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Review Article

A Systematic Literature Review of Augmented Reality–Oriented Professional Development Programs for Teachers

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Abstract
Augmented Reality (AR) combines real-world experiences with virtual elements and offers various positive educational outcomes. However, one obstacle hindering AR's use in education is teachers' limited pedagogical knowledge regarding the instructional implementation of AR in teaching. Supporting teachers with professional development programmes to integrate this novel technology into education is salient. Thus, this study analysed 17 professional development programmes focused on integrating AR into teaching. For this purpose, a framework was applied to examine dimensions that make training effective, including the type of activity (traditional and reform), duration, collective participation, content focus (theoretical, pedagogical and practical knowledge), active learning (e.g., observing teaching, planning classroom implementation, reviewing student work, and presenting, leading, and writing), and coherence (e.g., connections with goals, alignment with state and district standards and assessments). Findings from the systematic analysis indicated that the majority of teacher professional development programmes addressed theoretical, pedagogical, and practical knowledge. However, observation of teaching and review of students' work in active learning dimensions were lacking. Regarding the general characteristics of studies, most employed a mixed-method approach and delivered the programme in person. Marker-based augmented reality was the most preferred type, and smartphones and tablets were the most commonly used electronic devices. The findings can be beneficial for AR-oriented professional development studies by presenting an overview of effective professional development programme dimensions. Nonetheless, there is still a need for effective AR-oriented professional development programmes for pre- and in-service teachers, and this review can assist in developing new teacher professional development programmes focusing on AR.

Keywords: Augmented Reality, Teacher Education, Teacher Professional Development, Technology Education

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1. INTRODUCTION

Novel technologies such as augmented reality (AR), which combine real-world experiences with virtual elements (Azuma, 1997; Quintero et al., 2015), have the potential to transform education. AR enhances students' academic achievement and performance (Hsieh, 2021; Xu et al., 2022), facilitates learning abstract concepts by providing spatial experiences (Huang et al., 2022), engages students to participate in lesson activities (Sáez-López et al., 2020), and increases student motivation (Hsieh, 2021; Huang et al., 2022; Jesionkowska et al., 2020). It also provides skill development such as creative thinking (Sáez-López et al., 2020), collaborative skills (O'Shea & Curry-Corcoran, 2013), and 21st-century skills (Demircioglu et al., 2022; Jesionkowska et al., 2020).

Teachers' beliefs and attitudes are essential factors in effectively implementing novel technologies in classrooms (Teo, 2015), and sufficient knowledge to integrate related technologies is critical. Rahmat and Mohamad (2021) found that while pre-service teachers are motivated to incorporate AR into their teaching, they are uncertain about how to manage this integration. Studies investigating AR acceptance among pre- and in-service teachers show that the perceived usefulness of AR is also an essential factor in its classroom use (Ibili et al., 2019; Rahmat & Mohamad, 2021).

AR-enhanced lessons offer many opportunities for students, but they also pose a challenge for teachers due to the time required to create AR learning materials and identify suitable AR applications for integration across various subjects (Laine et al., 2016; Sırakaya & Alsancak Sırakaya, 2022). To ease the burden on teachers, teacher professional development (TPD) programmes that demonstrate the effective use of AR are crucial. However, it is not only important to enable these programmes but also to ensure they prioritise pedagogical use and other key factors for effective TPD. The effective integration of new technologies in education, with the help of TPD programmes, has been shown to enhance teachers' positive attitudes and confidence in integrating technology (Chiu et al., 2019; Garzón et al., 2019; Kim et al., 2013; Pellas et al., 2019; Sırakaya & Alsancak Sırakaya, 2022). Specifically, regarding AR technologies, researchers emphasise the need for high-quality TPD programmes to make AR more accessible and appealing to teachers (Sırakaya & Alsancak Sırakaya, 2022). However, previous studies indicate that teachers often lack theoretical and pedagogical knowledge concerning AR integration in teaching. Chiu et al. (2019) reported that teachers' unfamiliarity with using AR in the classroom hindered their ability to benefit from it. For example, teachers' lesson plans were not well-planned or lacked adequate scaffolding and guidance (Belda-Medina, 2022). Moreover, many teachers resist adopting AR for reasons related to limited technical knowledge and a lack of understanding of its educational use (Garzón et al., 2019; Sırakaya & Alsancak Sırakaya, 2022).

Garet et al. (2001) proposed a framework for developing effective TPD. According to this framework, six factors should be considered when designing a TPD programme. Those are (1) type of activity, (2) duration, (3) collective participation, (4) content focus, (5) active learning, and (6) coherence. The activity type is divided into two dimensions: traditional and reform. If a TPD programme provides continuous support and ongoing seminars to teachers, it is considered a reform activity. In terms of duration, Garet et al. (2001) state that longer activities are better since they allow more time for learning and implementation. Collective participation emphasises that participants from the same school have more opportunities to discuss and apply what they have learned in TPD programmes. Content focus includes activities that are divided into three dimensions: (a) theoretical knowledge, (b) pedagogical knowledge, and (c) practical knowledge. In terms of the active learning factor, Garet et al. (2001) discussed four activities that can be incorporated into TPD programmes: (a) observing teaching, (b) planning classroom implementation, (c) reviewing student work, and (d) presenting, leading, and writing. Finally, coherence addresses participants' experiences and associations with the curriculum across three dimensions: (a) connections with goals and other activities, (b) alignment with state and district standards and assessments, and (c) communication with others.

This study aims to systematically examine TPD programmes for pre- and in-service teachers that provide training for AR use in education, utilising Garet et al.'s (2001) framework. With this aim, the following research questions are asked:

RQ1: What is the current state of TPD programmes for AR in education?

RQ2: What are the characteristics of AR-oriented TPD programmes?

These questions are developed to understand the current status of TPD programmes related to AR in education. The intention is to facilitate TPD developers' decision-making while designing TPD for pre- and in-service teachers by providing systematic knowledge from previous AR TPD initiatives.

1.1. Literature Review

1.1.1. AR in Education

AR is a way of combining virtual objects by overlaying them onto the physical environment and allowing instant interactions (Azuma, 1997; Quintero et al., 2015). This approach enables abstract concepts to be presented through 3D virtual representations at relatively low cost (Ibili et al., 2019). Ensuring affordability is crucial for technology to be readily integrated into classrooms, a goal AR achieves through mobile applications accessible via phones and tablets.

AR offers opportunities across disciplines, for example, astronomy, natural sciences, physics, and science education (Cheng & Tsai, 2013; Chiang et al., 2014; Demircioglu et al., 2022; Huang et al., 2022; Ibáñez et al., 2016; Sahin & Yilmaz, 2020; Xu et al., 2022) as it solidifies abstract concepts (Chiu et al., 2019; Parga et al., 2023; Yoon et al., 2017). Moreover, AR fosters an interactive classroom environment with tools that facilitate cooperative work (Ke & Hsu, 2015). As such, students can easily engage in discussions while learning concepts through AR. The interactive nature of AR-enhanced lessons helps to increase students' participation and attention (Aziz et al., 2012; Belda-Medina, 2022; Ke & Hsu, 2015; Sáez-López et al., 2020).

Additionally, AR-enhanced lessons increase students' motivation toward the subject matter (Chiang et al., 2014; Hsieh, 2021; Jesionkowska et al., 2020). For example, Hsieh (2021) found that fourth-grade students were interested in using AR in their learning and motivated to study the subject, which in this study was marine education. Furthermore, AR can make learning complex concepts easier by demonstrating them in different ways (Barrow et al., 2019; Nikimaleki & Rahimi, 2022). Students can manipulate 3D objects using zooming and rotation functions (O'Shea & Curry-Corcoran, 2013). Interacting in these ways helps make the learning process more effective for students in less time (Lasica et al., 2020). In this manner, AR-enhanced lessons positively impact students' learning achievement (Sahin & Yilmaz, 2020; Sulisworo et al., 2021; Xu et al., 2022). Additionally, studies indicate that AR can reduce students' cognitive load (Buchner et al., 2022; Lai et al., 2018). Buchner et al.'s (2022) meta-analysis results showed AR-enhanced lessons induce less or equal cognitive load compared to traditional lessons.

