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Where are the teachers? Rethinking AR/VR research in teacher education

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Abstract

In this complete paper, we report a scoping review that maps what systematic literature reviews (SLRs) and review-type conference proceedings say and do not say about augmented reality (AR) and virtual reality (VR) in teacher education. While AR/VR scholarship continues to expand, teacher education remains comparatively underexamined within AR/VR synthesis work. Teacher readiness and pedagogical design are repeatedly identified as decisive mediators of whether immersive technologies lead to meaningful learning. Reflective practice further shapes how teachers interpret evidence, adapt implementation, and sustain equitable integration over time. To address this gap, we reviewed review-type literature published from 2020–2024 across Google Scholar, Wiley, and ScienceDirect, and synthesized how the field frames AR/VR "impact" when teachers and preservice and in-service teacher learning are treated as the unit of analysis.

Across the final 84 screened records, AR/VR is most consistently associated with improved engagement, motivation, and perceived learning experience. Evidence for durable learning gains, however, is mixed. Reported outcomes are frequently constrained by short interventions, small samples, inconsistent measures, and heavy reliance on usability and self-report data. Teacher education remains only partially visible: approximately 42% (35/84) of the records mention teacher education in meaningful ways, and only 21% (18/84) substantively discuss AR/VR affordances and challenges for teacher learning. Equity-relevant issues (e.g., access/cost, adverse effects and usability burdens, privacy/ethics, and unequal benefits across learners) are also more often framed as secondary constraints than as central design-and-evaluation imperatives. Grounded in concerns that immersive technologies can import and amplify persistent real-world inequities across access, identity, language, and distribution of harms and benefits, we argue that "Where are the teachers?" is not rhetorical but a methodological and programmatic challenge, one that should reshape AR/VR research agendas for K–12 teacher preparation, including engineering/computing education contexts where simulation, design, and human–technology interaction are central.

Introduction

As educational technology instructors and researchers (and former students) working across K–12 and higher education in Canada, the United States, and international contexts on augmented reality (AR), virtual reality (VR), and STEM education with pre-service and in-service teachers [1-5], we have repeatedly encountered a familiar justification for AR/VR in education in terms of its perceived ability to make the abstract visible, enable safe simulation, and support experiential and situated learning. These claims are compelling and, in many cases, intuitively aligned with long-standing aims of teaching and teacher preparation. Yet our reading of recent synthesis work also suggests a persistent tension that despite two decades of development and recurring waves of interest, educational settings have not consistently witnessed sustained, large-scale implementation of AR/VR in ways that meaningfully reshape classroom practice [6, 7]. This gap between what AR/VR is said to afford and what classrooms and teacher education programs routinely realize motivates our inquiry.

Large-scale synthesis efforts have helped consolidate, evaluate, and communicate evidence about immersive technologies across education. For example, Lou et al. [6] synthesized 20 years (2000–2019) of VR research spanning K–12 and higher education, while Wang and Li [7] reviewed how VR, AR, and mixed reality (MR) facilitate teacher education. Studies such as these provide an important foundation, but they also prompted a question that became difficult for us to ignore: where, exactly, are the teachers in the AR/VR research conversation, especially when we consider that teachers are the primary designers of learning conditions, the mediators of pedagogy, and the interpreters of whether a tool becomes instructionally meaningful or merely novel? In response, we undertake an evidence-based review focused specifically on AR and VR in teacher education, attending to K–12 education contexts with preservice and in-service teacher learning.

In defining the scope of this review, we intentionally focus on AR and VR, acknowledging that immersive technology nomenclature includes overlapping and competing definitions across the reality–virtuality continuum [8] and related terms such as Mixed Reality (MR) and extended reality (XR). We recognize that MR is often positioned between actual reality and VR along this continuum, and XR is frequently used as an umbrella term that includes AR, VR, and MR. However, because this definitional landscape can broaden the field to the point of conceptual diffusion, we delimit our synthesis to AR and VR while drawing on established definitions that have been compiled and used across recent review studies.

