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Teachers' Professional Training through Augmented Reality: A Literature Review

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Abstract: Practicum is regarded as a fundamental aspect of the training of prospective teachers. In addition, digital tools are increasingly used to enrich a traditional face-to-face experience. However, the technological exploitation of Augmented Reality (AR) by undergraduate students studying early childhood and primary education is low. A Systematic Literature Review (SLR) on the use of Augmented Reality (AR) in teacher training was conducted. Based on the overarching objectives of the ERASMUS+ project, entitled Digital Practicum 3.0 Exploring Augmented Reality, Remote Classrooms, and Virtual Learning to Enrich and Expand Pre-service Teacher Education Preparation (2020-1-ES01-KA226-HE-096120), the ultimate purpose of this study was to assess whether the use of this resource favors learning and expertise. Two main results are prominent. First, it is noteworthy how the use of this digital technology is limited, given the scarcity of studies. Second, the research studies available focus largely on the benefits of the use of AR in teacher education at a theoretical level. Thus, future research needs to further explore the use of AR in teacher training specially focused on student teachers' learning processes.

Keywords: augmented reality; teacher education; SLR; digital technologies for education

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1. Introduction

It is commonplace to consider a teaching practicum as a subject that plays a fundamental role in training prospective teachers in teacher education programs [1]. The reasons behind this point to the fact that prospective teachers have the opportunity to learn the profession within a school setting. However, the technological initiatives for undergraduate students in Early Childhood and Primary Education teaching programs to prepare them for such in practice learning from faculties are few [2].

Looking backwards, only a decade ago, great transformations occurred impacting society, economics, politics, and also education. One of the most significant transformations has been the digitalization of almost every representation (e.g., objects, images, sounds, documents, etc.) giving rise to the arrival of a so-called Information and Communication Technologies (ICT) society—a revolution that has promoted a different way of understanding our world and the rise of new types of learning that necessarily promote interactive and innovative processes [3]. Among these technologies, the use of immersive learning tools such as Virtual Reality and Augmented Reality have been brought to the forefront. This revolution was accelerated by the recent COVID-19 outbreak that forced professionals around the world to urgently adapt to digital formats [4].

Confronted with these changes, educational institutions have had to adapt rapidly to let their learners acquire and develop skills in, with, and for digital technologies that are necessary for new societal challenges [5]. Consequently, many schools at all levels have been prompted to include a number of technological resources that endorse the teaching-learning process through the use of innovative pedagogical approaches. It is commonplace that, nowadays, students do not learn in the same way as in years before. Therefore, it has been necessary to find effective and engaging pedagogical approaches to implement technologies and adapt the curriculum contents [6,7].

One of the current and future trends in education is the use of Augmented Reality (AR), an immersive technology that uses virtual elements in real scenarios and that teachers could make use of [8,9].

However, it is noteworthy that in the last five years, few systematic reviews have been published in the literature (as indexed in Scopus and the Web of Science) that are related to the use of AR in education. As Chang et al. [10] reported, there is a need for experimental studies to test the effectiveness of the use of AR in education. The available systematic reviews approach thorough bibliometric analysis of scientific production but fail to characterize the bibliometric indicators associated with the studies that analyze the use of AR in the specific domain of teacher training. Mainstream research provides evidence on the use of Augmented Reality and artificial intelligence in a general sense, that is, under the scope of ample concepts such education, teaching, or learning [11] and within specific contexts such as:

- Science Education [12–17]
- Language Learning [18],
- Student Training Through M-learning [19]
- Teaching Didactic Planning [20]
- Development of Emotions [21]
- Motivation and School Performance [22]
- The Use of Augmented Reality in Informal Learning Environments [23]

It is also important to note that those studies focus on analyzing the pros and cons of using AR as an eligible technology to be used in the teacher education process. In the present study, a Systematic Literature Review (SLR) was conducted to identify published research papers related to the use of AR in teacher education. Based on the main objectives of the ERASMUS+ project entitled Digital Practicum 3.0 Exploring Augmented Reality, Remote Classrooms, and Virtual Learning to Enrich and Expand Pre-service Teacher Education Preparation (2020-1-ES01-KA226-HE-096120), the ultimate goal was to examine whether the use of AR favors student teachers and school teachers learning the profession; specifically, whether it assists the teaching process when used as an active method.

1.1. Theoretical Framework

Technology-enhanced learning constitutes a crucial aspect of today's educational programs [24]. The use of technologies combined with active methods triggers quality teaching as it facilitates the process of attending to students' needs and pace of learning [25,26].

AR is defined as a part of the mixed reality within the reality–virtuality continuum that improves real environments through the use of the digital information projected onto them. AR uses technological applications "[...] to enrich users' perceived physical environment with interactive virtual objects and information in real time" [15] (p. 2). The immersive nature of this technology makes it adaptable across any educational level and subject [27].