1.1.1. Teacher Professional Development Programmes and AR

The effective integration of technology is closely tied to its utilisation in different parts of teaching (Wiest, 2001). In many countries, this effective utilisation is enabled by regularly organised government TPD programmes that aim to equip teachers with up-to-date information about rapid changes (Kennedy, 2016). This emphasis on regularly organised TPD programmes underscores the significance of continuous teacher support. With such a support system in place, teachers find it easier to keep up with the changes, given their already substantial workload (Teo, 2015). Integrating new technologies into classrooms is a multifaceted process requiring various skills and knowledge (Drijvers, 2019; Garzón et al., 2019; Pellas et al., 2019). Nonetheless, it is worth investing time, as integrating digital technologies offers benefits by providing different representations of knowledge (Ball et al., 2018).

In the technology integration process, factors such as curriculum, national policies, and school culture are important, but the pivotal factor remains the teacher (Drijvers, 2019; Hegedus et al., 2017). When teachers demonstrate strong motivation to use emerging technologies in classrooms, students are more likely to derive benefits from them (Carson & Chase, 2009; Kalyar et al., 2018; Thoonen et al., 2011). For example, a study investigating teachers' beliefs about integrating technology found that positive beliefs were associated with students' motivation and engagement in learning (De Souza et al., 2021). TPD programmes are vital at this point as they can reshape teachers' beliefs, increase motivation, and foster the development of knowledge and practices (Bebell & Kay, 2010; Ertmer et al., 2012; Thurm & Barzel, 2020). In the pursuit of integrating new technology into education, it is essential to present the knowledge base associated with the technology, as this influences teachers' acceptance of it (Antonietti et al., 2022). Ibili et al. (2019) investigated math teachers' perceptions of AR using the technology acceptance model and found a positive relationship between teachers' perceived usefulness, satisfaction, and ease of use of AR applications. Similarly, Rahmat and Mohamad (2021) highlighted perceived usefulness as a critical factor in AR acceptance. In addition, Ibili et al. identified anxiety as a negative factor affecting ease of use, indicating its relation to teachers' knowledge of AR. When teachers feel confident in leveraging this technology in their classrooms, they experience less anxiety and hold more favorable perceptions of its usefulness (Ibili et al., 2019). Therefore, TPD programmes and other supportive initiatives hold a salient place in positively shifting teachers' perceptions of successful, effective AR integration into classrooms.

Despite the common-sense importance of TPD programmes, there is still little consensus on effective TPD that alters teachers' habits (Kennedy, 2016). Designing an effective TPD programme involves multiple aspects; it requires teachers' voluntary involvement and willingness to learn and, at times, change their prior understanding of their classroom practices (Avalos, 2010; Bechtel & O'Sullivan, 2006). According to Kennedy (2016), designing a TPD programme involves incorporating specific design features tailored to teachers' needs and their context. These design features vary across TPDs. To effectively integrate AR into subject matter, teachers need high-quality training involving pedagogical approaches and technological tools (Lasica et al., 2020). Studies indicate that both pre- and in-service teachers lack sufficient pedagogical skills to create AR content (Belda-Medina, 2022). For example, their lesson plans may not be well planned or may lack scaffolding and guidance. The shortage of teacher support may contribute to this and constrain its use in classrooms. In this sense, pre- and in-service teachers require better training concerning both technological and pedagogical aspects of AR to successfully integrate it into education. However, the knowledge base for TPD remains limited in effectively engaging teachers to use AR technologies in the classroom.

2. METHODOLOGY

2.1. Research Design

This study employed a systematic review method to enhance understanding of AR in TPD. Following Xiao and Watson's (2019) protocol, the reviewing process consisted of three stages: (1) conducting an initial literature search, (2) screening articles, and (3) performing analytical coding.

2.2. Data Collection Procedures

2.2.1. Conducting an Initial Literature Search

Web of Science (WOS) and the Education Resources Information Center (ERIC) were selected for the literature search. WOS covers a broad range of disciplines and indexes leading journals across multiple fields. ERIC focuses specifically on education research. Their broad coverage and established use in systematic reviews guided the selection. In the Web of Science (WOS) database, a set of search strings comprising three groups of key phrases was utilised. The first group included "augmented reality" OR "AR" in the title; the second group included "teacher$" in the abstract; the third group included "professional development" OR "teacher training" OR "workshop" OR "training" OR "teacher development" in the abstract. In the ERIC database, this line of keywords was used: "augmented reality" AND "teacher$" AND ("professional development" OR "teacher training" OR "workshop" OR "training" OR "teacher development"). The truncation symbol $ was applied to the term teacher to retrieve both singular and plural forms. No time limitation was imposed on the search, and all studies available up to the date of the last search, November 28, 2023, were considered as candidates for inclusion in the systematic review. At the end of the initial literature search, 191 papers were retrieved for screening: 121 from WOS and 70 from ERIC.

2.2.1. Screening

The study's inclusion and exclusion criteria were used in determining papers' alignment with the research questions. Only original research articles and conference papers meeting the subsequent criteria were considered. First, studies primarily focused on AR were included; second, studies targeted pre- or in-service teachers as the primary audience were included; third, studies employing a TPD programme focusing on AR were included. Studies were excluded if they investigated only virtual reality or mixed reality rather than AR (e.g., Gilbert et al., 2018; Krug et al., 2023; MacCallum & Parsons, 2022), did not target pre- or in-service teachers (e.g., Wu & Tsai, 2023; Simonova & Kolesnichenko, 2022; Costa et al., 2021), lacked a TPD programme focusing on AR (e.g., Marín-Marín et al., 2023; Aso et al., 2021; Gómez-García et al., 2021), or were not written in English, or were review papers or book chapters. In WOS, the search excluded review articles and book chapters (n=9). The search was then refined by selecting only articles written in English (n=24). Next, the articles were screened, and those not providing full-text access were excluded (n=4). Ultimately, 84 articles from WOS were retrieved for screening. In the ERIC database, 70 articles were retrieved. After applying filters for only peer-reviewed articles (n=10) and removing duplicates (n=1), along with excluding review articles (n=3) and those not providing full-text access (n=5), 51 articles were left. Upon comparing the results with WOS, 18 articles were found to be duplicates and were removed. Duplicate records were identified during the screening process by reviewing all retrieved studies, and any duplicates found were removed. Finally, 33 articles were retrieved from the ERIC database. Screening continued with the remaining 117 articles to apply the inclusion-exclusion criteria.

After incorporating these criteria, 15 articles were included. Additionally, to identify other relevant articles, references cited in the literature review sections of the chosen studies were included, yielding two retrieved studies (Ke & Hsu, 2015; Oberdörfer et al., 2021). In the end, 17 articles were selected for systematic analysis. One article included two different TPD programmes (George et al., 2023); therefore, 18 TPD programmes were examined in total (Figure 1).