Following Wang and Li [7], we understand AR as enhancing actual reality with digital visual elements, sound, or other sensory stimuli delivered via technology, thereby bridging real and virtual worlds [8]. In parallel, VR refers to the use of software and hardware to create highly interactive virtual environments with varying degrees of fidelity [9]. VR experiences may be fully immersive, semi-immersive, or non-immersive, depending on the extent to which the user's senses are separated from the real world: fully immersive VR typically relies on head-mounted displays or VR glasses; non-immersive VR is commonly experienced through flat-screen devices; and semi-immersive VR can support virtual touring while retaining connection to physical surroundings.

Across educational contexts, prior syntheses suggest both promise and persistent challenges. For AR, Akçayır and Akçayır [10] observed that usability remains a dominant challenge for learners, even as AR systems tend to enhance enjoyment, motivation, and satisfaction. Within teacher education specifically, AR has been used to support a range of professional learning aims, including developing proportional reasoning among pre-service teachers, constructing teaching materials and supporting curriculum design [11].

For VR, use in teacher education has increased over the past decades [12], and research has positioned VR as a potentially effective training tool for both pre-service teachers and in-service teachers [13]. A frequently cited rationale is that VR environments can allow teachers to practise communicating with diverse students, rehearsing responses to unexpected classroom situations, and developing professional judgement without risking harm to students, particularly when the "learning by doing" that occurs in real classrooms carries social and emotional stakes. Stavroulia and Lanitis [12] further argued that such applications may support professional development in complex domains, offering opportunities for repeated practice and refinement.

At the same time, the broader AR/VR education literature including prominent reviews has often blended contexts and populations (e.g., mixing K–12 and post-secondary settings) or concentrated on particular learner groups and disciplinary domains. Review studies commonly target post-secondary education [6, 14, 15], K–12 education [6, 16], special education [17], subject-specific applications such as STEM [18] and language learning [19], or broad claims about the effectiveness of XR technologies. This landscape is valuable, but it also means that teacher education can become one context among many, present, but not central despite the reality that the sustainability of AR/VR in classrooms hinges on teacher learning, teacher decision-making, and teacher working conditions.

Our preliminary scoping of synthesis records from 2020–2024 reinforces this concern. The most prominent synthesis work in this period appears to concentrate heavily on disciplinary applications (e.g., science/STEM, health/medicine, engineering training, language learning), with teacher education often treated peripherally rather than as a primary research and design problem. This underrepresentation is especially striking in the current moment when generative AI (GenAI) dominates many "future of education" conversations; AR/VR risks being treated as secondary, even though its pedagogical affordances are distinct and its implementation demands are non-trivial (hardware, physical space, safety, accessibility, and sustained instructional design) [20]. From our perspective, this is not simply an issue of "coverage" in the literature; it is a signal about what the field positions as essential. If teachers are not foregrounded in synthesis work, then the practical conditions under which AR/VR becomes teachable, adoptable, and sustainable may remain under-theorized and under-supported.

In addition, we argue that any serious discussion of AR/VR in teacher education must attend to equity, inclusion, diversity, accessibility, and availability. These considerations are not optional add-ons. They matter ethically because educational technologies can reproduce or amplify existing hierarchies and practically because uneven access, linguistic and cultural assumptions, and design choices about whose bodies and experiences are centered shape who can participate meaningfully. Immersive technologies can import and augment stubborn real-world inequalities into virtual environments, raising urgent questions about access, gender, language, and the distribution of harms and benefits [21]. For teacher education, these concerns are doubly relevant: we as teachers are both learners in preparation programs and future designers of learning environments for diverse students.

