**Virtual Reality in Teacher Education From 2010 to 2020:
A Review of Program Implementation, Intended Outcomes, and Effectiveness Measures**

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Abstract

Virtual reality (VR) is a technology that recreates realistic scenarios in a controllable virtual environment. VR has been widely adopted in professional training of situational, adaptive, and complex skills within various occupations, yet the field of teacher education has only just started to utilize this technology in the recent decade. In order to advance the application of VR in teacher education, the current review presents a synopsis of state-of-the-art literature from 2010 to 2020. We conducted a review regarding the details of program implementation (e.g., VR system and simulated situations), intended outcomes (e.g., factual/conceptual or procedural knowledge), and measures used to evaluate the effectiveness of teacher education programs that implemented various VR systems. Based on the review of 46 empirical studies, we found that 1) VR-based training programs mostly targeted pre-service teachers, and that they most frequently simulated instructional situations; 2) VR has been used most often for fostering procedural knowledge; 3) the majority of studies reported positive results regarding the intended outcomes and the effectiveness of VR has been measured mostly by teachers' self-reports. We also identified areas of improvement and future directions for the application of VR in teacher education and teacher education research.

Keywords: practice-based training, review, teacher training, virtual classrooms, virtual simulation

1 Introduction

Learning to be a teacher not only involves “knowing that,” but also “knowing how,” i.e., the core practices required to become a proficient teacher (Grossman et al. 2009). Acquisition of such expertise benefits greatly from deliberate practice—activities that are specifically designed to improve complex skills and professional performance (Ericsson 2006). Therefore, being able to purposefully enact core teaching practices in realistic scenarios is critical for teacher candidates’ development, a notion often reflected in the call for more practical training opportunities in teacher education (Dalgarno et al. 2016; Grossman 2018). Yet, such practice scenarios are difficult to implement in university-based teacher education programs and might not be sufficiently focused on the essential skills (Chernikova et al. 2020). The field of teacher education hence calls for a solution that combines standardized practice and realistic experience. Virtual reality (VR), as the digital technology that recreates lifelike experiences in virtual environments, has opened up new possibilities and more opportunities for situated practice in teacher education (Billingsley et al. 2019; McGarr 2020).

VR environments have long been used in professional training within various fields (for a review, see Jensen and Konradsen 2018), such as surgeons (Alaraj et al. 2011) and fire fighters (Morélot et al. 2021). Yet, the application of VR in teacher training has only evolved noticeably in the last decade (McGarr 2020). With the exponential growth of consumer-level VR hardware and software during the last decade (Hodgson et al. 2019), both the creation and application of VR in the educational context has become increasingly feasible and scalable (Hamilton et al. 2020). Yet, little is known about how various VR systems have been implemented and evaluated for training pre-and in-service teachers. Such as, what kind of situations were simulated, what

the intended outcomes of these training were, and how effective were they in achieving these outcomes?

The rapidly developing field of VR and teacher education calls upon a synthesis of the recent use of VR technology in teacher education. Responding to this need, we reviewed the relevant empirical studies published from 2010 to 2020 with the guidance of the Cognitive Affective Model of Immersive Learning (CAMIL) (Makransky and Petersen 2021). In order to provide important insights for future practice and research in VR-based digital teacher education, we specifically investigated the details of program implementation (e.g., VR system and simulated situations), intended outcomes (e.g., factual/conceptual or procedural knowledge), and measures used to evaluate the effectiveness of these teacher education programs.

1.1 Simulation and Practice-Based Teacher Education

The professional growth of a teacher involves developing core teaching practices in dynamic and complex situations (Forzani 2014). Examples of essential teaching practices may include how to elicit students' ideas, set and maintain expectations, or respond to class disruptions (e.g., McDonald et al. 2013). As argued by Grossman and colleagues (2009), compared to learning *about* instructional practices, the opportunities for learning *how to* enact such practices is greatly lacking in teacher training courses, even in the method-oriented ones (also see Lampert et al. 2013). Driven by the motivation of helping novices develop core practices for teaching, researchers have proposed a practice-based teacher education that focuses on teacher development through situated “approximations” of practice, also called rehearsals or simulations (e.g., Ball and Forzani 2009; Grossman 2018; Lampert et al. 2013).

More formally, a simulation is a “simplified but accurate, valid and dynamic model of reality implemented as a system” (Sauvé et al. 2007) and is widely used for training

professionals such as surgeons, pilots, or athletes (for a review, see Ward et al. 2006). Similarly, the application of simulated environments in teacher education also involves simplified but realistic situations that allow teachers to experiment with different decisions and actions without the risk of harming real students (Kaufman and Ireland 2016). Simulations also enable the “cyclical process of feedback,” meaning that teachers could repeatedly modify their actions after experiencing results or receiving feedback (Dieker et al. 2014).