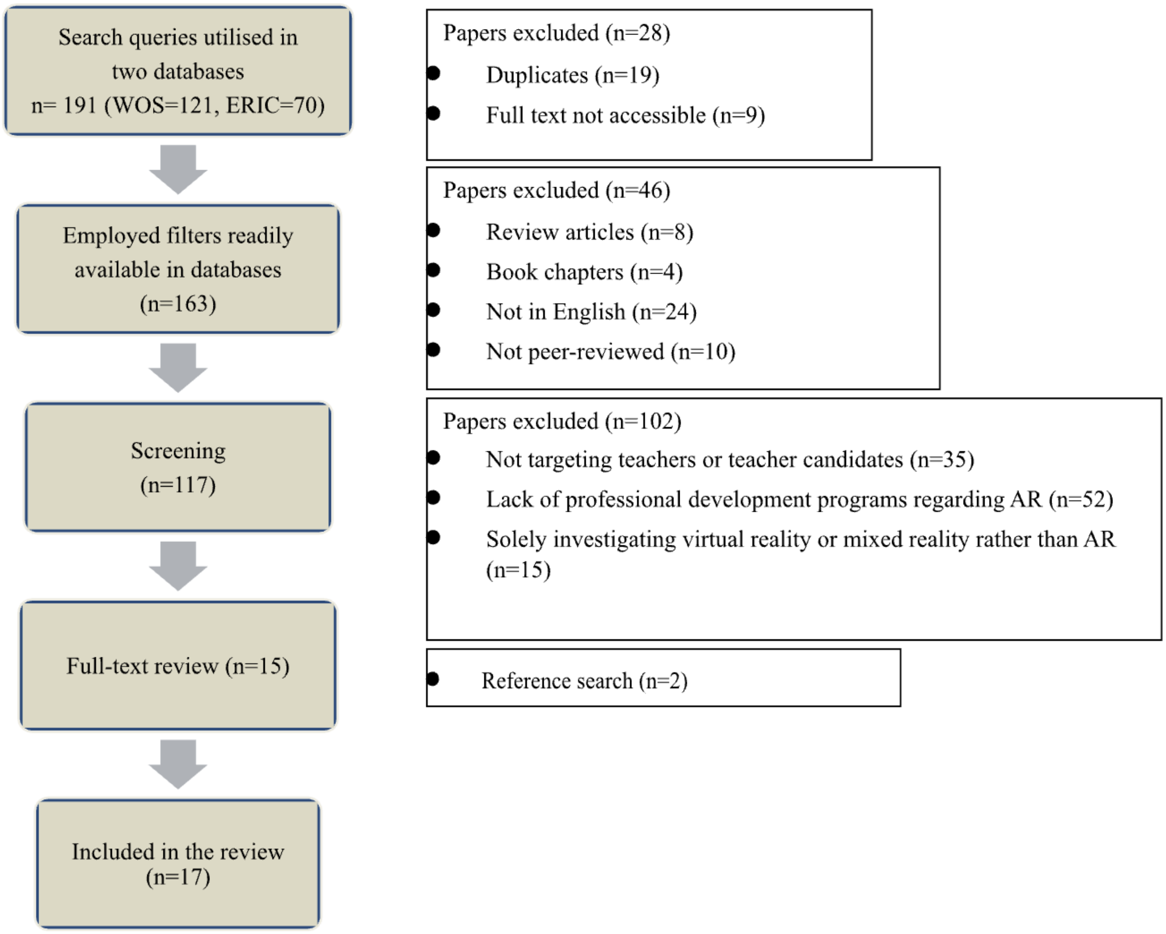

Figure 1. Flowchart of the Systematic Review

The Mixed Methods Appraisal Tool (MMAT) version 2018 (Hong et al., 2018) was utilised to appraise studies and critically assess the risk of bias. Out of 17 studies, ten clearly stated their research question (e.g., Pombo & Marques, 2021; Wang & Tan, 2023); others only stated their research aim (e.g., Meletiou-Mavrotheris et al., 2020; Wannapiroon et al., 2021). Some mixed-methods studies lacked detailed quantitative data analysis, making it challenging to appraise the quantitative section (e.g., Belda-Medina, 2022; Mystakidis et al., 2021). Additionally, some mixed-method studies did not clearly state why they chose the mixed-method approach (e.g., Belda-Medina, 2022; Freese et al., 2023). In quantitative studies, it was difficult to assess the risk of nonresponse bias because of insufficient detail. Otherwise, appropriate data collection tools were used, results were interpreted by addressing the data, and research questions were eventually answered.

2.3. Data Analysis

2.3.1. Analytical Coding

After selecting papers for the literature review, we conducted a comprehensive analysis of the chosen articles by extensively reading them and examining their content for analytical coding. The coding scheme was based on the effective TPD measures outlined by Garet et al. (2001). According to this framework, effective TPD comprises two main dimensions encompassing six measures. Structural features include (1) the type of activity, (2) duration, and (3) collective participation, while core features consist of (4) content focus, (5) active learning, and (6) coherence. In addition to these features, the characteristics of the studies and TPD programmes, as well as findings related to AR, were examined. In total, 18 TPD programmes reported across 17 articles were reviewed, with one study examining two separate programmes for in-service and pre-service teachers.

3. RESULTS

3.1. General Characteristics of Professional Development Programmes

3.1.1. Methods of Studies and Publication Years

The publication years of the articles ranged from 2013 to 2023 (Figure 2). Two studies were conducted before 2020, and interest in AR in TPD programmes surged in 2020, with the majority of publications occurring in 2021.

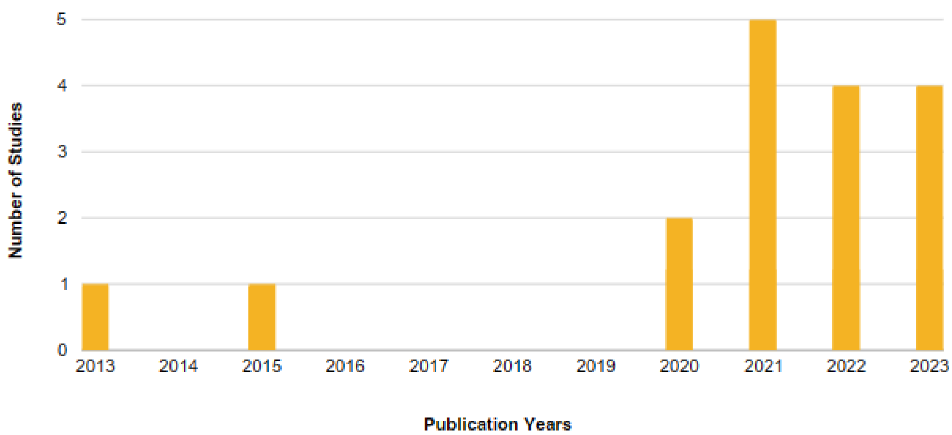

Figure 2. Publication Years of Studies

Results show that AR-oriented TPD programmes employed diverse research methods. Most studies used mixed methods (n=8), with others employing quantitative (n=3) and qualitative (n=2) methods. Quantitative studies primarily focused on identifying factors predicting intentions to use AR in classrooms and understanding views on AR using a correlational research design and questionnaires (George et al., 2023; Karacan & Polat, 2022; Marín et al., 2022). Qualitative and mixed-method studies mostly focused on developing a TPD programme and investigating the process through case studies and pre-post tests combined with interviews (e.g., Belda-Medina, 2022; Gokbulut & Durnali, 2023; Sulisworo et al., 2021). However, some studies did not specify their research methods as mixed, qualitative, or quantitative (n=4).

3.1.2. Delivery Methods

In terms of how TPD takes place, the most preferred method was face-to-face (Figure 3) (e.g., George et al., 2023; Nikimaleki & Rahimi, 2022; O'Shea & Curry-Corcoran, 2013). The hybrid approach was commonly used for independent work or for supportive online training programmes, incorporating face-to-face meetings and additional online content (e.g., Freese et al., 2023; Ke & Hsu, 2015; Lasica et al., 2020). Finally, there were two online programmes (George et al., 2023; Mystakidis et al., 2021); one mentioned it was initially intended to be face-to-face but had to be moved online due to COVID-19 (Mystakidis et al., 2021).