Accordingly, this scoping review maps what recent systematic literature reviews (SLRs) and review-type conference proceedings say and do not say about AR and VR in teacher education contexts. We ask: How do recent AR/VR synthesis records represent K–12 education contexts, and where, if at all, do they treat teacher education (pre-service and in-service teachers at K-12) as a primary research and design problem? We equally attend to whether the screened records or articles meaningfully engage equity, inclusion, diversity, accessibility, and availability. In brief, we address the following research questions:
(1) What themes are dominant in AR/VR synthesis work during 2020–2024?
(2) Where are the K-12 teachers (and teacher education) situated in this literature? and
(3) To what extent are equity, inclusion, accessibility, and availability present?

Methodology
We conducted a scoping review of review-type literature (systematic reviews, systematic mapping reviews, and scoping reviews) to align with the three objectives established in the Introduction. The review was guided by PRISMA-ScR reporting expectations [22], the scoping review framework of Arksey and O'Malley [23], and review-quality expectations commonly used in engineering education and aligned with Journal of Engineering Education guidance [24-26].

Using inclusion/exclusion criteria aligned to our purpose (review-type records on AR/VR in education, January 2020–December 2024, journal articles and review-type conference proceedings), we implemented a three-level screening process across Google Scholar, Wiley, and ScienceDirect (Fig. 1).

At Level 1, we retained review-type records within the time window and topical scope, yielding 69 (Google Scholar) + 33 (Wiley) + 32 (ScienceDirect) results; after removing duplicates, this produced 133 unique records. At Level 2, we screened these 133 records for explicit representation of K–12 and/or higher education contexts, resulting in 90 records. At Level 3, we applied teacher-education population terms such as teachers, students, pre-service teachers (PSTs), in-service teachers (ISTs), and teacher education to determine whether and how teacher education was substantively discussed, yielding 84 final records for analysis (Appendix). Importantly, Level 2 and Level 3 decisions were not based on abstracts alone: we downloaded all 84 records and examined key sections (purpose/aims, inclusion criteria, results/discussion) because abstracts frequently omit context-specific nuances central to our objectives.

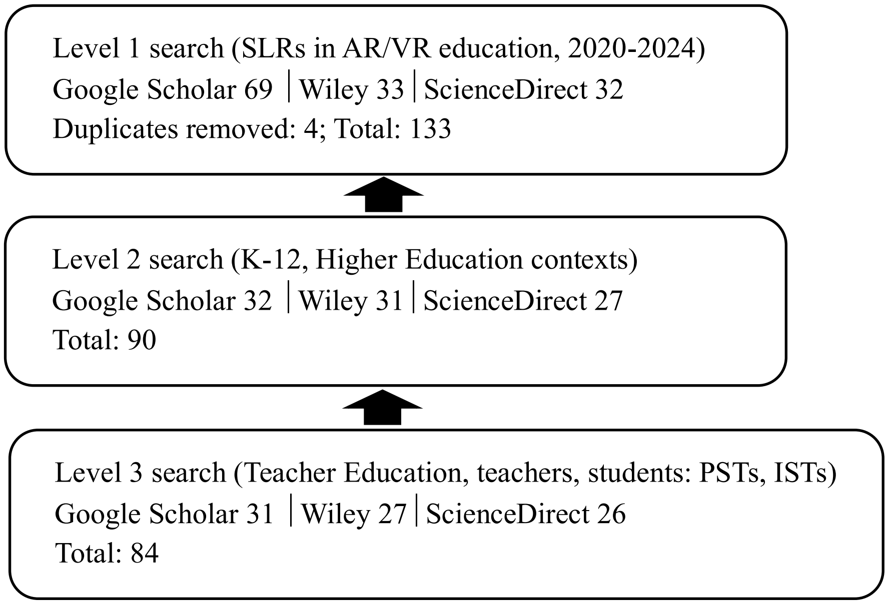

Figure 1. Three-level screening process and record counts

For data extraction, we charted each included record for education level representation (K–12, cross-level, or unspecified), application domain (e.g., STEM, health/medicine, language learning, professional training), the population(s) emphasized (learners, teachers, PSTs, etc.), and the main outcomes and constructs foregrounded in the synthesis (e.g., learning gains, skills, engagement, usability, cognitive load, presence, affective outcomes). We also extracted "quality signals" as reported by the reviews (e.g., patterns in sample size, intervention duration, use of validated measures, and presence of risk-of-bias or appraisal tools). To meet our third objective, we additionally tracked equity, inclusion, accessibility, and availability indicators when present, focusing on references to access and availability constraints (cost, infrastructure, training), accessibility and disability considerations, adverse effects (e.g., fatigue, cybersickness), privacy/security, and differential benefits across learner groups.

