to the spread of mobile devices. Furthermore, the results of our analysis, in combination with the increased technological maturity of AR applications, indicate that the applicability of AR technology in learning settings has improved in recent years (Akçayır & Akçayır, 2017).

Classifying the identified benefits of using AR in learning settings into the six dimensions of Fink's (2013) taxonomy of significant learning provides us with a comprehensive picture of how AR can significantly improve learning experiences across various scenarios and settings. Our study synthesizes research that shows AR can augment current learning scenarios and open the door for new types of learning scenarios, resulting in significant improvements in student learning. Students and lecturers benefit from AR tools because they make traditional teaching methods more interesting and challenging. Adding AR to traditional teaching methods can allow learners to see and hear supplementary digital information. AR can change the traditional world and create a new world. By presenting the information in an appealing way, students become more engaged in the subject compared to more traditional methods. While some benefits of using AR in learning settings have many occurrences in our taxonomy, such as motivation and enjoyment in caring, some benefits have few. Motivation (44), learning interest (42), and engagement (23) are the most identified benefits of AR, while critical thinking, practical skills, independent learning, concentration, and spontaneous learning are only mentioned twice each.

In addition, the high number of occurrences of some benefits could be related to the novelty factor of technology. The "novelty effect" of AR could be a disturbing factor (Ibáñez et al., 2014). Garzón and Acevedo (2019) have suggested that the positive outcomes may be attributable to the new technology's novelty effect on the students, which might diminish over time (Di Serio et al., 2013). Most identified studies discussed short-term benefits, which may be affected by the novelty effect, indicating the need for longitudinal studies, which can help to determine whether AR positively impacts learning after removing the novelty effect.

5.2 Implications

It is unrealistic to expect to find the best framework or model for IS effectiveness since it is a subjective and relative construct (Mirani & Lederer, 1998). Current literature on AR effectiveness, a taxonomy with inherent categorization in learning settings, enables researchers to have an overview of different AR benefits. In addition, it is important to note that broad, consensual categories of IS effectiveness may not be possible since the underlying criteria depend on individual and constituent group values and preferences, which may conflict with each other (Cameron & Whetten, 1983), as interpretations of their subjective models of reality. Research in different circumstances may require different effectiveness models based on the context and the problem (Mirani & Lederer, 1998).

This systematic approach attempts to identify AR benefits in educational settings by uncovering meaningful groups or categories in a comprehensive taxonomy. The results of this study are valuable to researchers and practitioners for several reasons. It can help researchers to develop a better understanding of the potential beneficial role of AR in learning settings. Specifically, applying the taxonomy of significant learning offers a new theoretical perspective on how using AR can offer new opportunities in designing courses. AR's limitations in learning settings and non-widespread adoption can be better understood by analyzing the content of educational applications in a comprehensive taxonomy. Fink's taxonomy has proven to be applicable when classifying the learning scenarios' benefits, so we argue that it could also be used to assess the benefits of other learning technologies in future studies. Even though this taxonomy has not been widely applied in the information technology field, especially for AR applications, it may provide a framework for evaluating student outcomes and designing courses in this environment.

Although our study focuses primarily on the general benefits of using AR in a learning setting, it still has implications for specific areas of the IS curriculum. The potential of AR has already been demonstrated in a variety of IS fields, including healthcare (Gerup et al., 2020; Zhu et al., 2014); marketing (Rauschnabel et al., 2022; Rauschnabel et al., 2019), and supply chain management (Rejeb et al., 2020). AR can play a significant role in the IS curriculum in the real world, and it can be used in the classroom to deliver visuals, sounds, and other sensory information. With handheld devices, students can view real videos and explore detailed 2D images and 3D models related to the lesson (Shirazi & Behzadan, 2015). They can promote interaction and teamwork by collaborating with peers and using their devices (Shirazi & Behzadan, 2015). AR can be used as an IT tool or educational computer system for learning IS, or it can be used as an IS to develop creative and innovative solutions to problems in IT concepts.

AR technology can assist students in learning more about IS principles and applications by incorporating interactive virtual content into the learning process. For example, Lin and Chen's (2020) study shows that AR enables students to visualize and manipulate complex data structures, simulate real-world IT scenarios, and explore innovative IT solutions. AR is a versatile and effective tool for teaching and learning IS concepts, fostering creativity, critical thinking, and problem-solving skills. With digital information overlaid in the real world and displayed in an AR device, a user's perception of the real world will be altered. AR may be beneficial when conducting interviews by providing live annotations, such as stress levels or detecting if a person is lying. Furthermore, exploring how AR can be used in different parts of the curriculum in conjunction with other technologies, such as AI (Artificial Intelligence) (Zhou & Li, 2021), may result in significant changes in all areas of the IS curriculum. Therefore, future research should investigate the potential application of AR in specific IS courses, such as database management, cybersecurity, and telecommunications.