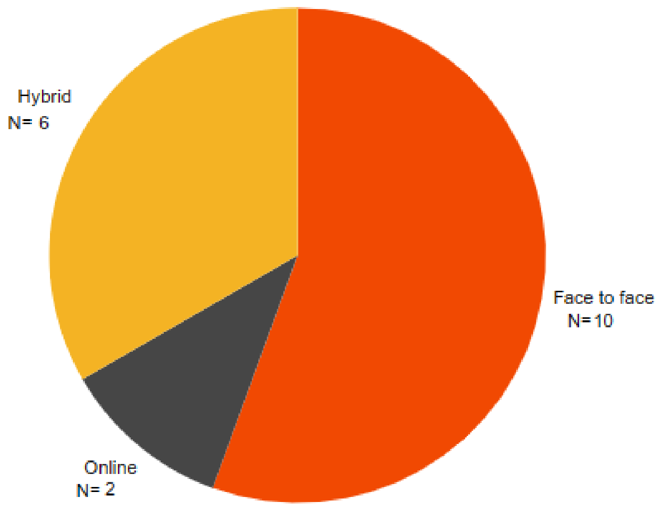

Figure 3. Delivery Methods of TPD Programmes

3.2. Findings Regarding AR Integration

3.2.1. Electronic Devices Used

Results show that smartphones were the most commonly used device (n=14), followed by tablets (n=6) and computers/laptops (n=2) (Figure 4). Some TPD programmes used more than one device; therefore, the numbers in Figure 4 differ from the total number of studies reviewed. AR's ease of use on mobile devices and its lack of need for expensive, specialised equipment are crucial features for its use in schools.

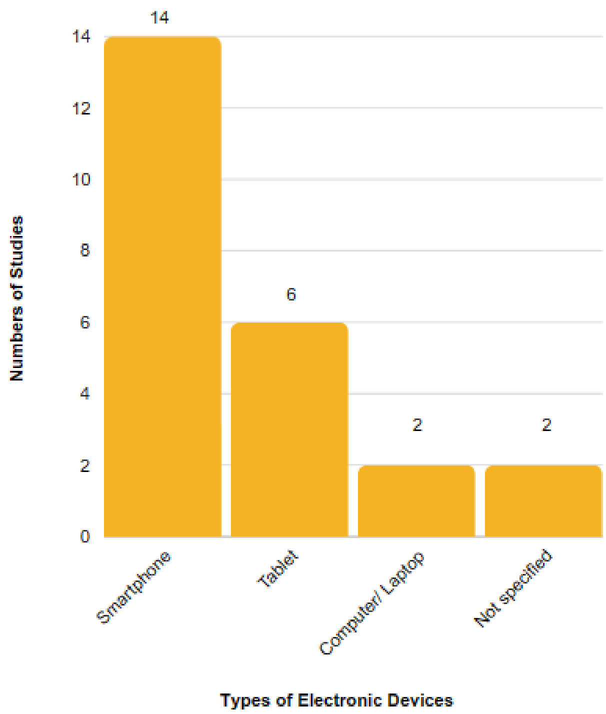

Figure 4. Type of Electronic Devices Used

3.2.1. Type of AR

Results show that the most commonly used type of AR was marker-based AR (Figure 5). Some TPD programmes used more than one type of AR; therefore, the numbers in Figure 5 differ from the total number of studies reviewed. Location-based and markerless-based AR were also used, but in limited numbers. Marker-based AR is the easiest to create and use with smartphones and tablets by scanning objects, making it the preferred option. However, location-based AR is also necessary for outdoor learning.

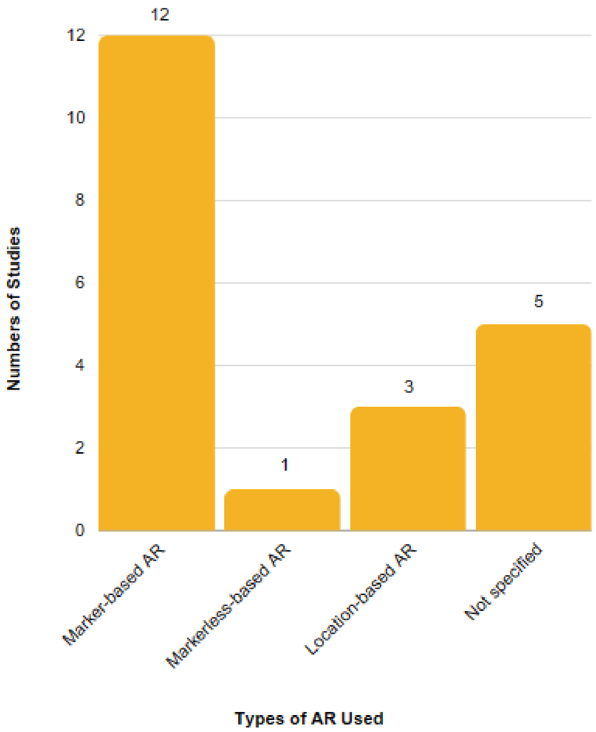

Figure 5. Types of AR Used

3.3. Type of Activity

Garet et al. (2001) structured the types of activity into two categories: traditional and reform. Traditional learning activities take place outside the teacher's school and have scheduled times. Examples of such activities include workshops, institutes, courses, and conferences. Reform activities are defined as activities occurring during the regular school day or as regularly scheduled events, while teachers continue their teaching in schools. Moreover, mentoring, coaching, and teacher academies that offer ongoing seminars and courses are considered reform activities.

The majority of the studies were classified as reform in terms of activity type. 13 studies were categorised as reform (e.g., Gokbulut & Durnali, 2023; Marques & Pombo, 2021; Oberdörfer et al., 2021), while five were classified as traditional (e.g., Ke & Hsu, 2015; O'Shea & Curry-Corcoran, 2013). TPD programmes chosen for reform type were generally lengthy programmes. These long-term programmes consisted of regularly scheduled sessions and provided opportunities for pre- and in-service teachers to enhance their instructional skills. Moreover, teachers received feedback as part of the reform-type activities. Further, with regular sessions, teachers were able to resolve issues within the allotted time frame and receive guidance on their materials and instruction. Also, some activities in the reform-type programmes provided authentic experiences with creating their applications and reflecting throughout the process with peer communication.

As Garet et al. stated, even though some programmes are short, they can still undergo reform-type transformations with other distinctive features, as evidenced in two studies (Gokbulut & Durnali, 2023; Wannapiroon et al., 2021). In those studies, participants were supported throughout the implementation process, a salient feature of the reform type. Additionally, participants actively engaged in creating lesson materials, implementing them, and receiving feedback from experts.

Five studies were classified as traditional (e.g., Ke & Hsu, 2015; O'Shea & Curry-Corcoran, 2013), mainly because they were relatively short. While these studies showed significant improvements in the implementation of AR, they lacked ongoing sessions and consistent feedback due to time constraints.

3.4. Duration

The duration refers to the period during which TPD programmes are conducted. Garet et al. (2001) argue that longer activities are more advantageous since they allow for more thorough content discussions. Figure 6 depicts the duration of TPD programmes. Five programmes lasted less than one month, with individual training sessions ranging from three days to two weeks. Four studies held the training programmes for 2-3 months, while seven lasted 4-5 months, which was the most commonly preferred duration. Finally, two studies conducted the training programme for six months, marking the longest duration.

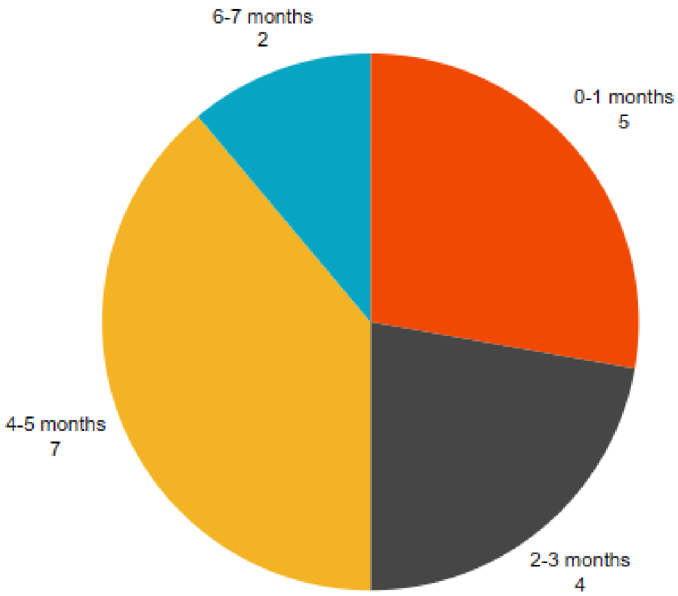

Figure 6. Duration of AR-oriented TPD Programmes

Based on the results, there is a tendency to design long-term, continuous AR-oriented training programmes. The length of TPD programmes may stem from the novelty of the AR and the need for theoretical and practical knowledge among pre- and in-service teachers.