We synthesized the dataset using an iterative codebook and thematic synthesis approach. Initial codes were anchored in our three objectives, then refined through constant comparison as we reviewed abstracts and when needed, which was often paper aims and main-body sections. Codes were clustered into cross-cutting themes, domain-specific emphases, and recurring "gap statements" (what reviews repeatedly claim is missing). This approach enabled us to distinguish promise narratives from evidence constraints while explicitly tracking the visibility of teacher education and the extent to which equity, inclusion, accessibility, and availability considerations are treated as central analytic concerns rather than incidental mentions.

Results

RQ1: What dominates AR/VR synthesis work in 2020–2024?

Across records, we see that the most consistent claims center on engagement, motivation, and perceived learning experience, often framed as key advantages of immersion and interactivity [27-29] (Table 1). Many reviews also report positive learning outcomes, but these are frequently moderated by immersion level, intervention duration, and outcome type [30, 31]. We notice that several reviews emphasize that evaluations often privilege usability and experience over rigorous learning measures or long-term retention [15, 32, 33].

Table 1. Theme co-occurrence map

Theme cluster	Common message across reviews	Representative reviews (examples)
Affective gains (engagement, motivation, satisfaction)	Consistent increases in engagement/immersion/presence and positive perceptions; often more stable than test-score gains.	Di Natale, et al. [34]; Ryan, et al. [35]; van der Meer, et al. [27]
Learning gains: positive but uneven	Effects vary by immersion level, task type, and comparison condition; sometimes equivalent to traditional instruction.	Villena-Taranilla, et al. [30]; Moro, et al. [36]; Luo, et al. [6]
Methodological limitations	Small samples, short interventions, non-validated measures, limited retention/transfer; heterogeneity complicates synthesis.	Hamilton, et al. [32]; Noah and Das [37]; Radianti, et al. [15]
Theory and pedagogy under-specified	Many studies lack explicit learning theory integration; calls for theory-driven instructional design and clearer outcomes.	Soliman, et al. [38]; Scavarelli, et al. [33]; Tastan and Tong [39]
Design-mediated effects (collaboration, feedback, task structure)	Collaboration, interactivity, feedback and deliberate practice often emerge as levers for stronger outcomes.	Garzón [40]; van der Meer, et al. [27]; Nassar and Tekian [41]
Cognitive load & usability trade offs	VR may add extraneous load for novices; AR design guidelines emphasize load-sensitive spatiality/interaction/guidance.	Poupard, et al. [42]; Gonnermann-Müller and Krüger [43]; Wiepke and Heinemann [44]

Domain concentration is visible in the abstracts: health/medical education (e.g., nursing, anatomy, surgery training), engineering and safety training, and language learning are repeatedly foregrounded [6, 35, 45-48]. This is notable because teacher education (whether preservice, in-service, or professional development), especially K–12 teacher preparation, rarely appears as a primary design context in these synthesis claims.

RQ2: Where are the teachers (and teacher education)?

As noted earlier, our analysis indicates that teacher education is sparsely represented in the 84 Level 3 records that met our inclusion/exclusion criteria. Specifically, studies that meaningfully highlight teacher education account for roughly 42% (35 of 84). Within these 35 studies, only 18 provide substantial discussion of AR/VR affordances and challenges in teacher education with an overall representation of only ~21% (18 of 84) across the full synthesis set. Even when "teachers" or "pre-service teachers" are mentioned, these references are often peripheral (e.g., in passing or framed as "future work") [37, 49, 50].

