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Using virtual reality for teacher education: a systematic review and meta-analysis of literature from 2014 to 2024

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The global demand for qualified teachers continues to rise, yet conventional training models often fall short in offering scalable, inclusive, and practically rich learning experiences that prepare educators for real-world classroom challenges. Virtual reality (VR) is increasingly recognized as a transformative tool in teacher education, offering immersive, interactive, and repeatable environments that support procedural rehearsal, affective engagement, and reflective practice. However, existing research remains fragmented, with few studies providing a comprehensive review of VR's application in teacher education, its overall effectiveness, and the factors that influence learning objectives. This study systematically reviewed 52 empirical studies published between 2014 and 2024, including 22 experimental and quasi-experimental designs, which were further synthesized through meta-analysis to evaluate the overall effectiveness of VR-supported instruction. The results indicate a positive moderate overall effect of VR in teacher education (Hedges' $g = 0.524$), with significant variations based on immersion level, equipment type, and learning objectives. These findings offer strong evidence for integrating VR into both pre-service and in-service teacher training and highlight its potential to support accessible, adaptive, and scalable professional development. The study provides practical implications for practitioners, teacher educators, and VR developers seeking to align VR tools with diverse learning needs in teacher preparation.

KEYWORDS

teacher education, teacher training, virtual reality, systematic literature review, meta-analysis

1 Introduction

In recent years, teacher education and professional development have been widely recognized as essential to ensuring high-quality education. However, many education systems continue to face challenges in recruiting, training, and retaining qualified teachers (OECD, 2024). According to UNESCO, addressing the global teacher shortage is urgent, with an estimated 69 million new teachers needed by 2030 to achieve universal education goals (UNESCO, 2023). This growing demand highlights the need to enhance teacher preparation programs that equip educators with practical skills for real-world classroom contexts. Despite this recognition, traditional training approaches face persistent limitations. Traditional teacher training often fails to bridge the gap between theory and practice, offering limited hands-on experience and lacking realistic simulations, which hinders teachers' ability to apply pedagogical knowledge effectively in complex

classroom settings (Badiie and Kaufman, 2015; Dawson and Lignugaris Kraft, 2017; Furman and Yarden, 2019; McGarr et al., 2016; Spencer et al., 2019).

Given these challenges, VR has emerged as a promising tool in teacher education, offering an innovative approach for bridging the gap between theory and practice. VR technology has been widely integrated into various fields, including healthcare (Thomas and Singh, 2021), entertainment (Rothe et al., 2020), tourism (Merkx and Nawijn, 2021), and education (Luo et al., 2021). In teacher education, VR provides realistic, interactive, and repeatable training environments, allowing teachers to develop classroom management and pedagogical skills in a risk-free environment (e.g., Li et al., 2024; Wang and Li, 2024). Shih (2014) defined VR as a computer-generated immersive environment that enables users to engage and navigate virtual settings, emphasizing key attributes such as presence and interactivity (Ryan, 2015). These features position VR as an effective alternative to traditional teacher-training models, enhancing teacher education (Bi et al., 2025; Chen, 2022; Lee and Wu, 2024).

Specifically, VR-based training offers three core advantages. First, immersion enables teachers to experience realistic classroom simulations that replicate the complexity of real-world teaching environments, allowing them to practice instructional decision-making or classroom management in a realistic yet controlled setting (Buragohain et al., 2024; Docter et al., 2024; Zhang et al., 2023). Second, interactivity distinguishes VR from traditional training methods, which often involve passive observations. VR-based simulations allow teachers to actively engage with virtual students, instructional content, and simulated classroom environments in real-time (Delamarre et al., 2021; Rodríguez, 2024). Third, repeatability allows teachers to perform complex teaching tasks multiple times. Unlike real classrooms, where trial-and-error opportunities are limited, VR provides a structured and iterative learning environment where trainees can reset scenarios, refine responses, and receive continuous feedback (Chen, 2022; Stavroulia et al., 2025). Although VR holds significant promise, several barriers hinder its widespread adoption in teacher education. High costs, along with issues such as motion sickness, physical discomfort, technical limitations, and safety concerns, remain key barriers to VR adoption in teacher education (Bajorunaite et al., 2022; Baniyadi et al., 2020; Lysenko and Kachur, 2023; Vlahovic et al., 2021). To realize its full potential, VR must be thoughtfully integrated into teacher education programs, aligning technological affordances with sound pedagogical principles.

Although VR offers valuable opportunities for immersive and repeatable teacher training, its use also presents significant challenges. One key issue lies in the realism of virtual student behavior. Many VR platforms rely on scripted responses, which often fail to reflect the spontaneity, diversity, and social complexity of real classroom interactions (Dieker et al., 2013). These design limitations may lead teachers to develop rigid or artificial response patterns during training, which may not transfer well to actual classroom situations. As a result, VR-based training has shown limited effectiveness in helping teachers apply acquired skills in real teaching environments (Lowell and Tagare, 2023). Improving the flexibility and behavioral richness of virtual students remains a critical task for enhancing

the practical value and instructional effectiveness of VR-based teacher education.

Research on VR in teacher education has expanded in recent years; however, several gaps remain. Most studies focus on pre-service teachers, particularly university-level students (e.g., Lee and Kim, 2024; Richter et al., 2022). Consequently, systematic reviews often exclude in-service teacher training, limiting insights into how experienced educators engage with VR (Nyaaba et al., 2024; Serin, 2020; Van der Want and Visscher, 2024). In addition, many reviews are outdated, summarizing literature published before 2020 and overlooking recent advancements in VR applications (Billingsley et al., 2019; Huang et al., 2023). Furthermore, the technological features of VR remain underexplored. VR is not a uniform intervention; aspects such as immersion, interactivity, and portability may influence training objectives (Hudson et al., 2019; Jerome, 2024; Petersen et al., 2022; Radianti et al., 2020). However, few studies identify which features most impact teacher learning. For instance, Huang et al. (2023) reported device types and immersion levels but did not analyze other VR characteristics. Finally, the lack of meta-analytic synthesis limits understanding of VR's overall effectiveness and generalizability in teacher education.

In this review, VR technologies are categorized into three types based on the hardware used to deliver virtual experiences: head-mounted displays (HMDs), computers, and projection. All three types are designed to present virtual environments for teaching and learning, but they differ in terms of device form, user engagement, and delivery mechanisms. HMDs are typically worn on the head and offer an immersive, enclosed experience; computers refer to desktop or laptop systems using standard monitors, and input devices and projection systems use large screens or room-scale displays to present shared virtual scenes. Despite their shared function of simulating virtual environments, these VR types vary in their technological features. HMDs generally provide high levels of immersion and interactivity. Computers tend to offer lower immersion, with more limited interactivity. Projection systems allow semi-immersive experiences and may support collaborative use in physical classrooms, though with restricted sensory engagement. These distinctions are directly related to the variables evaluated in this review, including immersion, interactivity, portability, and internet dependency, which serve as key factors in understanding the instructional impact of VR.

To address these gaps, this study conducted a comprehensive systematic review and meta-analysis of research on VR in teacher education. By integrating qualitative synthesis with quantitative meta-analysis, this research provides a rigorous, evidence-based evaluation of progress in this field and the effectiveness of VR as a teacher training tool. Both pre-service and in-service teacher training were examined, VR's technological features were analyzed, and overall effectiveness was quantified using meta-analytic methods. By incorporating recent studies, an up-to-date assessment of VR's role in teacher education is presented in this review. Specifically, this study seeks to answer the following research questions:

1. What is the current status of global research on VR in teacher education?
2. What are the technological characteristics of VR applications for teacher education?