3.4. Collective Participation

Collective participation is closely tied to developing TPD within the same school, department, or grade level. According to Garet et al. (2001), this allows teachers to discuss concepts and problems extensively, leading to shared understanding and solutions in their classes.

The TPD programmes in each study had varying participant disciplines or grade levels. Some studies included both pre-service and in-service teachers from the same discipline, while others involved participants from different disciplines. Out of the 18 TPD programmes, ten mentioned the disciplines of the training participants. Among those ten programmes, five had participants from the same department: three from English Language and two from Science Education. However, other TPD participants were from various disciplines, including STEM-related subject domains such as Mathematics, Science, Physics, Chemistry, Biology, Computer Science, and Geography. There were also participants from Preschool, Primary Education, and Social Sciences.

Additionally, in most studies, it was unclear which grades the participants taught or whether they worked at the same school. The remaining eight training programmes did not mention the participants' disciplines. Instead, they stated that participants were K-12 teachers from different disciplines. Additionally, the studies' target group was mostly in-service teachers (n=12).

In one study (George et al., 2023), training was provided to both pre-service and in-service teachers. Although the disciplines of pre-service teachers were specified, the subject domains of in-service teachers were unclear. Some were studying at the postgraduate level in the Department of Information and Communication Technology (ICT) in Education, while others only mentioned attending a teacher training seminar without specifying their disciplines. Therefore, the teachers' discipline was categorized as not defined.

The primary goal of TPD programmes was to demonstrate to both pre- and in-service teachers how to utilise AR in education. As a result, no particular discipline of study is exclusively represented. Instead, the aim was to showcase this novel technology to pre- and in-service teachers from various disciplines. Figure 7 shows the number of TPD programmes with participants from specific disciplines. The figure's numbers differ from the total count of reviewed studies, as some studies encompassed participants from multiple disciplines.

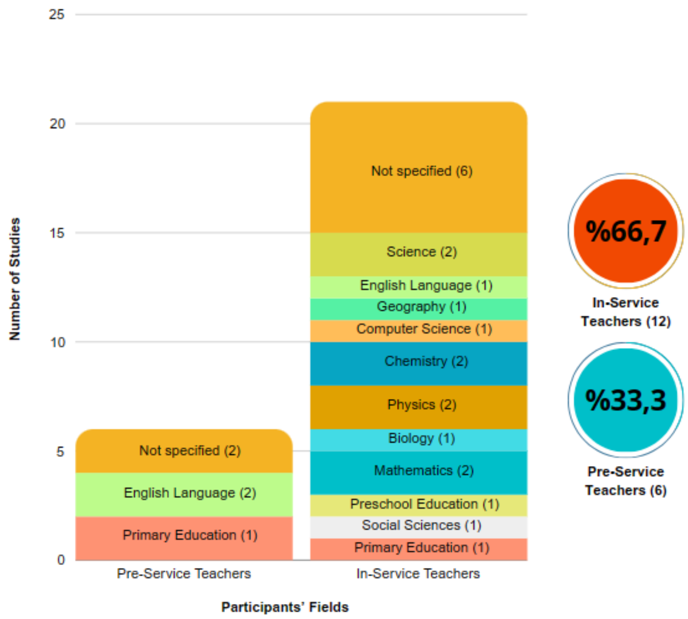

Figure 7. The Disciplines of the Participants in the AR-oriented TPD Programmes

3.6. Content Focus

Garet et al. examined the focus of activities aimed at enhancing teachers' knowledge about a specific subject matter. The content focus varied according to each program's emphasis. Nevertheless, most studies pursued a similar path: they first provided participants with theoretical knowledge about AR, followed by practical sessions to create materials to integrate into lessons. In addition, studies focused on the pedagogical aspect of effectively integrating information into lessons with AR. Furthermore, each study placed particular emphasis on a specific topic-related curriculum. These topics were varied, such as Physics, Chemistry, Biology, Earth Science, Science, STEM, Mathematics, and English. The skills incorporated were digital storytelling, creative thinking, and reading literacy. The contents of the training programmes are shown in Appendix A.

3.7. Active Learning

Regarding active learning, Garet et al. (2001) focused on four dimensions: (1) observing teaching, (2) planning classroom implementation, (3) reviewing student work, and (4) presenting, leading, and writing. First, in observing teaching, the main emphasis is on obtaining feedback and mentoring as part of TPD. Observing teachers by leaders or participants is an essential part of this dimension. Second, planning classroom implementation provides an opportunity to apply concepts learned during TPD. Practising under simulated situations, communicating with experts or other participants regarding classroom implementation, and designing lesson plans and curricula are components of this dimension. Thirdly, the primary focus of reviewing student work is to identify student problems and design lessons accordingly. Therefore, reviewing students' completed work and examining student outcomes are considered practices within this dimension. Lastly, in the fourth dimension, presenting, leading, and writing, active participation is taken into consideration. Practices such as conducting a lesson demonstration, facilitating group discussions, and writing papers, reports, or plans are considered practices in this dimension.

Regarding active learning, reviewed TPD programmes employed a variety of methods. These methods are grouped according to Garet et al.'s categorization (Appendix B). The most popular approaches to active learning involve planning classroom implementation, presenting, leading, and writing. However, there is a lack of attention given to observing teaching and reviewing students' work. This result arises because TPD programmes prioritise AR content creation by pre- and in-service teachers. Therefore, neither student outcomes nor teacher observations were targeted.

3.8. Coherence

In the last measure, three dimensions are considered: (1) connections with goals and other activities, (2) alignment with state and district standards and assessments, and (3) communication with others. The first dimension represents whether the activities are connected to teachers' previous experiences. The second dimension focuses on how well the activity aligns with standards and curriculum frameworks. The final dimension concerns whether teachers have discussed what they learned with other teachers and communicated outside formal TPD sessions.

Results showed that coherence in practices was mainly achieved through alignment with state and district standards and assessments, and through effective communication (Appendix C). When creating AR-enhanced materials, TPD programmes encouraged selecting topics aligned with the school curriculum. It is beneficial, since in-service teachers mostly prefer training opportunities that can be directly integrated into their classrooms. TPD programmes address this by selecting topics from the curriculum or by providing pedagogical guidance on integrating AR in the classroom.

Regarding communication with others, most TPD programmes utilise collaborative processes and group work (e.g., Nikimaleki & Rahimi, 2022; Oberdörfer et al., 2021). Discussions following these programmes are also essential for fostering a shared experience among teachers. Some studies have even established communities to share experiences and keep each other up to date on their work (e.g., Lasica et al., 2020; Meletiou-Mavrotheris et al., 2020). These communities are crucial for keeping teachers engaged in the long run. Furthermore, they provide an excellent opportunity to observe what other teachers do, learn about the challenges they encountered beforehand, and draw inspiration from them.

However, connections with goals and other activities were the least considered factor in coherence. Typically, TPD programmes do not assess teachers' previous experiences, knowledge, and needs, though doing so beforehand can be helpful. This approach allows the programme to focus on areas where teachers may need more assistance rather than covering topics they already know. Studies that gather this information in advance examine teachers' expectations, needs, and prior knowledge (e.g., Lasica & Katzis, 2020; Sulisworo et al., 2021). In addition, one study (Pombo & Marques, 2021) collected information on school conditions, which may be beneficial when developing the TPD programme, particularly regarding technological devices and potential challenges they may face at their school.