Notable exceptions include two more dedicated reviews that focus on, or substantially engage with, AR/VR in teacher education [6, 7]. These reviews discuss issues such as procedural knowledge (e.g., classroom management) and both pre-service and in-service teacher contexts, yet they also reflect recurring limitations with small samples while still reporting generally positive effects and calling for more theory-driven training design. In contrast, many education-focused AR/VR syntheses position teaching professionals primarily as curricular implementers who need "training," without specifying what such training should entail pedagogically [34, 37, 48]. Thus, the gap is not simply a matter of including "more teacher participants," but a deeper absence of teacher-learning constructs (e.g., professional vision, instructional decision-making, reflective practice, equity-oriented design competence, curriculum interpretation, and pedagogical design) in how AR/VR impact is conceptualized and evaluated.

Moreover, current evidence suggests that AR/VR use in K–12 classrooms is not yet routine or ubiquitous, and relative to higher education, K–12 adoption remains less extensive overall (Table 2). While we take this as a surprise result, within K–12, reported use appears more common in elementary settings than in middle or high school, indicating that immersive technologies are still frequently positioned as "enrichment" or "special experience" tools rather than a consistently embedded instructional medium across grade levels [7]. Consistent with this pattern, many documented implementations resemble short, intervention-style learning activities (single lessons or brief modules) rather than sustained, repeated use across a term [6, 7].

Where AR/VR is realistically implemented in K–12 tends to cluster in subjects and contexts that align with its core affordances, such as visualization, experiential learning, and authenticity. These implementations most commonly appear in the basic sciences (e.g., physics, chemistry, biology, geology) and the social sciences (e.g., history and culture-related learning). They also appear in health/safety education, often narrowed in K–12 to safety-oriented simulations such as pedestrian/fire safety and life-skills contexts. However, "typical" classroom uptake is constrained by practical realities, including cost and access to devices, technical requirements, and teachers' confidence and readiness to integrate immersive tools within limited curricular time. Even when lower-cost options (e.g., mobile-based viewers) reduce per-student costs, implementation remains non-trivial, which helps explain why AR/VR use often appears episodic and context-specific rather than widespread [6, 7].

Taken together, this landscape underscores why teacher preparation is central: building pedagogical, technical, and design capacity through teacher education is a key pathway for moving AR/VR beyond isolated pilots toward feasible, curricular, and equitable classroom integration.

Table 2. Current State of AR/VR Use in K–12: Prevalence, Implementation Contexts, and Feasibility Constraints

Category	How common AR/VR is?	What it looks like?
Overall prevalence in K–12	- Not yet routine/ubiquitous in typical classrooms results and - Less extensive use than higher education - Often reported through short, study-based interventions - Indicates emerging—not mainstream classroom practice	- Short lesson/unit integrations (not continuous use) - Demonstrations or "special activity" experiences - Occasional integration vs. standard weekly routine - Frequently pilot-style or one-off implementations
Where it shows up most	- Concentrated where experiential/visual affordances matter results and discussion prompts - Adopted when it clearly adds value over non-immersive tools results and discussion prompts - Use is domain-driven rather than general purpose - Often tied to specific curricular goals/activities	- Basic sciences (e.g., physics/chemistry/biology/geology) - Social sciences (e.g., history/culture learning) - Health/safety education (often safety simulation focus) - Contexts emphasizing authenticity/experience-based learning
Grade-level pattern	- More common in elementary than secondary - Less frequent in middle/high school settings - Suggests "early-grade fit" for engagement/experience - Reinforces uneven distribution across K–12	- Elementary: social science + safety education use-cases - Elementary: guided, structured experiences (teacher-led) - Secondary: selective, topic-specific applications - Secondary: less frequent and more constraint-sensitive
Feasibility constraints (what makes it "not typical")	- Cost/device access remains a limiting condition - Technical setup and maintenance barriers - Teacher confidence/readiness shapes uptake - Constraints encourage episodic (not sustained) use	- Mobile-based/low-cost viewers improve feasibility but don't remove complexity - 360°/lightweight experiences can be more practical - Station-rotation or teacher-guided setups are realistic models - Implementation often depends on local infrastructure/support

RQ3: Equity, inclusion, accessibility, and availability (how present are they?)