Even though AR and Virtual Reality (VR) are considered as part of the same spectrum (e.g., mixed reality), if they are confronted, it is noticeable that their relationship with the real world changes, which leads to different learning experiences when presenting the subject contents to students. Virtual Reality takes users to a world that does not exist, and AR allows us to be in the real world by adding a new perspective in which additional information is included through the superimposition of virtual elements in three dimensions [28]. The main characteristics of AR can be summarized as follows [29]:

- It is a mixed reality that allows a view of the physical environment accompanied by the visualization of interrelated digital components.
- The input is integrated and occurs in real time, i.e., both real and virtual information are delivered in parallel.
- It offers a variety of layers of digital information, allowing the interleaving of different digital elements, such as text, graphics, audio, video, web pages, 3D objects, etc.

- It allows interaction, which means the result of the digital information allows the user to interact with it; for example, 3D objects allow for a variety of options such as the objects being rotated or enlarged, where the animation can even be activated or deactivated. It can improve or change parts of reality when using technological devices that display additional information seen through the screen. It then requires the user's mediation for it to take place.

Types of Augmented Reality (AR)

Depending on the physical component or marker that activates the digital information, different types of AR can be differentiated. The levels are understood as a type of measurement, which indicates the complexity of the technologies that are involved in developing Augmented Reality systems. Thus, the more levels there are, the greater the possibilities the applications can provide. Table 1 shows all the levels that currently exist, taking into account their physical and virtual components, as well as their functionality [30–34].

Table 1. Levels of Augmented Reality.

(1) Based on Its Technological Component	**(2) Based on Its Virtual Component**	**(3) Based on Functionality**	
		(3.1) Functionality: Augmented Perception	**(3.2) Functionality: Artificial Environments**
Level 1: black and white pattern (QR codes)	Image	Documented reality and Virtual Reality	Envisaging a reality that could exist in the future, associating real and virtual components
Level 2: image	3D	Reality with augmented perception or comprehension	
Level 3: animation	Video	Perceptual association of the real and the virtual	Envisaging a reality that occurred in the past, associating the real with the virtual
Level 4: coordinates determined by GPS coordinates	Audio	Behavioral association of the real and the virtual	
Level 5: thermal footprint	Multimedia	Substitution of the real by virtual or virtualized reality	Envisaging impossible reality scenarios

As Table 1 shows, the AR levels are based on three criteria: (1) the predominant technological component used such as QRs, images, 3D objects, GPS, and thermal footprints; (2) the virtual component (images, videos, etc.); (3) the functionality such as augmented perception where the technology gives extra information (virtual) when projected over real scenarios and artificial environments which are the type of artificial environments and experiences that are projected when using AR. We think that the classification based on augmented perception (3.1.) provides a more comprehensive understanding from an educational point of view as the different virtual projections can evoke particular learning patterns for students.

2. Materials and Methods

A systematic review is a type of study that analyzes the production of scientific literature in a given range and area of knowledge [35]. For this reason, the PRISMA protocol and its extension PRISMA-S were used in addition to a meta-analysis of quantitative studies [36]. The PRISMA protocol consists of four steps to direct the design and implementation of systematic reviews. Step 1: main goal. Step 2: review protocol. Step 3: data mining. Step 4: data analysis. The PRISMA protocol was chosen on the basis that it is widely considered among the research community as an optimal procedure to carry out systematic reviews as well as a meta-analysis to allow for thorough quantitative and qualitative analyses.

Step 1: The main goal of the present systematic review is to analyze research related to the use of AR in teacher training. To meet this goal, the following research questions were posed:

Q1. What are the main bibliometric indicators of scientific production in terms of publication sources of a regional and institutional origin?

Q2. What are the most representative keywords used in the research studies?

Q3. What types of studies are most common in the scientific literature?

Q4. Which studies use reliability and validity processes in the design and application of the instruments applied?

Q5. Which augmented reality components are used depending on the user's virtual component? At which stage of teacher training were they applied?

2.1. Validity

Step 2: review protocol.

Three types of validity were measured in this SLR:

- Internal validity: the analysis of each study included the analysis of the keywords, abstract, article content, methodological approach, and type of research.
- External validity: the studies that lacked validation and discussion of the results were excluded.
- Conclusion validity: the Joanna Briggs Institute evaluation criteria for Systematic Literature Reviews were applied in relation to transparency, replicability, quality, and meta-aggregation [37].
- The validity of the study was carried out under three approaches: Internal validity, external validity and, conclusion validity. In short, the keywords, the quality of the methodological design, the coherence between the methodological design, the results and conclusions were analyzed by following the Joanna Briggs Institute guidelines. As a result data matrix (Excel document) was elaborated. This systematic review in turn used a quality protocol for data analysis (Section 2.4).

2.2. Inclusion and Exclusion Criteria

The Keywording technique and the Mendeley manager were used to manage the resultant 38 keywords. The following criteria were applied:

- Inclusion criteria: (a) publication period from 2012 to October 2022; (b) articles indexed in Scopus; (c) articles in English; (d) studies related to teacher training for the didactic use of Augmented Reality.
- Exclusion criteria: date of publication, type of research (tutorials, essays), and relation to the object of study and the aim of the research.