TABLE 1 Inclusion and exclusion criteria for study selection.

Screening criteria		Inclusion	Exclusion
1	Is the document duplicated?	No	Yes
2	Is the study available in full?	Yes	No
3	Is the study a review paper?	No	Yes
4	Is the study topic highly relevant to teacher education/teacher training/teacher development?	Yes	No
5	Does the study consider virtual reality technology as a tool for training teachers?	Yes	No

VR includes non-immersive forms such as desktop simulations, educational games, and virtual worlds. Studies focusing solely on AR or MR were excluded.

3. What are the main VR learning objectives in teacher education?
4. What is the overall effectiveness of VR in teacher education, and what factors moderate its effectiveness?

To address these research questions, a mixed-methods approach was adopted. Specifically, descriptive statistics were used for analyzing publication trends, participant characteristics, and research design (RQ1). Coding and frequency analysis were applied to identify technological characteristics (RQ2) and learning objectives (RQ3). A meta-analysis, complemented by moderator analyses, was conducted to evaluate intervention effectiveness and influencing factors (RQ4).

2 Methods

2.1 Study design

In accordance with the PRISMA 2020 guidelines, a systematic review and meta-analysis were conducted to identify, evaluate, and synthesize studies on the use of virtual reality in teacher education. The review procedure involved three core stages: literature retrieval, eligibility screening, and data coding, with the protocol registered on INPLASY (202530118). To estimate the overall instructional effectiveness of VR and examine potential moderating variables, the meta-analytic computations were performed using CMA 3.0 (Comprehensive Meta-Analysis 3.0).

2.2 Literature search

A comprehensive search strategy was implemented to identify relevant studies on VR in teacher education. Searches were conducted within two major academic databases, the Web of Science Core Collection (SCIE, SSCI, AHCI, ESCI) and Scopus, to ensure the inclusion of high-quality and interdisciplinary research. The search was restricted to English-language journal articles published between January 2014 and December 2024. The following search terms were applied to article abstracts: (“virtual reality” OR “VR” OR “metaverse”) AND (“teacher education” OR “teacher training” OR “teacher development”). The search, completed on 30 October 2024, yielded a total of 1,054 records.

2.3 Screening procedure

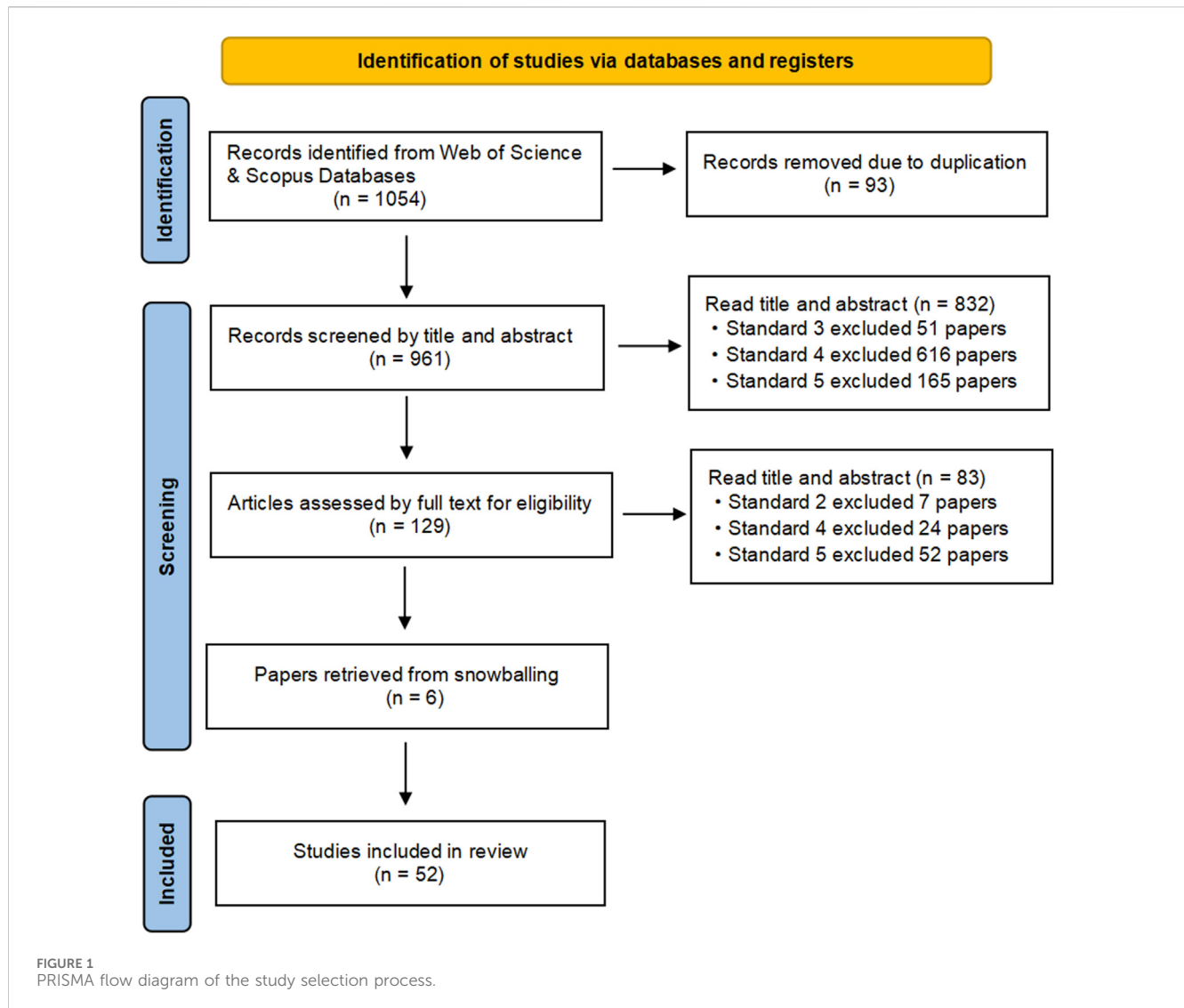
The initial screening involved duplicate removal and title/abstract screening. After eliminating 93 duplicate entries, the remaining studies were assessed according to inclusion and exclusion criteria developed collaboratively by the research team (see Table 1). Two researchers independently reviewed all titles and abstracts over a 2-week period. Articles were excluded if they clearly did not focus on VR-based interventions targeting teachers. Articles with ambiguous titles or abstracts were retained for full-text review.

Following this, a 1-h consensus meeting was held to resolve discrepancies, resulting in the exclusion of 832 articles. In the second round of screening, two researchers conducted a full-text review of the remaining 129 studies, with verification from a third researcher to ensure compliance with the inclusion criteria: (1) teachers as the target participants, and (2) use of VR as a training tool in teacher education. Studies involving augmented or mixed reality were excluded. Snowballing was also used to identify additional relevant works. After the final selection round, 52 studies met all inclusion criteria and were retained for analysis. The screening process is illustrated in Figure 1.

2.4 Coding protocol

To extract key information from the included papers, we systematically analyzed 52 studies by reading the full text. A coding manual was initially compiled by one researcher and refined collaboratively with two others. It was then reviewed by domain experts, and the final version was consolidated based on their feedback, as shown in Supplementary Table S1. The coding framework was adapted from established practices in systematic reviews and meta-analyses in educational technology (e.g., Means et al., 2009; Schneider and Preckel, 2017), and customized to the specific context of VR-based teacher education. It includes four major dimensions: basic information, research design, technological features, and instructional design.