Immersive technologies are not inherently equity neutral. As Franks [21] cautions, AR/VR can import and amplify stubborn real-world inequalities within virtual environments. This raises urgent questions about access, gender, language, and the distribution of harms and benefits. For teacher education, these concerns are doubly relevant because teachers are simultaneously (a) learners in preparation programs and (b) future designers and facilitators of immersive learning environments for diverse students. This dual role matters because teacher-education standards explicitly position teachers as responsible for constructing inclusive, safe, and productive learning environments. The AR/VR teacher-education literature also frequently frames immersive simulations as practice spaces for professional skills. These skills include classroom management and related competencies [51, 52]. In other words, equity and accessibility are not “add-ons” to AR/VR pedagogy; they should be treated as design constraints and evaluation requirements from the outset (Franks, 2017).

However, when we examined the 84 articles to elicit the representation of equity-relevant issues, we found that these concerns were often discussed as secondary constraints rather than as central analytic categories that are explicitly conceptualized, operationalized, and critiqued. The patterns below illustrate how equity/inclusion/accessibility tend to appear in the screened synthesis abstracts:

(a) access/availability and cost are described as limiting conditions (e.g., limited facilities/funding; “massive investment” and customization demands; and resource/training constraints) [37, 53, 54];

(b) adverse effects and usability burdens are treated as implementation cautions (e.g., visual exhaustion/mental fatigue; extraneous cognitive load and novice overload; and design guidance framed around cognitive-load measurement limits) [55, 56]; and

(c) accessibility, privacy, security, and ethics emerge as important but often under-theorized constraints, particularly in social or networked VR spaces [14, 33, 57].

Crucially, the screened evidence also suggests that equity challenges are not only about “who gets devices,” but also about who benefits and whose capacities are privileged by immersive designs. For example, interactive VR may advantage high-spatial-ability learners while disadvantaging low-spatial-ability learners, even if such gaps may be mitigable through training [58]. Likewise, some engineering-focused reviews note potential benefits for students with special needs and distance learners, yet relatively few records treat inclusion as a design-and-evaluation requirement with explicit measures and reporting practices [38]. Taken together, these patterns align with Franks’ warning that AR/VR can reproduce inequities through design defaults, access barriers, and the normalization of particular bodies, languages, and experiences in immersive spaces [21]. Yet this warning is still rarely foregrounded when articulating teacher-education–oriented AR/VR research agendas. This omission is especially evident in abstract-level synthesis discussions.

Discussion

1.1 Why K–12 teacher preparation matters here (even if “maybe, maybe not”)

If AR/VR is positioned as a classroom learning technology rather than a specialized lab tool, then K–12 teachers become the hinge between “immersive promise” and “instructional reality.” Across our screened synthesis records, the evidence base is repeatedly shaped by short interventions, small samples, inconsistent measures, and an over-emphasis on usability or self-report, which is consistent with long-standing critiques in AR/VR review literature [15, 32, 34]. These limitations are not merely methodological; they are also teacher-education problems, because everyday classroom integration requires teachers to make consequential decisions about: What is worth teaching with AR/VR? What counts as learning beyond excitement? What scaffolds reduce cognitive overload? How do I ensure equitable participation when devices, space, motion tolerance, and prior experience vary?

Our argument is not that every K–12 teacher must become an AR/VR specialist. Rather, consistent with AR/VR-based teacher education research emphasizing teacher professional standards and practice-oriented competencies (e.g., the centrality of classroom management and its need for practice), we argue for bounded but critical competence: (1) recognizing when AR/VR is instructionally justified, (2) designing for learning rather than novelty, (3) anticipating equity and accessibility barriers, and (4) evaluating learning using appropriate measures beyond attitude/usability [51, 52]. Without this, AR/VR risks reproducing a familiar adoption cycle: enthusiasm → pilot novelty → unclear learning evidence → abandonment or inequitable implementation.