4. DISCUSSION AND SUGGESTIONS

This study aimed to systematically examine AR-oriented TPD programmes. Regarding the first research question, the general characteristics of TPD programmes were reviewed. The findings revealed that the majority of AR-oriented TPD programmes were conducted between 2021 and 2023, despite several studies being conducted in 2013 and 2015. Irwanto et al. (2022) stated that AR studies in education peaked in 2020-2021. As a result, AR-oriented TPD programmes began to emerge during these years.

A mixed-methods approach was the most preferred research method. The majority of qualitative and mixed-method studies focused on developing a TPD programme and investigating the process through case studies and pre-post tests with interviews. Quantitative studies investigated the factors predicting intentions to use AR in teaching and understanding pre- and in-service teachers' views on AR.

AR-oriented TPD programmes were primarily delivered face-to-face. A hybrid approach was also used, with theoretical sessions delivered online and practical implementations delivered in person. Nevertheless, the number of online TPD programmes was limited; one programme planned initially for face-to-face delivery had to transition online due to COVID-19. Hybrid approaches in TPD programmes encourage social interaction among participants, prompting them to apply knowledge gained from online sessions (Burns, 2010). However, online sessions may lead to disengagement, as studies on hybrid TPD programmes have shown lower participation and interactivity than in in-person sessions (Widodo & Riandi, 2013; Yılmaz & Malone, 2020), with fewer participants (Widodo & Riandi, 2013). Therefore, face-to-face models for AR-oriented TPD programmes can be preferred over online programmes.

In AR implementations, smartphones and tablets were the most commonly used electronic devices in TPD programmes. This opportunity is highly valued because it enhances accessibility. Recent systematic reviews indicate that AR applications on mobile devices have increased AR use (Garzón et al., 2019; Pellas et al., 2019).

The most common type of AR was marker-based. Location-based and markerless AR were also used, but to a lesser extent, which is in line with previous studies (Aktamiş & Arici, 2013; Pellas et al., 2019; Sharma et al., 2022; Xu et al., 2022). A recent meta-analysis of various types of AR and their effects on academic achievement found that marker-based AR is most beneficial (Xu et al., 2022). It is more commonly used in education because it is easier to manage, whereas markerless and location-based AR require more advanced technical skills (Sharma et al., 2022). This could also be because current educational AR applications use marker-based systems, and studies are limited to using ready-made ones. This result highlights the need for markerless and location-based AR applications that can be used in teaching.

Concerning the second research question, AR-oriented TPD programmes were systematically examined using Garet et al.'s (2001) framework for developing effective TPD. The first dimension in the framework was the type of activity. According to the findings, most studies were classified as reform in terms of activity type. Long-term programmes were a common feature of reform-type programmes, and these TPD programmes provided more opportunities for pre- and in-service teachers to experience AR. However, traditional TPD programmes tended to be one-time, short seminar workshops. There were also TPD programmes classified as reform types despite their short duration. Participants in those TPD programmes (Gokbulut & Durnali, 2023; Wannapiroon et al., 2021) were supported and closely monitored throughout the implementation process, a distinctive aspect of the reform type in addition to its duration. Also, duration dimension results showed that most TPD programmes lasted between four and five months or less than a month.

The TPD process for teachers is acknowledged as a long-term, continuous learning journey (Deglau & O'Sullivan, 2006; Dori & Herscovitz, 2005; Luneta, 2012). Typically, long-term TPD programmes are seen as more beneficial than short-term programmes. As a result, there is an effort to plan long-term TPD programmes for pre- and in-service teachers. Furthermore, review studies show that long-term TPD programmes are more effective at improving teachers' skills (Basma & Savage, 2018; Garrett et al., 2019). However, a recent study found no impact of TPD duration on teachers' learning processes and discussed whether duration is a mediator of effectiveness (Lindvall et al., 2023). Thus, the duration of TPD programmes is not the only determinant of their effectiveness. Similarly, in our review, we found that while some AR-oriented TPD programmes were short, those could still be classified as reform-type TPD.

The third dimension was collective participation, which was related to teachers' disciplines and whether they were from the same school. According to Garet et al. (2001), teachers from the same schools and similar disciplines can develop a shared understanding and create solutions for their classes. According to the findings, there is no specific emphasis on bringing teachers together from the same discipline. Some TPD programmes didn't specify participant disciplines, usually only mentioning pre-service and in-service teachers, with most participants being in-service teachers. Parker et al. (2015) implemented a STEM-focused TPD programme for K-5 teachers and found that collective participation was an essential part of it. Teachers who received the TPD programme in grade-level groups continued to meet with their peers after the programme ended. Desimone et al. (2003) also reported limited opportunities for collective participation in the TPD. They looked at collective participation in the same department and grade level. However, only 14% of participants were from the same school or grade level, limiting collective participation as teachers attended these programmes individually. Schools typically do not offer opportunities for all teachers in the same department. A recent study also investigated collective participation and found it did not hinder teachers' learning (Kyureghyan, 2023). It was also noted that teachers from the same school had more opportunities to share their experiences and observe effective practices in each other's classrooms.

The fourth framework dimension was content focus, divided into three sub-dimensions: (1) theoretical, (2) pedagogical, and (3) practical knowledge. The findings revealed that most TPD programmes addressed all those knowledge areas, with varying emphasis depending on the programme's focus. Studies suggest that TPD programmes targeting technology integration should cover technical, pedagogical, and classroom management content rather than focusing solely on the technology (Amanatidis, 2015; DeSantis, 2012; Unger & Tracey, 2013). Our findings indicate that TPD programmes focused on AR meet these requirements by addressing theoretical, pedagogical, and practical knowledge. This is a promising development in the field of AR-oriented teacher TPD programmes, as educators often find integrating new technology into a learning environment complex and stressful (Ledger, 2021). For instance, it can lead to new classroom management issues (Avci & Lawson, 2020). Thus, it is recommended that teachers receive guidance on managing the classroom in line with the technology they plan to integrate (Barrett-Greenly, 2013). Therefore, training should focus on both technological and pedagogical knowledge.

Regarding the active learning dimension, the results indicated that the majority of studies focused on lesson planning, presenting, leading, and writing. Similarly, ICT-focused TPD programmes provide theoretical knowledge first through introductory sessions, then proceed to practical work such as project development, lesson planning, and classroom implementation (Ajani & Govender, 2023; Hennessy et al., 2022). In TPD programmes, creating tangible materials reflecting what has been learned is beneficial. As adult learners, teachers prefer task-oriented TPD activities that provide them with ready-made materials for their classrooms (Collins & Liang, 2014). However, observation of teaching and, especially, review of students' work is lacking. Observing teaching in this framework was not limited to observing teaching practices in schools but also included observing pre- and in-service teachers implement their materials through micro-teaching, which is still uncommon in TPD programmes. However, micro-teaching practices in TPD programmes provide teachers with opportunities to receive feedback and revise their approaches and lesson plans (Lo, 2021). Alshehri (2021) investigated the impact of micro-teaching on science teachers' AR learning. Results showed that teachers engaged in micro-teaching had better practical solutions and skills in utilising AR applications in the post-test. The least preferred type of active learning was reviewing students' work. This relates to the primary aim of these programmes, which is to provide training and support for teachers' potential use of this tool without prioritising follow-up initiatives. However, it is also critical to fully assess whether TPD achieves its goal of teaching teachers the necessary knowledge by examining student outcomes. A common critique of TPD programmes is that they often fail to effectively transfer knowledge and skills to real classroom settings. However, this issue can be addressed through firsthand classroom experience, which helps teachers build confidence in applying what they have learned and allows them to better evaluate its potential. (Ledger, 2021; Ripsam & Nerdel, 2024). As such, AR presents challenges that can only be understood when implemented in the learning environment. In an AR-enhanced lesson, classroom management is different because students move around while investigating with AR, which might not be typical in a regular classroom setting (Perifanou et al., 2022). Furthermore, teachers need to balance providing feedback to students with engaging them in AR to prevent it from becoming merely a fun activity (Cai et al., 2023). To achieve this, teachers should be given the opportunity to experience AR technology during TPD sessions and then reflect on their classroom experiences afterward (Getenet, 2020; King, 2002; Walker et al., 2023). Because AR is unfamiliar to many teachers, they may feel unsupported when using this new technology without proper guidance (Costa et al., 2021; Jančaříková & Eva, 2019; Romano et al., 2023; Wei et al., 2015).