Basic information (e.g., publication year, source, and study location) facilitates trend analysis and global mapping, helping to identify research concentration areas and regional disparities. The newly separated dimension, Participant characteristics, includes variables such as teacher status (pre-service or in-service), disciplinary focus, and grade level. This allows for more fine-grained subgroup analyses and enhances the understanding of sample diversity across studies. Research design encompasses methodological parameters such as study type, sample size, intervention duration, and data sources. These elements ensure methodological transparency and support the classification of evidence



strength across designs. Technological features (e.g., level of immersion, interactivity, internet dependency, and portability) are critical to evaluating the functional affordances and implementation constraints of various VR systems. Prior studies have shown that such characteristics can significantly influence learning effectiveness in educational environments (Petersen et al., 2022; Radianti et al., 2020). Instructional design captures pedagogical approaches, learning objectives, and assessment modes. Learning objectives were coded with reference to the TPACK framework (Mishra and Koehler, 2006), which emphasizes the intersection of technological, pedagogical, and content knowledge in teacher development. To accommodate inconsistent reporting practices, categories such as “Not mentioned” and “Mixed” were used where applicable (see [Supplementary Appendix A](#) for details).

To ensure reliability, two researchers independently coded all 52 studies, with the third researcher conducting a consistency check. The initial inter-rater reliability was 0.642 (Cohen’s Kappa). Discrepancies were discussed in subsequent team meetings, and coding rules were refined through repeated consultation until consensus was reached.

3 Results

3.1 Publication trend

Research on VR in teacher education has shown an overall upward trend over the past decade, as shown in [Figure 2](#). A modest rise in publications emerged around 2016, coinciding with the release of commercial head-mounted displays such as the Oculus Rift and HTC Vive (Luo et al., 2021). Adoption remained limited until 2020, when the number of studies began to increase more rapidly, likely due to advances in VR technology and the shift to digital learning during the COVID-19 pandemic (Bailenson et al., 2025). This trend contextualizes the increasing academic interest in applying VR technologies to teacher training, which aligns with the focus of the current review. In terms of publishing sources, the reviewed studies were published across a wide range of interdisciplinary journals, particularly in the fields of educational technology, computing, and digital learning. This range underscores the cross-disciplinary nature of VR-related research in teacher education. Geographically, studies originated from multiple countries and continents, with Europe and Asia emerging as the most active

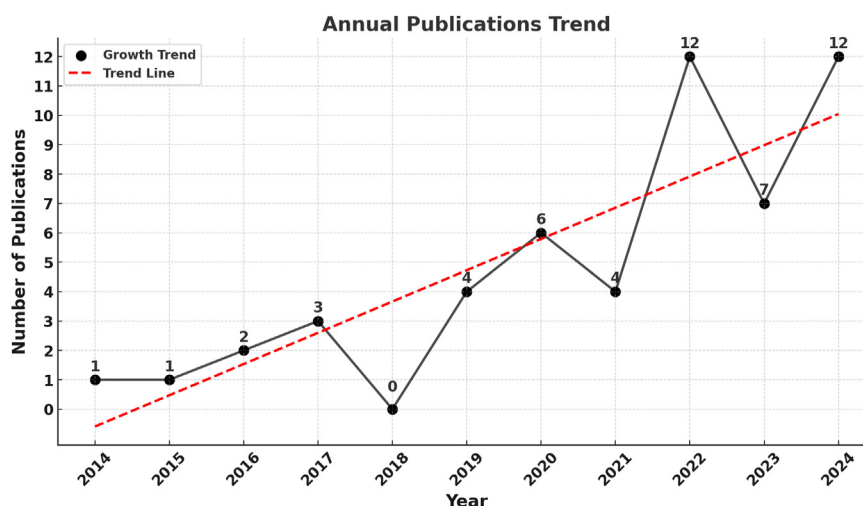


FIGURE 2
Annual publication trend over past decade.

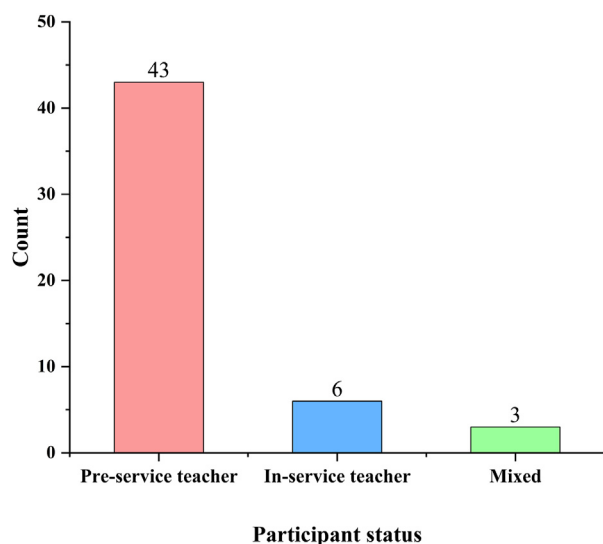


FIGURE 3
Distribution of participant status in included studies.

regions. This global distribution emphasizes the increasing international recognition of VR's potential to enhance teacher preparation and professional development across varied educational contexts.

3.2 Participant characteristics

3.2.1 Participant status

Figure 3 shows that, in terms of participant status, 43 studies focused on pre-service teachers, accounting for approximately 83% of all studies, while only six targeted in-service teachers. This distribution, which aligns with the findings of Huang et al. (2023), reflects the current research trend in VR-based teacher education. The emphasis on pre-service teachers suggests that

many studies aim to support the development of teaching skills and technological adaptability among future educators prior to their entry into the profession. In addition, the three studies involved a mixed group of participants, both of which included pre-service teachers and in-service teachers, making the sample more diversified and representative. Álvarez et al. (2024) further analyzed the data from pre-service and in-service teachers. The results showed that there were differences in perceived usefulness, behavioral intention, and related variables between pre-service and in-service teachers.

3.2.2 Disciplines and grade level taught by participants

Figure 4 shows the distribution of VR applications across disciplines in teacher education. The most common context was mixed-subject environments, followed by language education and basic sciences. STEM and special education were also represented, though both occurred less frequently. Regarding the grade levels taught by participants, VR has been applied to teacher education across multiple educational stages, with a substantial portion of studies situated in mixed-level contexts, where the grade levels were broadly defined (e.g., “elementary” or “K–12”) rather than specified precisely. Moreover, the majority of VR-based teacher training research has focused on K-12 settings, aiming to prepare educators for primary and secondary school teaching. This emphasis is unsurprising, as teacher education research has traditionally centered on the K-12 context. In contrast, relatively few studies have specifically targeted the training of university-level instructors. Notably, 14 studies did not clearly specify the educational stage or subject area, which may be due to their focus on evaluating the overall effectiveness of VR rather than its application within specific disciplines.