As part of our SLR, we argue that AR can be used effectively in learning settings to enhance student engagement, motivation, and active learning. To provide students with an immersive and interactive learning experience, we suggest educators and instructional designers integrate AR technology into their teaching and learning practices. Based on our review, AR appears to be particularly effective in designing learning activities that promote higher-order thinking skills such as analysis, synthesis, and evaluation. Therefore, we recommend that instructional designers include AR-based learning activities that promote these skills in their curriculums. The above findings highlight the results of experiments that can assist practitioners in implementing AR, identifying challenges and benefits, and finding areas for further research. These results allow the investigation of the technology in various contexts and to invest appropriately in workforce training. The provided overview allows developers to create various applications on various topics. It is also shown that most AR benefits can be attributed to education, training, and laboratory environments, while other areas, such as industrial ones, will also play a significant role in the future of AR implementation. So, practitioners can use AR to provide multiple applications that can be combined with different topics. In addition to illustrating which topics/subjects benefit from using AR, it will provide insight into the adoption of industry-based learning apps, their subscription rates, and their monthly average users. Furthermore, we briefly mentioned some challenges of using AR that can be explored in more detail in the future.

This article also identified various vital limitations of existing studies. Limited sample sizes, application limitations, generalizability limitations, time limitations, and technical problems were the most reported limitations of studies. Hence, a bigger sample size and more longitudinal studies are needed to understand AR impacts better. It is worthwhile to mention that despite technical limitations, our study has shown that the use of AR in learning settings has numerous benefits that cannot be achieved through traditional teaching methods. AR technology is expected to reduce delivery flaws over time despite these limitations. Therefore, we believe that the potential benefits of using AR outweigh these limitations, and the technology is mature enough for instructors to use.

5.3 Directions for Future Studies

While AR may have demonstrable benefits in learning settings, these benefits are not certain, and contingencies on how AR is used have been identified. One of these conditions is the novelty factor of AR, which could be disturbing but may diminish with time. Also, AR can be more or less effective depending on the learning context and the nature of the educational content. AR integration may benefit different subject areas or topics in different ways. Using AR in learning settings can be limited by hardware and software limitations and user proficiency. Future researchers should focus on understanding how AR can be applied effectively in different contexts for its broader adoption. They also should include long-term studies to determine whether AR positively impacts learning after removing the novelty effect.

Furthermore, while AR has many occurrences in learning settings, such as motivation and enjoyment, some benefits, such as critical thinking, practical skills, independent learning, concentration, and spontaneous learning, are less frequent. In Fink's taxonomy's application categories, these less-occurring benefits are crucial in learning how to learn. The novelty factor of technology may also explain the high frequency of some benefits.

Moreover, our analysis showed that almost all reviewed studies evaluated the use of AR in a laboratory setting and as a pilot study. Therefore, we suggest that future researchers conduct more AR assessments in real-life situations. As the impact of AR solutions is ultimately expected in real-world contexts (Fite-Georgel, 2011), such as industrial settings, further research should be undertaken on AR learning solutions in these areas.

In the realm of education, it is worth exploring the source of AR content: Do teachers and schools use pre-made AR apps, with their own materials, or do they get the content from elsewhere? Additionally, understanding the role of external providers and the cost-effectiveness of these content sources is crucial (Friedrich et al., 2002). Surveys, case studies, or partnerships with educational institutions could be used to collect practical data on AR content procurement and its impact on learning outcomes in this context, the 'metaverse' and its immersive nature have the potential to revolutionize education (Richter & Richter, 2023). Future research should focus on using AR's unique abilities in the metaverse to place students as content creators to make learning more immersive and engaging.

In addition, although previous studies have shown that AR has many advantages over traditional methods in past studies (Sakellariou et al., 2009; Zhu et al., 2014) and some comparisons have been made to assess its benefits and limitations, including cost-benefit analysis (Chen et al., 2018; Lodetti et al., 2021), there is still a need for a better understanding of what makes AR unique. Future researchers can focus on identifying the specific benefits of AR in different contexts and comparing them with those of other methods to understand AR's value and competitiveness fully. As mentioned earlier, many of the benefits of using AR were achieved through short-term studies, so assessing its long-term impacts to capture its full potential is important. Short-term studies can shed light on AR's immediate benefits, but a longer-term study can reveal the technology's lasting impact and potential return on investment. Through a long-term study, we can better understand AR's value compared to other methods and make informed decisions about its future use.