In terms of TPD programme coherence, studies reported alignment with standards and communication with others through learning communities. However, connections with goals and other activities were missing. Teachers' prior experiences, knowledge, and needs were not collected, which can lead to difficulties such as unfamiliarity with specific applications. Similarly, this issue was highlighted in the literature, noting that reform efforts were scarce because studies failed to consider teachers' prior knowledge and perceptions (Verloop, 2001; Warford, 2011). Furthermore, studies show that training programmes are more effective when teachers are involved in determining TPD goals. According to a recent study, teachers' involvement in designing learning was found to be a statistically significant factor regarding TPD outcomes (Cole, 2023), indicating that greater levels of control over the learning process may result in more positive outcomes.

These findings have implications for AR-focused TPD studies. Future AR-oriented TPD programmes could incorporate more active learning activities, including opportunities for teachers to plan and implement lessons in the classroom. This allows teachers to directly apply what they develop during TPD in their teaching practice. At the same time, activities that emphasise in-class practices are essential, as practicing and receiving feedback helps teachers integrate improvements effectively. This is especially salient in the AR context, where challenges such as classroom management may arise. While longer TPDs tend to benefit teachers more, they often demand considerable effort, which can limit the number of AR-oriented programmes offered. Our results suggest that even shorter TPDs can be effective when complemented by features such as continuous support and feedback. Prioritising only longer programmes, without the capacity to implement them, may hinder the growth of AR-oriented TPDs. Consequently, well-designed short workshops can still provide substantial benefits, raising teachers' awareness and confidence in using this technology.

Moreover, in the planning phase of TPD programmes, considering teachers' prior experiences is important for coherence, as it is known that determining the TPD's aim together with teachers or collecting what teachers already know before the TPD makes the process more efficient (Cole, 2023). Furthermore, information on teachers' school conditions can help tailor TPD activities to those conditions. For example, if it is impossible to give each student an electronic device for AR activities, teachers need to consider group work to minimise the number of devices used, and the TPD programme can focus on how teachers can plan effective AR-oriented lessons using collaborative learning. Collective participation is also a critical component of these programmes. Selecting pre- and in-service teachers from similar disciplines and schools for the TPD programme participants can help maintain acquired knowledge and motivation (Kyureghyan, 2023; Parker, 2015). If it is not applicable, building teachers' communities where teachers can share their experiences can be another way to achieve this.

These findings also have implications beyond individual TPD programmes. For higher education institutions involved in pre-service teacher training, integrating AR-focused coursework early in teacher education programmes can support teachers' use of AR in teaching. Curriculum developers can incorporate guidance on AR-specific classroom management, including how to manage the physical activity involved when students explore AR content, which might differ from conventional classroom settings (Perifanou et al., 2022). Providing teachers with clear strategies for these situations can ease AR integration. Educational application developers can similarly account for these dynamics, for instance, by designing tools that support structured collaborative use of AR.

This study has several limitations that should be acknowledged. First, the review was limited to Web of Science and ERIC databases. Thus, some valuable studies may have been excluded. Researchers seeking a more thorough examination should consider expanding the search to include additional databases, such as Google Scholar. Additionally, the review was restricted to English-language publications, which may have excluded relevant work. Second, although the inclusion and exclusion criteria for studies were discussed by the authors, a single researcher systematically examined the studies, which may be a potential limitation. Moreover, the literature search was completed in late 2023. Therefore, more recent studies were not included. In addition, the use of Garet et al.'s (2001) framework, while theoretically grounded, may not fully capture AR-specific dimensions of professional learning.

5. CONCLUSION

This study examined 17 TPD programmes that focused on enhancing pre- and in-service teachers' AR integration into teaching using Garet et al.'s (2001) effective TPD characteristics framework. Overall, the majority of teacher professional development programmes cover theoretical, pedagogical, and practical knowledge, which is promising for teachers' professional development related to AR. However, TPD programmes usually do not follow up with participants after TPD ends. This is essential, especially for new technologies like AR (Barrett-Greenly, 2013; Ledger, 2021). Future TPD programmes can incorporate this follow-up process in the planning phase of the TPD. Additionally, because AR is a new technology for teachers, classroom observations or micro-teaching activities are needed after receiving TPD (Alshehri, 2021; Jagari, 2016; Lo, 2021). This way, teachers can better learn and overcome the complexity of AR in classrooms. Furthermore, there is still a need for effective AR-oriented TPD programmes for pre- and in-service teachers. AR is a promising technology across various disciplines, so future tech-focused TPD initiatives can focus on it and help teachers achieve widespread positive AR outcomes.

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Appendix A. Examination of TPD Programs in Terms of Content Focus

Study	Theoretical Knowledge	Pedagogical Knowledge	Practical Knowledge
Belda-Medina, 2022	Different AR types (location-aware and vision-based); tool limitations; possible obstacles	Organising materials in a scaffolded manner	Creating AR materials with three software development kits (Linkreader, Augmentaty, Roar)
Freese et al., 2023	The basic principles of models; creating 3D models with GeoGebra to	Instructions to create AR experiments in classrooms; meaningful usage of AR experiments in STEM lessons	Developing AR experiments by creating 3D models using GeoGebra
Gokbulut & Durnali, 2023	AR Applications with Visual Coding Languages	Fundamental principles behind the use of AR in education; steps to create educational materials using the Waterfall Model; the standards for successfully transforming digital materials into digital teaching materials	Learning to use software programs and tools; design practices with TinkerCad, SketchUp; transferring 3D models designed with TinkerCad and SketchUp to an AR environment
George et al., 2023 (in-service)	Mobile AR affordances in education; four tools and platforms for developing image-based and location-based AR apps are presented (ARIS, Zapworks, BlippAR, and ROAR)	-	Creating an example of AR for a subject area utilising each of the AR technologies presented
George et al., 2023 (pre-service)	Introduced BlippAR in use of augmenting school textbooks	Set learning objectives for prepared AR materials according to the revised Bloom's cognitive taxonomy	Utilised a marker-based AR platform BlippAR to augment school textbooks
Karacan & Polat, 2022	Introduced to AR platforms on the market to utilise ready-made materials (e.g., HPReveal, Arize, Aurasma)	How to develop AR-based applications for vocabulary teaching purposes	Taught how to create their own AR experiences using the introduced platforms
Ke & Hsu, 2015	The design heuristics of making an instructional video or an informative animation via Aurasma	-	Creating a collection of smartphone-based AR videos or animations via mobile software (Aurasma Lite) to illustrate and teach the concept and calculation of buoyant force
Lasica et al., 2020	Sharing various applications/tools for developing AR content (e.g., HP Reveal, Metaverse, ARTutor)	Inquiry-based instruction within the school curriculum through the integration of AR; development of AR learning objects	Development of AR lesson plans with proper tools and applications
Marín et al., 2022	Theoretical aspects of emerging technologies, with a focus on AR	Provided knowledge to implement AR in creating content for primary schools	Designed AR content
Meletiou-Mavrotheris et al., 2020	Benefits of AR as a learning tool; related AR applications	Pedagogical aspects of AR; assessing AR-integrated learning outcomes	Use of AR applications; design and implementation of AR content
Mystakidis et al., 2021	Describing the concepts of AR; digital storytelling with AR	Determining learning objects to integrate AR into teaching	Using AR applications; employing collaborative AR-supported learning scenarios