2.3. Search Indicators

The Scopus database was used for selecting the papers, limiting the search to the last 10 years (2012–October 2022). Combinations between AND/OR logical operators were used, and the keywords were practicum, teachers, training, initial teacher education (ITE), pre-service, candidate, student, and Augmented Reality. Several terms established in the semantic framework of teacher training were used such as teachers, professors, initial, pre-service, and candidate.

The search string used was the following: (KEY (practicum) OR KEY (teachers AND training) OR KEY (initial AND training) OR KEY (preservice AND teachers) OR KEY (candidate AND teachers) OR KEY (student AND teachers) AND KEY (augmented AND reality)) AND PUBYEAR > 2011 AND PUBYEAR < 2023 AND PUBYEAR > 2012 AND PUBYEAR < 2023.

2.4. Data Analysis

Step 3: data mining.

A data matrix was used to analyze each study in depth and to achieve the analysis, synthesis, and grouping of the information [36,38] which included authors, studies, publication sources, type of research, stage of teacher training, reliability and validity of the instruments, and the components of Augmented Reality according to the user's virtual component used in the studies. The three researchers rated each component from 1 (lowest score) to 5 (highest score). The process followed the established PRISMA method stages: grouping of variables, trend analysis, and statistics (see Figure 1). Cohen's Kappa reliability coefficient (k = 0.826) was applied to the observations, achieving 96% and adequate coincidence [39].

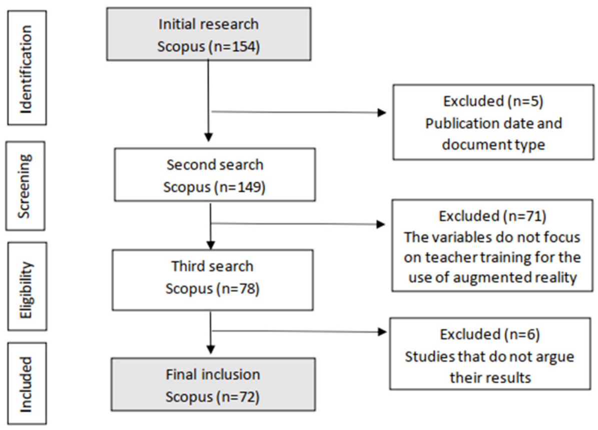

Figure 1. PRISMA flowchart summarizing the procedure followed.

2.5. Information Selection and Representation

Step 4: data analysis.

Functions of the VOSviewer were employed to determine the most common terms used from among the authors' keywords using the co-occurrence of keywords and the networks they formed. In this regard, the functions were applied to clusters and subclusters. This software was used because it allowed the construction and visualization of networks based on clustering techniques [40].

3. Results

Q1. What are the main bibliometric indicators of scientific production in terms of publication sources of a regional and institutional origin?

A total of 72 documents were selected from the SCOPUS (meta)database, including 50 articles and 22 conference proceedings. The years with the highest scholarly production (Figure 2) were 2013, 2019, and 2020.

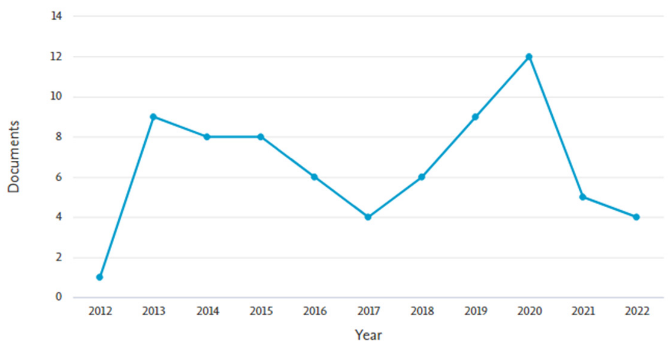

Figure 2. Number of documents per year.

The research papers were published in the following journals (Figure 3): Computers and Education (23), Procedia Computer Science (19), Computers in Human Behavior (6), Heliyon (2), International Journal of Human-Computer Studies (2), and Teaching and Teacher Education (2). It was observed that for subject matter, the conference proceedings presented in Procedia Computer Science had a great influence. Therefore, the indexing categories related to education and general computer science were the most representative, which reaffirms the interdisciplinary nature of the educational technology domain.