3.3 Research design

3.3.1 Sample size

The study with the largest number of participants included 278 pre-service teachers from China who used a desktop VR system,

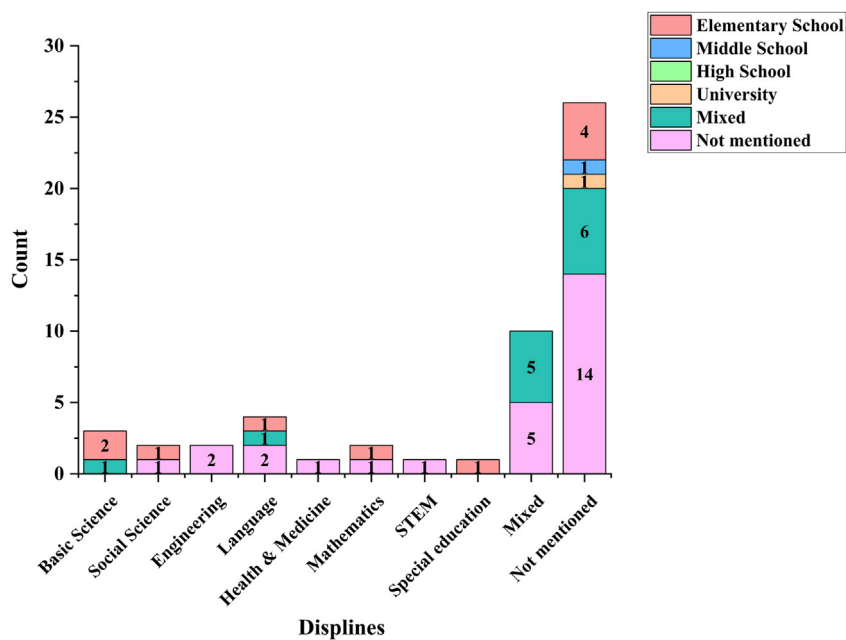


FIGURE 4
Distribution of participants by discipline and grade level.

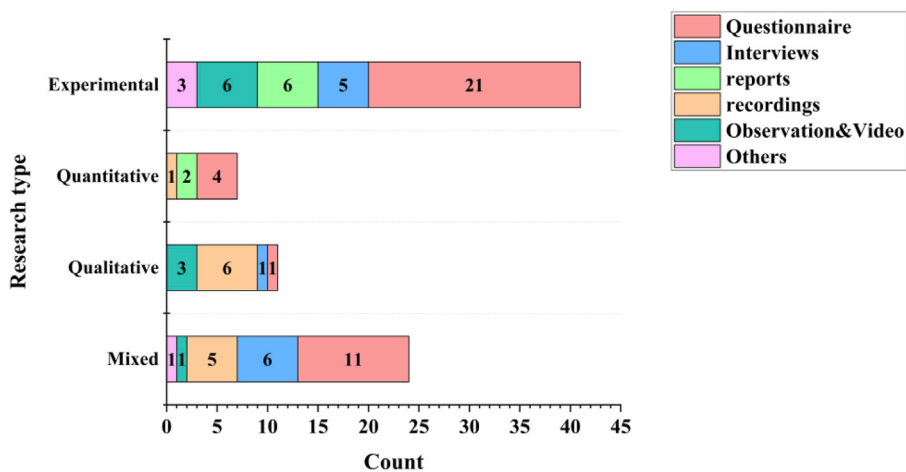


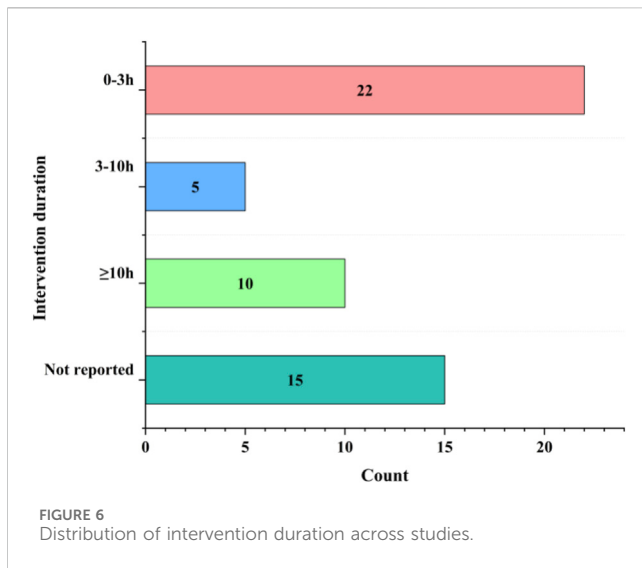
FIGURE 5
Distribution of data sources across research types.

followed by a questionnaire survey. This study aimed to investigate the factors influencing the intention and usage behavior of pre-service teachers in China regarding the adoption of VR training systems (Xie et al., 2024). The smallest sample size was only 4 participants, all pre-service special education teachers, making this the only study related to special education. This study explored the effectiveness of the TLE TeachLive™ simulation lab in enhancing the basic teaching skills of pre-service special education teachers and examined their ability to transfer these skills from a virtual environment to real classrooms (Dawson and Lignugaris Kraft, 2017). As shown in Figure 5, 24 studies had sample sizes ranging from 1 to 50 participants, representing small sample

studies that accounted for 46% of the total studies reviewed. Three studies did not mention the sample size, because the focus of these three studies was on introducing and exploring the application and effects of virtual reality, rather than conducting detailed statistical analysis or in-depth case studies of specific study samples.

3.3.2 Research type and data sources

As shown in Figure 5, most studies have combined multiple data sources to ensure research rigor. Questionnaires were the most widely used method, interviews were primarily used in experimental and mixed-methods research, while reflective reports were commonly employed in both qualitative and

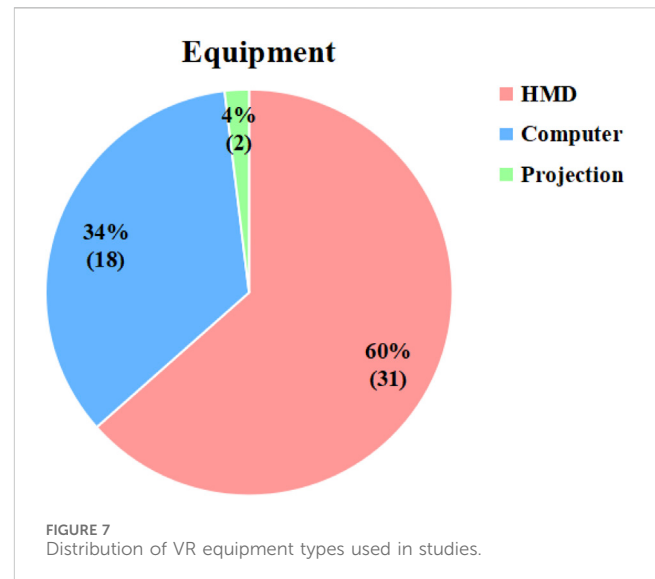


mixed-methods studies. Tests and observation/video recordings were used less frequently, mainly in experimental studies. Additionally, some studies have adopted other methods. For example, Kim et al. (2017) utilized ECG measurements to analyze how different shot sizes (e.g., close-up vs. full shot) in VR drama scenes affected pre-service teachers' psychological distance and physiological responses.

The majority of studies employed experimental designs ($n = 25$), followed by mixed methods ($n = 13$), qualitative approaches ($n = 9$), and quantitative methods ($n = 5$). Experimental studies typically adopted pre- and post-test control group designs to assess whether VR could enhance specific teaching competencies. Mixed-methods research combined surveys, interviews, and classroom observations to provide a comprehensive view of VR's impact (e.g., Álvarez et al., 2023; Pendergast et al., 2022). Qualitative studies relied on interviews and reflective reports to explore how VR supports professional growth and pedagogical reflection (Kosko et al., 2022). In contrast, quantitative studies used standardized instruments such as questionnaires to evaluate instructional skills (Badilla-Quintana and Sandoval-Henríquez, 2021).