Nikimaleki & Rahimi, 2022	Use of AR-supported 3D models to facilitate comprehension of concepts	Pedagogical procedure for collaborative learning	Creating a collaborative AR-enhanced learning environment using the AR app
Oberdörfer et al., 2021	Usability concepts, individual-centred design, conceptual design, and guidelines for 3D interface design	Pedagogical design of media; integration of AR applications in the classroom; instructional design with AR; assessment with AR topics	Creation of a gamified AR experience
O'Shea & Curry-Corcoran, 2013	Game elements for an AR-supported experience: creation of student roles, storyboarding of virtual characters and objects, integration of academic content	Integration of AR-supported educational games	Creation of student-authored AR experiences
Pombo & Marques, 2021	The theoretical background of AR in education; tools related to mobile AR games	AR-enhanced mobile and game-based learning	Creating collaborative resources to integrate into the AR app
Sulisworo et al., 2021	AR-based materials; AR-enhanced measurement instruments for science learning	Use of AR to develop higher-order thinking skills in science education	Utilising AR-based applications for global warming (KOFIN)
Wang & Tan, 2023	AR technologies; benefits of AR from recent educational research	Multimodal literacies' interaction with AR apps	Tested and assessed various AR applications
Wannapiroon et al., 2021	Fundamentals of creating AR-enhanced interactive learning media	Development of interactive learning materials using the Imagineering process	Developing AR-enhanced interactive learning materials

Appendix B. Examination of TPD Programs in Terms of Active Learning

Study	Observe Teaching	Plan Classroom Implementation	Review Students' Work	Presenting, Leading, and Writing
Belda-Medina, 2022	-	Designed an AR-supported lesson plan	-	Implemented lesson plan in a real classroom setting
Freese et al., 2023	Teachers were provided with a document outlining the implementation process; received student feedback and revised the materials; input from experts on teachers' learning processes and their understanding of AR experiments.	Developed AR experiments to implement in lessons	-	Incorporated the finished AR experiments into lessons
Gokbulut & Durnali, 2023	During the course, if teachers had questions or needed help with the applications, the instructor or assistant provided assistance	Developed digital materials with AR for students' actual use in classrooms	-	Developed instructional materials, presented them to other teachers and experts, and revised them based on feedback
George et al., 2023 (in-service)	-	-	-	Developed materials for a subject area by using various AR applications
George et al., 2023 (pre-service)	Assisted pre-service teachers throughout the augmentation process via teleconference meetings	Augmented chapters of the school textbooks	-	-
Karacan & Polat, 2022	-	Built an AR application for vocabulary learning, integrated it into a 3rd-grade course book, and planned classroom implementation	-	-
Ke & Hsu, 2015	-	Created AR-enhanced videos and animations	-	-
Lasica et al., 2020	Observed teachers while they were executing their instructional practices	Created AR-enhanced STEM lesson plans	Examined students' learning outcomes (worksheets,	Executed lesson plans in a real classroom setting

			achievements, tests, etc.)	
Marín et al., 2022	-	Designed AR content that is suitable for Spanish legislation for primary school students	-	-
Meletiou-Mavrotheris et al., 2020	Observed teaching practices	Designed lesson plans	Assessed learning outcomes (reading skills and the competence of augmented readers were examined)	Implemented lesson plans in a real classroom setting
Mystakidis et al., 2021	-	Designed and implemented an applicable, collaborative scenario with AR and integrated it into lesson plans	-	Executed lesson plans in a real classroom setting and made critical reflections and decisions about the suitability of AR
Nikimaleki & Rahimi, 2022	-	Planned a classroom implementation and designed a curriculum aligned with the syllabus	-	-
Oberdörfer et al., 2021	-	Created AR-supported learning content with Unity	-	-
O'Shea & Curry-Corcoran, 2013	-	Created narrative-based AR games and integrated them into classrooms	-	Implemented AR games in a real classroom setting
Pombo & Marquez, 2021	-	Designed educational resources considering the National Science Curriculum	-	Presented designed educational resources to other participants and engaged in discussion
Sulisworo et al., 2021	-	-	-	Presented an AR-supported learning evaluation instrument
Wang & Tan, 2023	-	Implemented AR apps suitable for assisting students in achieving targeted learning goals	-	-
Wannapiroon et al., 2021	-	Created AR-enhanced interactive	Assessed the quality of the	Presented materials and got

	learning materials and a learning management plan for planning	products that students created	feedback from the experts

Appendix C. Examination of TPD Programs in Terms of Coherence

Study	Connections with Goals and Other Activities	Alignment with State and District Standards and Assessments	Communication with Others
Belda-Medina, 2022	-	Selected an English topic that aligns with the curriculum to teach while using their AR materials in the intervention	Evaluation of AR-enhanced materials among participants; sharing thoughts on AR effectiveness and teaching experiences; discussions with semi-structured debates about the learning outcomes of PD
Freese et al., 2023	Teachers' existing knowledge and skills were considered	Developed AR experiments suitable for use in classrooms	Reflections on the classroom implementation with the group; peer evaluation for AR experiments
Gokbulut & Durnali, 2023	-	Aimed to design materials to use in classrooms, considered standards for integration, and determined themes and content of lessons for relevancy	Participants actively communicate through teamwork, sharing experiences, and giving feedback
George et al., 2023 (1)	-	-	-
George et al., 2023 (2)	-	Augmented chapters of the school textbooks and set learning objectives according to them	-
Karacan & Polat, 2022	-	Aimed at improving vocabulary learning with the AR app and created an English course book for 3rd-grade students	Discussion among the participants at the end of the TPD related to AR in language learning
Ke & Hsu, 2015	-	Chosen a topic from the curriculum, buoyant force	Review and discussion sessions for each AR-enhanced video among participants
Lasica et al., 2020	-	Emphasised the necessity of learning materials aligning with the primary curriculum	Discussion and reflection on teachers learning experiences; creating an AR STEM teachers' community
Marín et al., 2022	-	AR content was developed for the primary school stage, taking into account Spanish legislation	-
Meletiou-Mavrotheris et al., 2020	-	Integrated a module on how to fit AR content into the curriculum; aimed for core curricular ideas while designing materials	An online discussion forum where teachers communicate with each other
Mystakidis et al., 2021	Determining teachers' previous knowledge; analysing the alignment between the planned learning outcomes and teachers' needs with SWOT self-diagnostic assessments and critical reflection on knowledge and skills	Used Cyprus Pedagogical Institute guidelines for educational materials; evaluated content for relevance, inclusivity, and applicability across all student age groups and school settings	Peer communication; group discussions; collaborative learning throughout the program

Nikimaleki & Rahimi, 2022	-	Developed materials in the context of language curriculum design	Preparation of materials with other teachers; collaboration throughout the process
Oberdörfer et al., 2021	-	Encouraged pre-service teachers to choose topics that align with the curriculum concepts and integrate them into the lesson	Group work for AR projects; collaborative process throughout the PD
O'Shea & Curry-Corcoran, 2013	-	Pedagogical lesson given to teachers about integrating AR experience into their curriculum	-
Pombo & Marquez, 2021	Information related to teacher expectations, school conditions, and previous experiences was gathered before the training	Designed educational resources considering the National Science Curriculum to be able to use in their schools	Encouragement to be involved in peer discussions and group reflections throughout the TPD process
Sulisworo et al., 2021	Executed needs identification via open-ended questionnaires	Integrated AR into a curriculum-related topic and added special sections for school quality improvement in the era of the Industrial Revolution 4.0	Discussions about subsequent actions; program evaluation at the end of PD
Wang & Tan, 2023	Workshop developed based on teachers' prior experiences	Evaluated the suitability of various AR apps for developing primary students' multimodal literacies; reviewed AR app suitability for various school year levels' coursework	-
Wannapiroon et al., 2021	-	Considered compliance with the fundamental education core curriculum while constructing the content	-