1.2 Concrete implications for teacher education programs

Interpreting the 84-record synthesis patterns through a teacher-education lens suggests a concrete program design response: an AR/VR instructional design studio embedded within methods coursework and EdTech integration requirements. Such a studio should explicitly address (a) learning outcomes and validity-aligned assessment, (b) cognitive-load–aware design and scaffolding, and (c) implementation feasibility and ethical constraints, reflecting recurring calls for stronger methodological rigor and clearer instructional design strategies in AR/VR research [15, 32, 43]. In addition, the studio should build teachers' capacity to read AR/VR evidence critically by using design cases from domains where evidence is comparatively more mature (e.g., safety training, anatomy/nursing skills) to help candidates identify moderating factors and translate insights responsibly to K–12 settings [35, 45, 59].

Beyond coursework, we argue for practicum-linked simulation-based rehearsal as a practical bridge between evidence and enactment. AR/VR teacher-education studies show that professional competencies—especially classroom management—require repeated practice, and that simulation can increase authenticity and immediacy. However, training scenarios have often remained "traditional," which implies the need to design simulations that reflect more complex, high-stakes, and equity-relevant classroom situations [51, 52]. Practicum-linked "evidence logs" could further strengthen teacher judgment. These logs would require teacher candidates to compare promise versus evidence, such as engagement gains versus learning or retention, and usability versus instructional effectiveness. This approach mirrors tensions repeatedly documented in meta-analytic and mapping reviews [30, 42, 60].

1.3 What teachers need to know and be able to do to use AR/VR well

To implement AR/VR meaningfully, teachers need a blended competency set that goes beyond "knowing how to run the headset/app." AR/VR-based teacher education research consistently targets three competency domains: procedural and conceptual knowledge (understanding content and the instructional rationale for AR/VR use), professional/practice skills (e.g., classroom management and facilitation), and psychological readiness (especially teacher self-efficacy, frequently used as an outcome measure). This pattern aligns with the broader teacher education literature that treats competence as a combination of knowledge, practice, and professional confidence built through rehearsal and feedback [51, 52].

Operationally, these domains imply that teachers should be prepared to: (a) select an AR/VR experience that fits a specific learning goal, (b) design the learning sequence (briefing, guided participation, debriefing), (c) manage pacing, safety, space, and student behavior during immersive activities, (d) assess learning outcomes (not only engagement), and (e) reflect and iterate based on evidence from implementation. Importantly, these competencies also support methodological improvement: moving the field beyond heavy reliance on self-report toward stronger measures of instructional effectiveness and learning outcomes.

1.4 Why teacher preparation is a key barrier in engineering/computing education contexts

Our synthesis suggests that capacity-building through teacher preparation is a plausible bottleneck. Much AR/VR teacher-education work concentrates on pre-service teachers (PSTs). This focus implicitly treats readiness to teach with immersive technologies as something that must be built rather than assumed. The evidence also shows how preparation sometimes extends beyond classroom use toward technical production competencies, including training PSTs to develop VR educational software using platforms such as Unity 3D and related 3D engines. This is especially salient for engineering/computing education, where effective implementation may require more than "consumer use." Teachers may need to understand how simulations are designed and how interactions map onto disciplinary practices such as modeling, design iteration, and prototyping. They may also need to troubleshoot or adapt immersive experiences to support learning goals.

When this preparation is absent, AR/VR tends to remain episodic (demo-like, one-off) rather than embedded within authentic engineering/computing learning progressions contributing to the same cycle of novelty, weak evidence, and uneven participation [6]. Therefore, reshaping research agendas for K–12 engineering/computing teacher preparation requires foregrounding teacher learning mechanisms. These mechanisms include design skill, facilitation skill, assessment validity, and ethical governance. This shifts the focus away from treating AR/VR effectiveness as primarily a function of hardware or immersion level.