3.3.3 Intervention duration

As shown in Figure 6, the duration of VR interventions in teacher education varies considerably. The majority of studies have focused on interventions of 0–3 h in duration, with limited research exploring the effects of interventions extending beyond 10 h. For example, Stavroulia and Lanitis (2019) implemented a brief, single-session VR intervention lasting approximately 5 minutes to assess the emotional impact of classroom conflict scenarios on pre-service teachers. In contrast, Lamb and Etopio (2020) conducted a week-long clinical practicum in a virtual reality environment to investigate the sustained impact of VR on participants. Some studies adopted medium-duration interventions (3–10 h), serving as a bridge between short- and long-term designs. However, 15 studies did not report the duration of their interventions. For instance, Nissim and Weissbluth (2024) conducted a qualitative study exploring how teachers develop self-efficacy through VR by analyzing written reflections from pre-service teachers enrolled in a Master of



Education program in a VR-based course. Such studies often emphasize participants' in-depth experiences rather than specifying the duration of training, which may explain the lack of reported intervention time (details on basic information and resource design can be found in Supplementary Appendix B).

3.4 Technological features

3.4.1 Equipment type

As shown in Figure 7, HMDs are the most widely used hardware in VR-based teacher education, followed by computer-based systems. Their popularity reflects a trade-off between immersion and accessibility: while HMDs offer a high level of presence in virtual classrooms, computer-based systems allow for broader implementation without the need for specialized equipment (Ventura et al., 2019). Although less prevalent, projection systems have been adopted in several studies, they offer the lowest level of immersion but support shared visual experiences.

3.4.2 Main technical characteristics of VR

3.4.2.1 Immersion level and interactivity level

Immersion and interactivity are key determinants of VR's instructional effectiveness. First, fully immersive and highly interactive VR, such as student avatars in HMDs, enables real-time teaching simulations and fosters experiential learning. For instance, Perinpasingam et al. (2023) implemented a 5-week micro-teaching intervention using Engage VR, where pre-service teachers participated in role-playing scenarios via avatars in fully immersive, interactive virtual classrooms. The study reported improvements in confidence and classroom management, with participants expressing increased enthusiasm and instructional efficacy.

Second, while high immersion and complex interactivity enhance realism, they may also overwhelm users, potentially reducing learning efficiency (Haji et al., 2016). For example, Theelen et al. (2022) employed 360-degree classroom videos viewed through VR headsets to immerse pre-service teachers in realistic teaching scenarios. Despite lacking interactivity, the

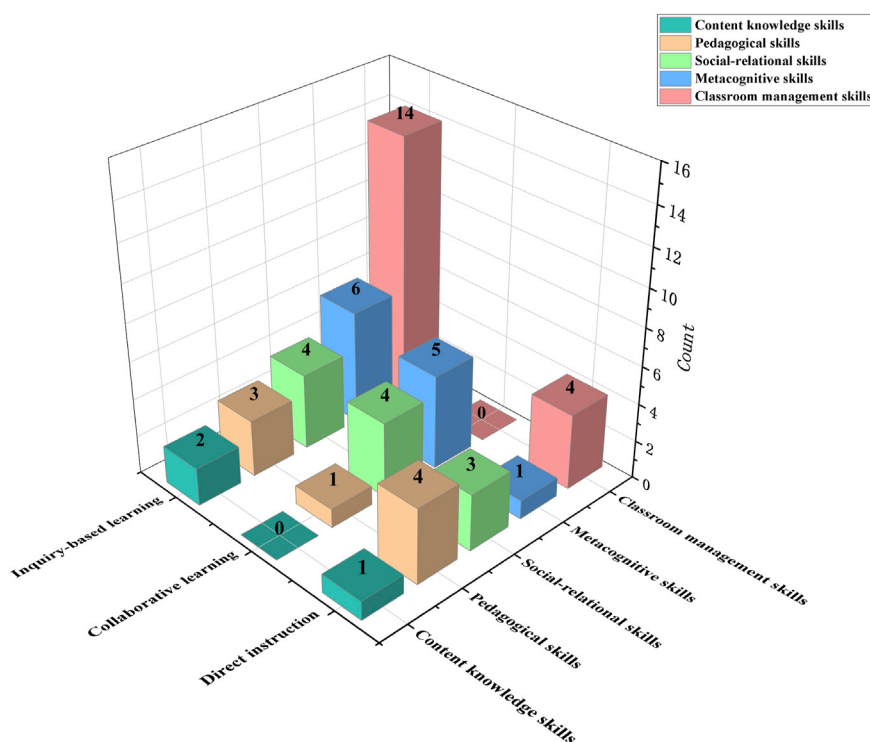


FIGURE 8
Pedagogy and learning objectives targeted by vr applications.

intervention reduced anxiety and enhanced self-efficacy, showing the value of passive immersion with effective instructional framing. Semi-immersive and moderately interactive VR (e.g., desktop-based systems or large-screen projections) can offer a pedagogically balanced alternative, especially for tasks that emphasize decision-making rather than full-body engagement (Anand, 2024).

Third, non-immersive VR, such as 360-degree video viewed on monitors, typically enables passive observation (Daltoè et al., 2024). However, when combined with high interactivity, it can simulate dynamic teaching practice. Dalgarno et al. (2016), for example, studied avatar-based classroom role plays in Second Life, where pre-service teachers alternated between student and teacher roles. Despite the non-immersive format, participants developed practical classroom management and behavioral response skills, especially benefiting those with limited access to in-school placements. These findings suggest that well-designed, interactive non-immersive systems can offer pedagogically rich experiences.

3.4.2.2 Portability and internet connectivity

Some platforms, such as Second Life and OpenSimulator, support real-time, collaborative simulations through internet-connected environments. These platforms are often categorized as social virtual worlds (VWs), which differ from immersive VR in that they are typically accessed via desktop and lack embodied interaction. Nevertheless, they offer flexibility and accessibility that make them useful in educational settings. For example, Dai et al. (2023) designed an online, portable desktop VR training environment using OpenSimulator to support STEM graduate teaching assistants. Using laptops, participants interacted with

virtual agents in real time. This connected, portable setup supported flexible deployment and improved adaptive teaching and decision-making.

By contrast, offline solutions such as stand-alone VR modules and 360-degree videos reduce network dependency and ensure stable performance. For instance, Atal et al. (2024) employed 360-degree video VR in a portable, offline setting for classroom management training. Participants used standalone VR headsets to view classroom scenarios and engage in structured reflection sessions conducted offline. This setup reduced disruptions and improved classroom management efficacy through immersive, distraction-free observation.

Systems like HTC Vive require high-end PCs and fixed setups, limiting their deployment to lab-based or institutionally supported settings (Westphal et al., 2024). For example, Stavroulia and Lanitis (2023) implemented an online, non-portable empathy training program using Oculus Rift. The system supported immersive perspective-taking but required fixed setups and high-performance computers, limiting its scalability. These constraints hinder scalability across varied educational settings.

Ultimately, the interplay between connectivity and portability shapes VR adoption in teacher education. While offline portable VR enhances accessibility, it may limit interactivity; meanwhile, online non-portable VR enables rich collaboration but demands technical infrastructure. For instance, Stavroulia and Lanitis (2019) developed a fully immersive, offline, non-portable VR framework using Unity and HTC Vive. Featuring 3D-modeled classrooms and avatars, the system offered rich sensory input but lacked internet access and required fixed hardware, limiting it to individualized use in

controlled settings. Balancing these trade-offs is essential for scalable and context-sensitive VR implementation in teacher education.