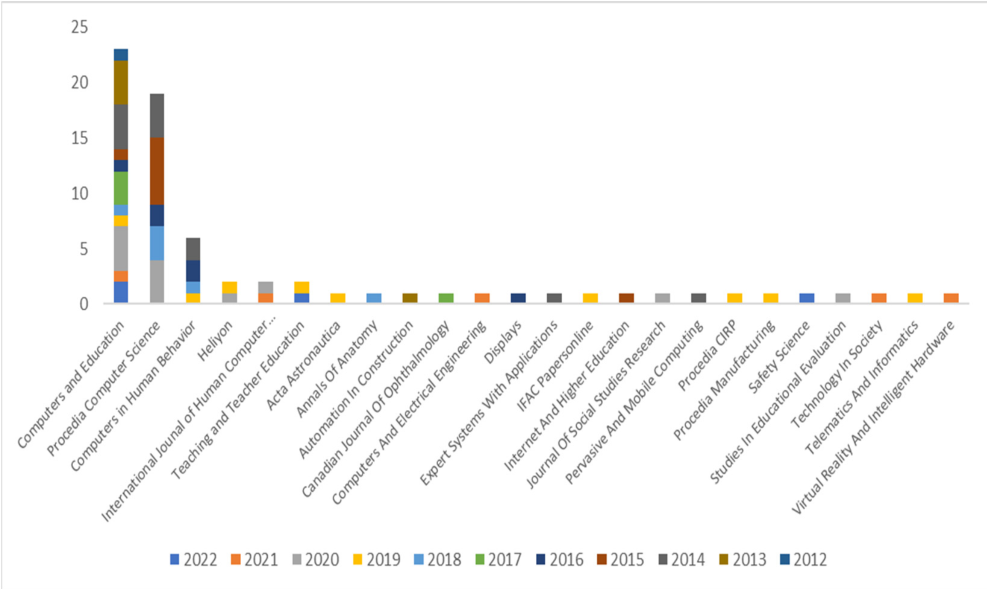

Figure 3. Relationship between publication resources and years.

Q2. What are the most representative keywords used in the research studies?

The most frequently used keywords were found to be (Table 2): Augmented Reality (59), students (34), education (26), computer-aided instruction (21), teaching (21), E-learning (17), engineering education (15), Virtual Reality (14), interactive learning environment (12), and learning systems (11).

Table 2. Keywords (number in brackets) vs. top articles.

Keywords	Articles with at Least 100 Citations
Augmented Reality (59)	[41–57] (Chen and Tsai 2012, Kamarainen et al., 2013, Lin et al., 2013, Wojciechowski and Cellary 2013, Di Serio et al., 2013, Cai et al., 2014, Sommerauer and Müller 2014, Zhang et al., 2014, Chiang et al., 2014, Fonseca et al., 2014, Ibáñez et al., 2014, Akçayir et al., 2016, Yilmaz 2016, Huang et al., 2016, Hsu 2017b, Chang and Hwang 2018, Sahin and Yilmaz 2020)
Students (32)	[41–43,45–49,51,52,54,55,57] (Chen and Tsai 2012, Lin et al., 2013, Di Serio et al., 2013, Kamarainen et al., 2013, Zhang et al., 2014, Chiang et al., 2014, Fonseca et al., 2014, Ibáñez et al., 2014, Akçayir et al. 2016, Huang et al. 2016, Hsu 2017b, Chang and Hwang 2018, Sahin and Yilmaz 2020)
Education (26)	[47,51,52,54] (Kamarainen et al., 2013, Akçayir et al., 2016, Huang et al., 2016, Hsu 2017b)
Computer-aided instruction (21)	[41–43,46–48,50,54–57] (Chen and Tsai 2012, Di Serio et al., 2013, Lin et al., 2013, Wojciechowski and Cellary 2013, Zhang et al., 2014, Chiang et al., 2014, Ibáñez et al., 2014, Sommerauer and Müller 2014, Huang et al., 2016, Hsu 2017b, Chang and Hwang 2018)

Table 2. *Cont.*

Keywords	Articles with at Least 100 Citations
Teaching (21)	[44,46,48,51,58] (Kamarainen et al., 2013, Chiang et al., 2014, Zhang et al., 2014, Yilmaz 2016, Chang et al., 2018)
E-Learning (17)	[55,56] (Chen and Tsai 2012, Sommerauer and Müller 2014)
Engineering education (15)	[52,54] (Akçayir et al., 2016, Huang et al., 2016)
Virtual Reality (14)	[49,55,57] (Chen and Tsai 2012, Lin et al., 2013, Sahin and Yilmaz 2020)
Interactive learning environments (12)	[42,43,46,48,50,54,55,57,59] (Chen and Tsai 2012, Lin et al., 2013, Wojciechowski and Cellary 2013, Chiang et al., 2014, Ibáñez et al., 2014, Zhang et al., 2014, Huang et al., 2016, Hsu 2017a, Chang and Hwang 2018)
Learning systems (11)	[42,43,46,50,54,55,57] (Chen and Tsai 2012, Lin et al., 2013, Wojciechowski and Cellary 2013, Chiang et al., 2014, Ibáñez et al., 2014, Huang et al., 2016, Chang and Hwang 2018)

Concerning the keywords used in the research studies (Figure 4), a total of 211 were found in the sample of which 36 had appeared at least twice, with the most frequent being Augmented Reality (39), interactive learning environments (12), Virtual Reality (9), education (8), applications in subject areas (6), and mobile learning (6).