Most AR publications have highlighted the benefits of using AR technology in education. Still, AR technology is not being used broadly and is far from a standard tool in educational settings for many reasons. First of all, since AR is a relatively new technology, it is still essential to understand its challenges and limitations. Secondly, AR hardware still has several technical limitations (e.g., the quality of the display or the field of view that makes it difficult to display complex virtual content). Another reason is the costs of buying AR hardware and developing AR content for educational purposes. Companies need to be convinced of the positive impact AR will have on their business for investing in AR, but this is impeded by the lack of transparency regarding the equally numerous and manifold challenges and benefits, the corporate inertia of companies, and the willingness to take risks. For this purpose, future researchers need to conduct more long-term studies on the educational impact of AR technologies that not only look into a small dedicated educational scenario but also consider the application of AR in a broader setting. With the identified benefits of AR with Fink's taxonomy of significant learning (Fink, 2013), this article created a foundation for such studies that ultimately will lead to a broader application of AR in educational settings.

In the future, researchers could build upon the concept of students as co-creators of augmented reality (AR) experiences, drawing inspiration from studies such as Gerard et al. (2022). It illustrates the potential for students to actively engage in the development of immersive content through a participatory design process in which academics and students collaborate to develop a VR game. Using similar participatory design methodologies in the context of AR could shed light on effective approaches to fostering students' creativity, digital literacy, and subject knowledge. By leveraging students' active participation in AR content creation, this research could uncover innovative pedagogical strategies that enhance students' learning experiences and contribute to the advancement of AR technology.

Future work needs to identify particular topics that may benefit from using AR (for example, engineering, natural science, etc.) by considering industry/practice-based learning apps; their adoption and features would also clarify topics and subjects that benefit from using AR. Also, it is necessary to examine the effects of AR by analyzing it among broad and larger sample sizes. Identifying how the population and situations differ can help us understand how AR influences other domains besides education.

Among AR types, marker-based AR was the most common, with location-based AR and marker-less AR receiving less attention. Since marker-based AR systems require users to keep their position relative to the markers to present virtual objects, learners can feel exhausted after long working hours (Turkan et al., 2017). It is recommended that future research focuses on using marker-less AR applications since marker-less AR promises to be more interactive than marker-based AR (Cheng et al., 2017; Chi et al., 2013).

6 Conclusion and Limitations

In this study, we systematically review the benefits of using AR in learning settings by synthesizing the results of 93 relevant articles. Twenty-one benefits related to AR learning gains and outcomes were identified and categorized with Fink’s taxonomy of significant learning. This classification allowed us to analyze the frequency of benefits mentioned and draw conclusions from it. Our study further provides a consistent overview of the beneficial uses of AR in learning settings and can help to improve learning designs. Also, the study showed the applicability of Fink’s taxonomy when classifying the learning scenarios’ benefits, so we argue that it could also be used to assess the benefits of other learning technologies in future studies.

This systematic literature review comes with some limitations. The first issue is that only articles from one database (i.e., Web of Science), were considered, but this database may not cover all relevant research on the use of AR in learning. Due to time constraints and limited resources, we used a single database. However it is worth noting that previous studies show that searching multiple databases often produces overlapping search results and the number of unique studies may be relatively small (Hood & Wilson, 2003). Some studies also have concluded that searching only one database can be sufficient since searching other databases does not affect the outcome (Rice et al., 2016; van Enst et al., 2014). Additionally, focusing on a single database can facilitate efficient retrieval of relevant articles and maintain consistency in search strategies. Other databases, such as ACM digital library, ERIC, and ProQuest, also may contain research articles on the educational uses of AR. Further, the number of studies on the use of AR has proliferated in various domains, and we have excluded studies that are currently being reviewed or prepared. It may be worthwhile for future researchers to review editorials, magazines, and reports to ensure a more comprehensive exploration of AR's applications in education.

We used Fink’s taxonomy as it gives us a comprehensive and complete picture of using AR in learning settings without overlapping the benefits. Our results show that the taxonomy enables AR to support significant learning outcomes more effectively by covering the diversity of benefits. One methodological limitation of Fink's taxonomy is that it categorizes benefits subjectively, and some benefits can fit into several categories. Therefore, we have incorporated Tesch's (1990) process into our methodology section to categorize the benefits using the authors' descriptions and interpretations. Consequently, Fink's taxonomy might not capture all possible benefits of using AR in learning settings in future studies, which could lead to some important discoveries being missed. The interpretation and application of Fink's taxonomy may differ across studies, leading to inconsistencies in categorizing and comparing results. Research in the future may also consider other valid taxonomies or frameworks to analyze the benefits of using AR in learning settings.

Another limitation concerns the restricted time of this study. As a result of the restricted time and keyword selection, only a limited number of articles could be accessed. In another study, future researchers may find more relevant documents in different time spans using various keywords. Notwithstanding, the current study provides a comprehensive overview of the current state of the art and directions for future research.

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