3.4.2.3 VR platforms and cost

The most frequently reported systems in the reviewed studies were Oculus Rift, HTC Vive, and Quest, reflecting a strong preference among educators for head-mounted displays that support immersive and interactive learning experiences. Simulation-based platforms such as TeachLivE, OpenSimulator, and ClassVR also appeared frequently, underscoring their relevance in teacher-specific VR training. Additionally, 360-degree video content has been widely adopted, likely due to its cost-effectiveness and ease of implementation. The growing use of customizable platforms such as Unity, Engage, and OpenSim suggests an emerging trend toward the development of tailored VR environments designed to support specific instructional goals. Overall, the findings reveal a dual pattern of use: high-end immersive systems are employed for complex interactive simulations, whereas more accessible video-based or semi-immersive tools serve as practical alternatives in teacher education contexts.

Among the 52 included studies, only four explicitly reported the costs associated with VR implementation. The reported costs varied widely, ranging from approximately \$150 to €2,500. For instance, King et al. (2022) employed 360-degree video capture devices costing around \$150, while Ye et al. (2019) adopted a low-cost TrainCM2 system, highlighting affordability as a design feature. In contrast, Lugin et al. (2016) employed a multi-component setup comprising the Oculus Rift DK2, Microsoft Kinect 2, and multiple computing stations, with a total cost of approximately €2,500. Ferdig and Kosko (2020) utilized Oculus Quest 2 headsets (\$300 each) with two controllers per unit, though the number of units used was not specified. While some studies, such as Ferdig and Kosko (2020), discussed cost to emphasize accessibility, others, like Lugin et al. (2016), mentioned it primarily for procedural transparency. Overall, cost was rarely treated as a central variable in study design, suggesting that financial considerations may be underreported unless directly relevant to the intervention goals. However, the cost range identified here (approximately \$150 to €2,500 per setup) illustrates the considerable variability in technological investment. This has important implications for scalability and equity in VR-based teacher education, particularly when comparing low-cost mobile solutions to more immersive, high-end systems.

3.5 Instructional design

3.5.1 Pedagogy and learning objectives

Learning objectives in VR-based teacher education can be categorized into five domains: classroom management (e.g., behavioral regulation and real-time decision-making), metacognitive skills (e.g., reflection, self-regulation, and efficacy), pedagogical skills (e.g., teaching strategies and lesson planning), content knowledge (e.g., conceptual understanding), and social-relational skills (e.g., collaboration and communication).

As shown in Figure 8, inquiry-based learning was most frequently associated with classroom management skills ($n = 12$).

Its exploratory and problem-centered nature aligns well with the complexity of navigating dynamic virtual classrooms. For instance, Alvarez et al. (2022) developed a training program where teachers engaged with classroom conflict cases in VR, thereby strengthening their classroom management strategies. Similarly, Kugurakova et al. (2021) implemented a VR simulator targeting conflict resolution, where teacher candidates interacted with virtual student agents in scripted scenarios. Both interventions improved participants' responsiveness and strategic decision-making under pressure, demonstrating the effectiveness of inquiry-driven VR for preparing teachers to address authentic behavioral challenges.

Collaborative learning was primarily linked to metacognitive skills ($n = 5$) and social-relational skills ($n = 4$), leveraging collaborative role-play and peer dialogue to foster empathy and professional agency. For example, Liaw et al. (2024) designed an immersive VR telecollaboration program via the "Immerse" platform, where language teachers from diverse cultural backgrounds co-taught virtual lessons and participated in guided reflection sessions. This collaboration enhanced self-regulation, intercultural communication, and peer-supported learning. Similarly, Østerlie et al. (2024) used 360-degree video observations in physical education teacher training, supplemented with group reflections. The intervention supported collective sense-making, peer scaffolding, and critical introspection, contributing to deeper professional understanding and relational awareness.

Direct instruction was most commonly applied to classroom management ($n = 5$), pedagogical skills ($n = 3$), and content knowledge ($n = 2$). Its structured and goal-oriented format is particularly effective for delivering procedural knowledge and behavioral strategies within VR environments. For example, Gold and Windscheid (2020) designed a structured VR-based observation program using 360-degree classroom videos. Pre-service teachers were trained to identify classroom management events based on an expert framework, demonstrating how direct instruction in VR settings supports teaching quality. Zhang et al. (2024) introduced a VR microteaching platform to develop nine sub-dimensions of teaching performance. The system improved participants' instructional strategies compared to traditional methods. Additionally, Liu et al. (2022) employed a fully immersive VR system to deliver CPR training through direct instruction, providing prospective kindergarten teachers with sequential procedural scaffolding.

3.5.2 Assessment mode

Traditional assessments remain the most prevalent approach in VR-based teacher education. These typically include pre- and post-tests, surveys, and reflective journals conducted outside the virtual environment. For instance, Bautista and Boone (2015) employed the STEBI-b instrument alongside qualitative reflections to examine changes in pre-service teachers' self-efficacy. VR-based assessments remain limited, though they illustrate the potential for authentic, immersive evaluation within the virtual setting. Huang et al. (2021) recorded pre-service teachers' responses to varying levels of classroom disruption in real time and used a VR-based simulation to assess their classroom management skills. Additionally, three studies failed to specify any formal assessment procedures, underscoring a methodological gap that warrants greater attention in future VR-based instructional designs (details

TABLE 2 Overall effectiveness of VR-based interventions in teacher education.

Model	<i>k</i>	Hedges' <i>g</i>	95%CI	Heterogeneity			
				<i>Q</i>	<i>df</i>	<i>p</i>	<i>I</i> ²
Fixed model	22	0.404	0.282–0.525	75.002	21	0.000	72.001
Random model	22	0.524	0.285–0.764				

on technology feature and instructional design can be found in [Supplementary Appendix C](#)).

3.6 Meta-analysis

To comprehensively synthesize the growing body of research on VR in teacher education, this study first conducted a systematic review to map key trends, intervention characteristics, and potential factors influencing outcomes. Based on these insights, several potential moderators were identified, including immersion level, equipment type, interactivity, portability, pedagogical approach, intervention duration, participant status, and learning objectives. A subsequent meta-analysis was conducted to quantitatively estimate the overall effectiveness of VR interventions and to examine how these moderators contribute to variations in outcomes. This two-phase approach enables a deeper and more integrated understanding of VR's educational potential by combining qualitative synthesis with robust statistical evaluation.

This study included 17 articles comprising 22 experimental and quasi-experimental studies for meta-analysis. (1) The inclusion criteria were as follows: studies had to be experimental or quasi-experimental in nature, compare teacher education objectives with and without VR interventions, report sufficient data to calculate effect sizes (e.g., means, standard deviations, and sample sizes), and include at least one teacher-related outcome variable. (2) To reduce small-sample bias, Hedges's *g* was selected as the effect size metric, as it is more robust compared to Cohen's *d* and Glass's delta. (3) Given the considerable variation in sample sizes, designs, and methodologies across studies, a random-effects model was primarily adopted to account for heterogeneity and enhance the generalizability of the findings. (4) Main effect and moderator analyses were conducted under the selected model. (5) Publication bias was visually assessed using a funnel plot and further examined quantitatively through the fail-safe *N* test.

3.6.1 Overall effectiveness

As shown in [Table 2](#), the *Q*-test was significant ($Q(df = 21) = 75.002, I^2 = 72.001, p < 0.001$), indicating substantial heterogeneity across studies; therefore, a random-effects model was adopted. According to [Cohen \(1992\)](#), the combined effect size of 0.524 suggests that VR has a moderate impact on teacher education. To further explore factors contributing to this variability, moderator analyses were conducted.