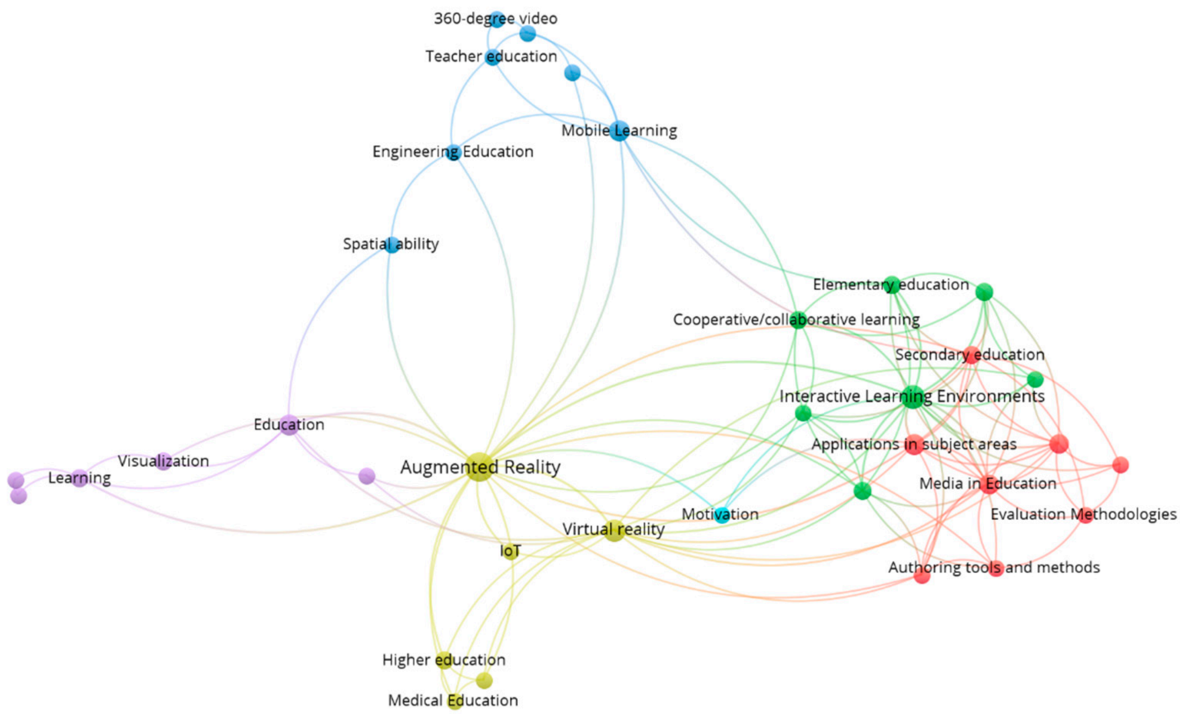

Figure 4. Keyword network.

In the first and second clusters (Figure 5), the nodes for applications in subject areas and interactive learning environments stand out, respectively, and are interconnected through the nodes for teaching/learning strategies, simulations, and interactive learning environments.

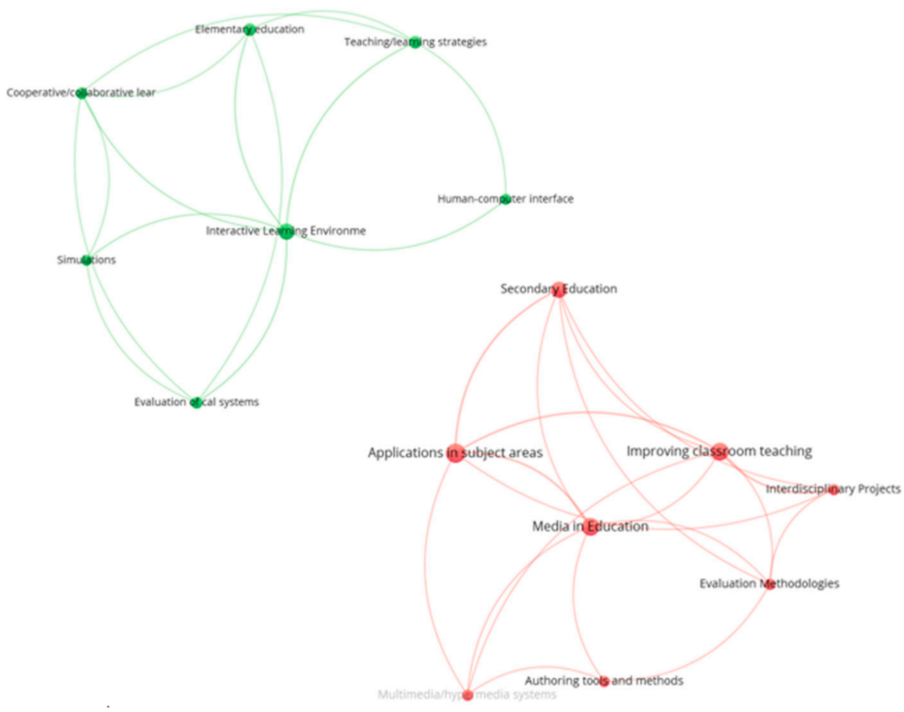

Figure 5. First and second clusters (left to right).