1.5 Applying teacher-focused strategies in resource-limited K–12 contexts

Teacher preparation is important, but many K–12 schools face significant budget constraints. Our synthesis supports a crucial feasibility point: teacher-focused strategies do not have to presume fully immersive, high-cost systems, because benefits are not exclusive to the most expensive hardware. AR/VR teacher education literature argues that selecting appropriate AR/VR technologies under different contexts requires comprehensive consideration of local opportunities and constraints and does not imply that only fully immersive systems are warranted. In resource-limited settings, teacher education can emphasize tiered implementation models. This can start with lower-cost AR (mobile-based), lightweight VR/360 experiences, and shared-device pedagogies such as stations/rotations, small-group facilitation, or whole-class projection paired with guided inquiry and debrief. At the same time, programs can build portable expertise in lesson design, classroom management, and assessment alignment.

This framing keeps the teacher-preparation argument intact under scarcity by prioritizing transferable pedagogical capacity, designing, facilitating, assessing, and reflecting on immersive learning. It positions AR/VR as adaptable across a spectrum of technologies rather than as an "all-or-nothing" investment. Resource constraints, in this view, become part of teacher competence. Teachers learn to decide when AR/VR is justified, adapt designs to available infrastructure, and prevent inequitable participation when access is uneven.

Conclusion and Future Directions

This review-of-reviews scoping study uses synthesis evidence as a diagnostic lens to identify what the AR/VR knowledge base has tended to center and what it has tended to marginalize. Across 84 synthesis records, AR/VR research remains abundant and often optimistic, yet it advances primarily through domain-specific applications and learner-centered outcomes, while teacher preparation is comparatively under-theorized and under-measured. The field repeatedly flags methodological constraints such as short interventions, small samples, inconsistent measures, and limited retention data. It also highlights implementation barriers including cost, access, and training needs. However, it too rarely treats teacher learning and readiness as the central mechanism required for durable and equitable classroom integration. Consequently, our contribution is not only descriptive but also practice-facing. We translate evidence patterns into teacher education design moves, including an instructional design studio, practicum-linked simulation rehearsals, and faculty development that prioritizes pedagogy over device operation. These moves are aligned with the weaknesses repeatedly identified in the synthesis literature.

A key conclusion of our equity analysis is that equity-relevant issues often appear as secondary constraints rather than as central analytic categories. This pattern aligns with Franks' warning that immersive technologies can import and amplify persistent inequalities through design defaults, access barriers, and whose bodies, languages, and identities are normalized in immersive spaces [21]. For teacher education, this is doubly consequential: teachers are both learners in preparation programs and future designers of learning environments for diverse students. Our synthesis underscores that equity-by-design must be treated as a teacher-preparation outcome. This requires teacher candidates to anticipate constrained access and uneven funding, learner variability, usability burdens and adverse effects, and ethical challenges in social or data-intensive AR/VR environments. These issues should be addressed proactively, rather than appended as limitations after adoption.

Future work should therefore rebalance AR/VR research agendas toward teacher education by (1) conducting teacher-education–specific meta-analyses that isolate pedagogical design variables and professional learning outcomes, (2) developing shared, validated measures of AR/VR teacher readiness beyond attitude/usability (e.g., facilitation competence, assessment alignment, classroom management under immersive conditions, equity-by-design decision-making), and (3) foregrounding equity-by-design and governance in immersive learning research, explicitly attending to how AR/VR can replicate inequity and exclusion if access, safety, identity, and data ethics are not built into teacher preparation [21]. For experiential learning in engineering/computing education, this agenda positions AR/VR not only as a tool for technical simulation but as a test case for how we prepare teachers and future educators of engineers to design, evaluate, and govern emerging technologies responsibly [26].

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Appendix. **Synthesis: Number of records (84) after the 3rd level selection**
(Provided as a link to save space. Downloadable and accessible.)