3.6.2 Moderator analysis

The analysis was primarily based on these 22 experiments, with detailed categorization of the following variables: (a) participant status, including pre-service teacher and in-service teacher; (b)

intervention duration, including short-term intervention (<3 h) and long-term intervention (>3 h); (c) immersion level, including immersion and non-immersion; (d) equipment, including HMD and computer; (e) interactivity, including no interaction, low level, and high level; (f) portability, including not portable and portable; (g) pedagogy, including inquiry-based learning, collaborative learning, and direct instruction; (h) learning objectives, including classroom management skills, metacognitive skills, pedagogical skills, content knowledge skills, and social-relationship skills; and (i) effect size. The coding results are shown in [Supplementary Appendix D](#).

The moderating effects of eight variables were examined, including participant status, intervention duration, immersion level, equipment type, interactivity, portability, pedagogy, and learning objectives, as presented in [Table 3](#). Among these, immersion level, equipment type, and learning objectives showed statistically significant moderating effects ($p < 0.05$). Studies conducted in immersive environments reported a moderate effect size ($g = 0.651$), substantially larger than those conducted in non-immersive settings. In terms of equipment, head-mounted displays outperformed computer-based systems, with respective effect sizes of $g = 0.651$ and $g = 0.182$. Regarding learning objectives, VR programs targeting content knowledge skills ($g = 1.019$) achieved the largest effects, followed by interventions aimed at developing social-relational skills ($g = 1.002$) and classroom management skills ($g = 0.719$). Moderate effects were observed for pedagogical skills ($g = 0.326$), whereas interventions focusing on metacognitive skills produced minimal gains ($g = 0.121$). These results suggest that immersive experiences, advanced VR equipment such as HMDs, and carefully aligned instructional goals significantly enhance the effectiveness of VR-based teacher education programs.

3.6.3 Publication bias test

Publication bias was assessed using a funnel plot, which showed a symmetric distribution of studies, suggesting no apparent bias ([Figure 9](#)). The fail-safe *N* was 307, far exceeding the threshold of $5k + 10$ ($k = 22$) proposed by [Rosenthal \(1979\)](#), indicating robust results. In addition, studies on both sides of the mean effect size were reviewed, further supporting the absence of significant publication bias.

4 Discussion

By integrating system review and meta-analysis, this study comprehensively examines the application status of VR in teacher education. The discussion will be carried out from four dimensions: participant characteristics, research design, technological features and instructional design.

TABLE 3 Moderator analysis of vr intervention effectiveness.

Moderator	k	g	95% CI	Q _B	P value
Participant status				0.743	0.389
In-service teacher	3	0.319 ^a	[−0.138–0.777]		
Pre-service teacher	19	0.554 ^b	[0.282–0.826]***		
Intervention duration				1.176	0.555
Short-term	14	0.510 ^b	[0.187–0.833]**		
Long-term	3	0.738 ^b	[0.339–1.138]*		
Not mentioned	5	0.425 ^b	[−0.042–0.893]		
Immersion level				5.851*	0.016
Immersion	16	0.651 ^b	[0.324–0.977]***		
Non-immersion	6	0.182	[−0.013–0.376]		
Equipment				5.851*	0.016
HMD	16	0.651 ^b	[0.324–0.977]***		
Computer	6	0.182	[−0.013–0.376]		
Interactivity				3.036*	0.219
No interaction	9	0.288 ^a	[0.076–0.449]**		
Low level	2	0.489 ^a	[−0.481–1.460]		
High level	11	0.707 ^b	[0.281–1.134]***		
Portability				1.106	0.293
Portable	15	0.425 ^a	[0.171–0.678]***		
Not portable	7	0.733 ^b	[0.216–1.250]**		
Pedagogy				3.251	0.197
Collaborative learning	5	0.236 ^a	[−0.024–0.497]		
Inquiry-based learning	5	0.423 ^a	[0.143–0.704]		
Direct instruction	12	0.942 ^c	[0.171–1.713]		
Learning objectives				17.467***	0.002
Classroom management skills	6	0.719 ^b	[−0.026–1.464]		
Content knowledge skills	1	1.019 ^c	[0.438–1.600]***		
Metacognitive skills	7	0.121	[−0.089–0.331]		
Pedagogical skills	6	0.326 ^b	[0.180–0.872]**		
Social-relational skills	2	1.002 ^c	[0.482–1.521]***		

k, number of independent studies; g, Hedges' g; Q_B, between-group homogeneity. Abbreviation: CI, confidence interval.

^aSmall effect.

^bMedium effect.

^cLarge effect. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

First, research on pre-service teachers is more prevalent, whereas studies on in-service teachers remain relatively scarce. The meta-analysis supports this trend by showing greater learning gains among pre-service participants. This disparity may stem from the fact that pre-service teachers are more accessible within university research settings, whereas recruiting in-service teachers as study participants presents greater challenges. Additionally, researchers may prioritize examining how in-service teachers apply and reflect on VR-based training in real classroom settings rather than focusing

on their learning experiences during the training phase. This assumption is supported by the findings of [Álvarez et al. \(2024\)](#), who noted that in-service teachers tend to emphasize application and feedback and seek more advanced training content. Furthermore, the distinction between pre-service and in-service teachers is pedagogically meaningful. Pre-service teachers are often at an early stage of identity development and skill acquisition, making them more receptive to experimental and immersive learning formats. In contrast, in-service teachers tend

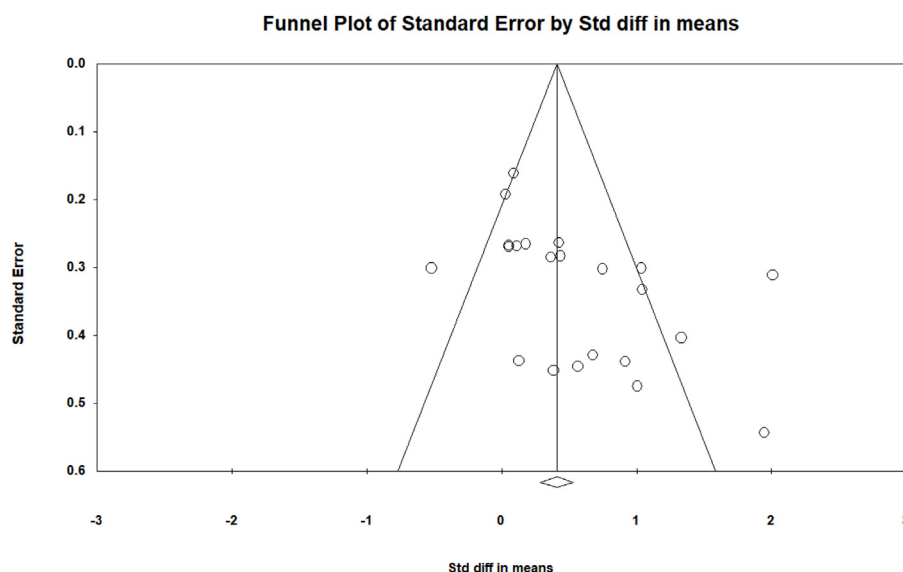


FIGURE 9
Funnel plot for assessing publication bias in effect sizes.

to prioritize efficiency, alignment with curriculum goals, and practical applicability due to their professional responsibilities and institutional constraints. These differences imply that VR interventions should be tailored to the needs, contexts, and learning orientations of each group (Bullock, 2004; Teo, 2011; Tondeur et al., 2017).