In the third cluster, the nodes for mobile learning and engineering education were prominent, while in the fourth cluster, Augmented Reality and Virtual Reality stand out. Both clusters are interconnected through Augmented Reality, which highlights the strong relationships among user experience, mobile learning, and spatial ability (Figure 6).

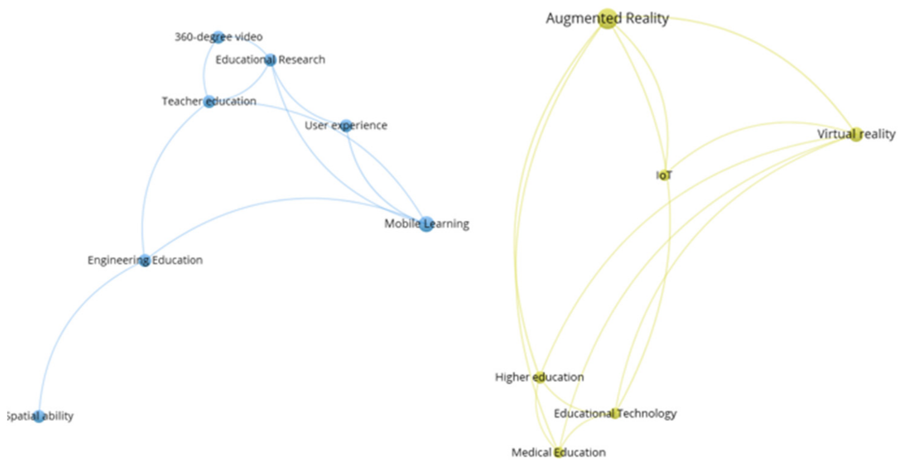

Figure 6. Third and fourth clusters (left to right).

In the fifth cluster (Figure 5), the nodes for Education and Mixed reality stand out, while the sixth cluster only contains the node for motivation. In addition, the fifth cluster shows a relationship with the third through the nodes associated with AR and Virtual Reality. For the sixth cluster, there is a strong interaction with the first three clusters through the terms applications in subject areas, interactive learning environments, and Augmented Reality, respectively (Figure 7).

Figure 7. Fifth cluster.

Thirty-six countries were identified of which Spain, Taiwan, and Turkey were the most notable (Figure 8). Out of the total, 17 countries accounted for two published papers on the topic, but only three of them were specifically related to the use of AR in the classroom. They come from Spain, Venezuela, and Portugal.

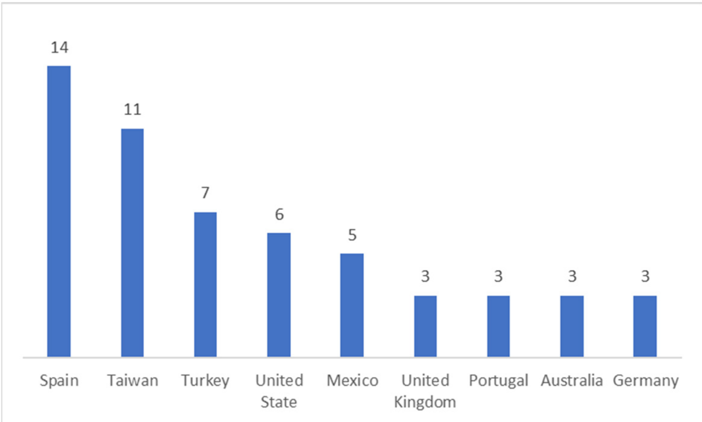

Figure 8. Countries with the highest scientific production.

Among these countries, the higher education institutions with the largest scientific production in the selected sample are the National Taiwan University of Science and Technology (Taiwan), Ataturk University (Turkey), Carlos III University (Spain), University of La Laguna (Spain), Tecnologico de Monterrey (Mexico), and the University of Aveiro (Portugal), all of them accounting at least three publications.

Q3. What types of studies are the most common in the scientific literature?

As shown in Table 3, exploratory and quasi-experimental studies are the most common.

Table 3. List of study types (n = 72). Some listed below.

Quantitative Studies			Qualitative Studies		Mixed Method	
Exploratory	**Descriptive**	**Quasi-Experimental**	**Exploratory**	**Descriptive**	**Quasi-Experimental**	**Exploratory**
[50,55,60–82]	[41,83,84]	[43,45–49,52,54, 56,57,85–104]	[51,105–112]	[51,53]	[44,113]	[42,114]

As shown in Table 3, a total of 27 (41.5%) studies implemented quasi-experimental designs, and 23 studies (35.3%) were exploratory, making the quantitative analysis approach the predominant type of research (76.8%). Another group of 11 studies (16.9%) were found to be of a qualitative nature, and just 4 (6.1%) were mixed method.

Q4. Which studies use reliability and validity processes in the design and application of the instruments applied?

Reliability indicates the degree to which repeated application of the instrument to the same subject will produce the same results, and validity refers to the degree to which a given instrument measures what it is supposed to measure [115]. Of the 72 documents, only

17 explicitly state reliability [41,47–49,51–53,63,68,72,77,89,97,99,100,112,114], and 9 explicitly state the validity of the instruments applied [42–44,46,57,87,88,105,106], which provides evidence of the limited transparency in data sharing.

In turn, only eight studies show the reliability and validity obtained in the design and application of the instruments [48,53,63,68,97,100,112,114].

Q5. Which AR components are mainly used by teachers? At which stage of teacher training were they applied?

The answers to these two questions can be found in Table 4 based on the following three legends.

Table 4. List of study types (n = 72).

Classification		Augmented Reality Component	Teacher Training Phase
Research topic	**Studies (Reference)**		
1	[75]	2	3
	[63]	2	3
	[114]	1	3
	[106]	1	1, 2, 3
2	[73]	1	3
	[69]	1	1, 3
	[105]	1	1
	[113]	1	3
	[108]	1	3
	[101]	3	3
	[102]	2	3
3	[91]	1	1, 3
	[111]	1	3
	[68]	-	1
4	[49]	1	3
	[83]	1	3
	[44]	1	1, 3
	[51]	1	3
	[70]	1	3
	[107]	1	3
	[85]	1	3
	[76]	1	1, 3
	[86]	1	3
	[43]	1	3
	[77]	1	3
	[87]	1	3
	[110]	1	3
	[109]	1	3
	[78]	1	3
	[79]	1	3
	[80]	1	3
	[88]	1	3
	[89]	1	3
	[81]	1	3
	[90]	1	3
	[91]	1	3
	[92]	1	3
	[41]	2	3
	[93]	3	3

Table 4. *Cont.*

Classification		Augmented Reality Component	Teacher Training Phase
Research topic	**Studies (Reference)**		
4	[84]	1	3
	[48]	2	3
	[94]	1	3
	[82]	4	3
	[54]	2	3
	[95]	1	3
	[96]	1	3
	[60]	2	3
	[46]	2	3
	[42]	1	3
	[50]	1	3
	[61]	1	3
	[97]	1	3
	[98]	4	1, 3
	[64]	1	3
	[99]	1	3
	[62]	1	3
	[100]	2	3
	[53]	1	2
	[52]	1	3
	[55]	1, 2	3
	[47]	1	3
	[65]	3	3
	[66]	1, 3	3
	[45]	1	3
	[57]	1	3
	[67]	1	3
	[56]	1	3
	[103]	1	3
	[71]	1, 2	3
	[104]	-	3
	[72]	-	1
5	[112]	1	3

Legend 1—research topic (related to AR) (first column):

(1) Use of 360° videos in AR. Studies based on the use of immersive videos in Augmented Reality.
(2) Virtual environments embedded in AR. Studies based on virtual learning environments and their integration with Augmented Reality technology.
(3) Teacher's digital competencies. Studies focused on the development of digital teaching skills through the use of Augmented Reality.
(4) Learning applications for AR. Studies focused on the use of various gaming applications and learning environments; for example, mobile learning or ubiquitous games.
(5) Development or adaptation of new Augmented Reality technologies. For example, plugin development (COPIE-STEM protocol).

Legend 2—Augmented Reality component (third column):

(1) With markers (e.g., images, QR, printed images). A visual or activation key is provided to know where to position the AR content.
(2) Without markers. A visual or activation key is not provided.
(3) Projection-based. The projection of virtual animations (from a mobile device, for example) is used on a surface of the world, whether a "real or physical world".

(4) Superimposition-based. It partially or totally replaces the view of a physical object with an augmented view of that same object.

Legend 3—teacher training phase (fourth column):

(1) Expert (teachers with teaching experience).
(2) Beginner (teachers new to teaching).
(3) Pre-service (teacher-training students).

As Table 4 shows, the most frequent research topics in the reviewed articles are learning applications for AR (79.19%), virtual environments embedded in AR (9.72%), and the use of 360° videos in AR (5.55%). As for the AR component, physical markers such as QRs or images are the most used in educational research (54; 75%) while other studies (10) research AR with no markers (13.88%). However, to a lesser extent, five research works focused on a more sophisticated technology: projection-based AR (4; 5.55%) or superimposition AR (1; 1.38%).

Finally, the majority of the studies included in this SLR performed AR research within the pre-service teaching period (66; 91.66%); eight (11.11%) investigated the AR components as used by expert teachers, whereas only two (2.77%) tested AR in the teaching induction period (beginner teachers).

4. Discussion

The aim of this research was to conduct a Systematic Literature Review related to the use of AR in teacher education. To this end, five research questions were posed in relation to (1) the analysis of academic production using bibliometric indicators (publication resources, author keywords, and countries), (2) methodological analysis, and (3) the analysis of the topics (subjects of study) related to the research topic.

The research production analyzed mainly came from three well-known journals in the field of technologies applied to education: Computers and Education (23), Computers in Human Behavior (6), and the conference proceedings published in Procedia Computer Science (19). Our analysis of the papers indicates that technologies in teacher education with an emphasis on the use of Augmented Reality has been increasing over the last ten years (2012–October 2022).