In addition, intervention duration is heavily skewed toward short-term formats, with most studies reporting training sessions under 3 hours. In this review, “short-term” refers to interventions in which the total VR exposure time as reported was less than 3 hours. However, some interventions involved multiple short sessions spread across several weeks, and these were coded based on the total reported duration. While our meta-analysis showed slightly higher effect sizes for longer interventions, this trend should be interpreted with caution. Extended session duration does not necessarily lead to deeper learning outcomes. Prior research has shown that prolonged VR use can lead to physical discomfort and cognitive fatigue. For example, Ratan et al. (2025) reported that learning performance began to decline after approximately 45 min of continuous VR use, likely due to sensory overload. Similarly, Han et al. (2023) noted that although extended use may increase familiarity and engagement, the novelty effect of VR tends to diminish over time.

At the same time, very short-term exposure may not be sufficient for developing complex instructional skills such as classroom management or pedagogical decision-making. A more effective model, supported by Roswell et al. (2020), may involve multiple brief VR sessions combined with structured debriefing and reflection. This aligns with experiential learning theory (Kolb, 1984), which emphasizes iterative cycles of experience, reflection, and refinement. Similarly, cognitive load theory (Sweller, 1988) underscores the importance of distributing practice to reduce extraneous demands and support schema formation. In summary, multiple short and well-structured VR sessions may be more effective than single prolonged exposures. They support

deeper learning while minimizing fatigue. Future research should further investigate how the interplay between session frequency, instructional design, and learner characteristics influences outcomes in VR-based teacher education.

Furthermore, the meta-analysis indicates that immersive environments and high-interactivity designs yielded the strongest effects. These findings highlight the potential instructional value of combining high sensory presence with meaningful interaction. Nevertheless, the cognitive impact of such combinations may vary, and future studies should explore whether they support or hinder learning depending on context and learner characteristics. Portability did not emerge as a significant moderator, although both portable and non-portable VR systems demonstrated positive effects. While portable systems may enhance accessibility and scalability, high-performance stationary systems often provide deeper immersive experiences, suggesting a need to balance technological feasibility with pedagogical effectiveness in VR design.

Lastly, the systematic review reveals a trend toward aligning pedagogical strategies with specific learning objectives. Meta-analytic results show that direct instruction yielded the strongest effects. In addition, the results revealed notable variations in the effectiveness of VR interventions across different learning objectives. These results can be explained by the specific affordances and limitations of immersive VR environments. On one hand, VR can support the acquisition of complex procedural and conceptual knowledge through vivid visualization (Liu et al., 2022). Research by Lorenzo (2014) and Remacle et al. (2023) also suggests that VR environments promote social-relational skills by enabling realistic interpersonal simulations in safe, low-risk contexts. Simulated classrooms further offer opportunities for repeated practice, fostering decision-making and behavioral regulation (Seufert, 2022; Li et al., 2024). On the other hand, immersive environments characterized by high levels of presence and agency may constrain learners’ ability to monitor, regulate, or reflect on emotional, cognitive, metacognitive, and motivational

processes. Without explicit scaffolding, such settings may not naturally support metacognitive development (Makrinsky and Petersen, 2021). These characteristics may help explain why VR interventions targeting metacognitive skills tended to yield smaller effect sizes than those addressing other learning objectives.

Beyond identifying the overall effectiveness of VR interventions, it is essential to consider the pedagogical integrity and contextual relevance of the content used. As Vishwanath (2023) points out, much existing VR content is generic, lacking integration with specific curricular goals or scaffolding for cognitive and pedagogical development. In domains such as classroom management and metacognitive training, where situated practice and feedback are crucial, the absence of high-quality content may constrain both engagement and skill acquisition (Ferdig and Kosko, 2020; Jensen and Konradsen, 2018). While some purpose-built applications, such as those examined by Dai et al. (2023), demonstrate promise, they remain the exception rather than the norm. For in-service teachers in particular, meaningful use of VR hinges on whether the content is perceived as relevant, feasible, and aligned with institutional and curricular frameworks. Moving forward, the co-design of VR content with educators and instructional designers is essential to ensure pedagogical coherence and real-world applicability.

5 Conclusion

5.1 Summary of key findings

This study systematically reviewed VR in teacher education over the past decade and used meta-analysis to assess VR's overall effectiveness and potential moderating factors. Key findings are outlined below:

1. The number of studies on VR in teacher education has shown an overall upward trend over the past decade, with nearly half not specifying the discipline or grade level taught by participants.
2. Research predominantly targets pre-service teachers, with limited focus on in-service ones. Training duration varies, with short-term interventions (0–3 h) being most common and long-term applications scarce.
3. HMDs are the most used VR devices with most research centers on highly immersive, interactive, non-portable, and internet-dependent VR systems.
4. Studies most commonly combined inquiry-based learning with training in classroom management skills, and traditional assessment methods were the most frequently used.
5. Meta-analysis shows VR has a moderate overall effectiveness in teacher education. Level of immersion, VR equipment type, interactivity, and learning objectives are significant moderating factors.

5.2 Implications for practice and research

From a practical standpoint, the findings of this study offer several insights for stakeholders involved in teacher training and

technology integration. First, for practitioners, virtual reality presents a promising opportunity as a supplemental tool for professional development. Its strengths in procedural rehearsal, behavioral simulation, and complex content visualization allow teachers to engage in low-risk, repeatable practice that may not be feasible in real-world settings. This is particularly valuable for enhancing classroom management, conveying abstract concepts, and strengthening self-efficacy through immersive learning experiences. Second, for teacher educators, integrating VR into pre-service and in-service programs should be approached strategically. VR-based microteaching, reflective observation, and scenario-based decision-making can complement traditional pedagogical approaches. To maximize impact, VR activities must be tightly aligned with instructional goals and accompanied by guided feedback, peer discussion, and iterative reflection opportunities. Professional development models should be flexible and scalable, accommodating diverse teaching schedules and educational contexts. Third, for VR developers, the results underscore the importance of designing pedagogically coherent and contextually adaptable systems. Cost-effective, portable, and user-friendly solutions are crucial for broader adoption, especially in resource-constrained settings. Developers are encouraged to prioritize features that support adaptive feedback and customizable instructional scenarios, ensuring that technological innovation remains anchored in sound educational practice.

Beyond practical applications, this study also points to several priorities for advancing research in this field. Future studies should expand sample diversity by including teachers from various career stages, disciplines, and cultural backgrounds to enhance external validity. Longitudinal designs are needed to capture the sustained impacts of VR on evolving teaching practices, while design-based research can facilitate the iterative optimization of VR environments. Mixed-methods approaches, integrating behavioral observations and experiential data with outcome measures, can provide a more comprehensive understanding of learning processes. Furthermore, future research should investigate how specific VR features—such as immersion, interactivity, portability, and network dependency—influence learning outcomes across instructional scenarios. Attention should also be directed toward developing VR systems that remain pedagogically relevant and accessible, particularly for institutions with limited technological infrastructure. Finally, more sophisticated assessment strategies are critical. Traditional *post hoc* evaluations may fail to capture the dynamic and situated nature of VR learning. Embedded, real-time assessment approaches leveraging artificial intelligence, behavioral analytics, and affective data offer promising avenues for authentically measuring learner engagement, decision-making, and adaptability. In doing so, VR can move beyond its role as a technological novelty to become a transformative catalyst for teacher professional development.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: <https://doi.org/10.17632/y4j8fjyjh6.1>.

Author contributions

XH: Data curation, Investigation, Writing – original draft, Formal Analysis, Visualization. HL: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review and editing. ZW: Formal Analysis, Investigation, Writing – original draft. DZ: Formal Analysis, Investigation, Writing – original draft.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/frvir.2025.1620905/full#supplementary-material>

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