Moreover, the analysis of author keywords highlights the importance of the use of AR in education and, more specifically, in teacher education. In this regard, recent theoretical studies [12,116] and empirical studies carried out at the university [117], primary education [118], and high school [119,120] levels shed evidence on the pedagogical use of AR as an effective tool to promote student learning. However, the analysis of the scientific production gathered from Scopus reaffirms a lack of sufficient empirical research related to the importance of AR for the teacher training process. The related scarcity of qualitative and mixed studies carried out in educational research has had a negative impact on the generalizability of our results [121].

The results of other similar theoretical studies [122] scrutinizing the effect of gamification on academic performance have also reaffirmed the need for teacher training not only in the use of serious games based on AR but also in the understanding and pedagogical use of several digital technologies [123–125].

Five clusters were identified from the analysis of the author keywords, which show there is a strong relationship between Augmented Reality, mobile learning, interactive learning environments, and motivation.

Concerning mobile learning, the effectiveness of Augmented Reality in improving student engagement and providing a sense of reality is well known, especially in science education [12,13,15,19]. In this context, the concerns related to pedagogical usability [126,127], safety and privacy [19], and pedagogic practice are also important [128,129].

In the studies related to the keywords Augmented Reality and interactive learning environments, the need for educational software to be able to record, interact, and visualize objects in 3D is pointed out. However, the design of this software can be executed with or without bookmarks. The essence and effectiveness of interactive learning lies in selecting the right environment, instructional design, teacher training, and content management tools. The main tools used in educational studies for visualization are commercial or open-source ARs such as ARToolKit and Unity 3D. While content management tools such as Vuforia (virtual content storage) and Maya 3D are used for virtual content creation [130,131].

In the relationship between AR and motivation, it is noteworthy that the motivational factors of attention, satisfaction, and confidence increase with the use of AR, but not for the factor related to relevance [85,108,132].

This SLR of 72 research works shows that there is a great deal of diversity in the type of studies conducted, with a focus on exploratory and quasi-experimental studies. However, only 27 works explicitly state the reliability of the instruments applied, 9 mention the validity, and only 8 show the reliability and validity obtained in the design and application of the instruments. This does not detract from the quality of peer review and the editorial process of the journals, but it is a call to the community to offer reliable data and instruments for subsequent use (replicability).

Although the 72 studies are related to teacher training through AR, only 52 focus explicitly on this topic. As for the AR component used according to the user's point of view, the studies focus their application on the use of markers (53) with an emphasis on the technological training of teachers. Few studies were related to the components of artificial intelligence based on projection and superimposition. On the other hand, regarding the stage of teacher training, 66 studies focus their attention on initial training (66), which highlights the limited number of studies on in-service teacher training. This reinforces the idea that educational research on AR is still in a preliminary phase and needs more evidence to test whether this technology is efficient for teacher training.

Finally, an overwhelming number of studies focus on student teachers, leading us to think that the main results are limited to the initial teacher training and could be different when applied in other teacher education phases such as beginner or expert teachers [133].

5. Conclusions

A Systematic Literature Review (SLR) was conducted to find research articles related to the use of AR in teacher education. However, it is important to consider that the study selection was based on the articles detected by Scopus during a period ranging from the year 2012 to October 2022 and on articles written in English. Therefore, valuable studies written in other languages may have been excluded from this study. Although 72 studies by authors from 32 countries were analyzed, this does not imply that it is representative of the world's current educational reality but may, however, offer a possible perspective on the use of AR in the field of education.

The results of this systematic review reaffirm the scarcity of studies on teacher training using Augmented Reality. However, regardless of the type of studies, the didactic use of Augmented Reality in teacher training requires (a) initial and ongoing didactic training of teachers, (b) digital literacy appropriate to the new technological environments, and (c) the adaptation of techno-pedagogical models for teacher training in the context of Augmented Reality.

Another relevant finding from this review is the lack of research papers connecting the use of AR with the teaching practicum, which highlights the importance of this type of study for empirically validating the extent to which this immersive technology could be useful in preparing future teachers. Further research could consider conducting qualitative and mixed method studies to enrich the comprehension of the phenomenon under study, especially to those areas that are less researched and more prominent such as AR based on artificial intelligence (e.g., superimposition). Only generating a robust corpus of knowledge around this topic would enable teachers and teacher educators to know whether this type of technology would be beneficial for learning purposes.

Current trends in the use of AR in teacher education do not often include emerging concepts and tools related to Situated Visualization [134]. For this reason, it is suggested that future research assesses its techno-pedagogical use, since it contributes to the integration between space, timelines, place, activity, and the community.

Recent empirical research reinforces the importance of the use of AR in initial teacher training, allowing the development of digital skills for teachers to use AR in their pedagogical practice [135]. In this sense, it is advisable to promote the use of emerging pedagogies before the use of these emerging technologies [136–138].

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