Increasingly, research that focuses on training core teaching practices via simulations has utilized VR environments for its realism and controllability (e.g., Cohen et al. 2020; Dalgarno et al. 2016; Ke et al. 2020). VR is advocated by these researchers because it aids in bridging the gap between abstract theory and practical teaching skills, providing feedback with vivid examples, and relieving pre-service teachers’ performance stress by ensuring a safe environment for practice and experimentation (McGarr 2020). These benefits are attainable because of the unique features and affordances of VR which will be introduced in the next sections.

1.2 Features of Virtual Reality

VR is defined as any media system that provides “synthetic, highly interactive three dimensional (3D) spatial environments” that simulate real or non-real situations using a mosaic of technologies (Mikropoulos and Natsis 2011, p. 769). All VR systems, to varying degrees, have two important technological features: multisensory immersion and interaction (Dalgarno 2002; Makransky and Petersen 2021).

First, VR systems are able to substitute information from the real-world with the virtual world through sensory channels including visual, auditory, and kinesthetic to achieve a sense of *immersion*—the level of sensory fidelity, which depends on measurable system attributes such as display resolution and head-tracking (Slater and Wilbur 1997; Bowman and McMahan 2007;

Ded 2009). This multisensory immersion reduces the user's awareness of what is happening in the surrounding, sometimes to the extent that both the physical space and objects from the external world may be imperceivable. Immersion is achieved to a greater or lesser extent in various VR systems (Slater and Wilbur 1997). The current VR systems can thus be categorized as either non-, semi-, or fully-immersive VR (see Fig. 1). Non-immersive (also called desktop) VR systems utilize traditional input/output devices such as a desktop monitor, keyboard, mouse, joystick, and touch screen in presenting and interacting with the virtual environment (Kozhevnikov et al. 2013). Semi-immersive VR systems use wall-mounted displays and motion tracking devices for a higher degree of immersion and more intuitive interactions (Kyriakou et al. 2017). Finally, fully-immersive VR systems almost completely cover the users' field of view and block out visual information from their surroundings (Jensen and Konradsen 2018). The immersion in fully-immersive VR is typically achieved with 360° visuals through a head-mounted display (HMD), auditory information through headphones, and proprioception of limbs through controllers and tracking sensors (Hamilton et al. 2020).

Fig. 1 Types of VR Systems Based on Immersion

The second distinctive feature of VR systems is that they offer intuitive interaction through natural manipulations in real-time (Mikropoulos 2006). Users can interact with or manipulate the objects, virtual avatars, or other users inside the VR environment in a natural way (Hamilton et al. 2020). For instance, users can move around and pick up objects in the virtual environment by walking and extending their arms in the physical reality.

Immersion and interaction are the distinctive features of the VR experience, together with controllability, which is innate to a synthetic environment (Gray 2002). But technical features alone cannot justify the adoption of VR over physical reality in professional training. Rather, it is more useful to examine these features from the perspective of psychological and educational affordances: What unique opportunities can VR offer in the context of professional training compared to physical reality?

1.3 Affordances of Virtual Reality for Learning and Training

VR presents two distinct affordances for learning and training: presence and agency (Makransky and Petersen 2021; Slater 2018). Sherman and Craig (2019), among others, have claimed that the fundamental characteristic of VR experience is the sense of actual *presence* in and control over the virtual environment (also see Lessiter et al. 2001). Presence may thus be defined as an experience of “being there” (Ijsselstein and Riva 2003). Additionally, the intuitive interaction with the VR environment invokes a sense of *agency* in users, which can be described as a feeling of initiating and commanding actions at one’s own will (Moore and Fletcher 2012).

Presence and agency have been found to be positively associated with various factors that contribute to learning (Merchat et al. 2014; Parong and Mayer 2018). For instance, Makransky and Lilleholt (2018) found that higher VR presence was associated with stronger motivation and enjoyment in learning. Higher degrees of agency, as indicated by interaction and control,

correlate positively with self-efficacy, according to Gegenfurtner and colleagues' meta-analysis (2014).

Based on these empirical findings on VR affordances and learning-related variables, Makransky and Petersen (2021) recently presented the Cognitive Affective Model of Immersive Learning (CAMIL) as a theoretical framework for describing the learning process in VR. According to CAMIL, VR affordances (presence and agency) stem from technological features such as immersion and interaction, and then indirectly lead to learning outcomes through affective and cognitive factors including interest, motivation, self-efficacy, embodiment, cognitive load, and self-regulation (see Fig. 2 for a visual representation of the model).

Fig. 2 Graphical Representation of the Cognitive Affective Model Of Immersive Learning (CAMIL)

Note: Adapted from the “Fig. 2 Overview of the CAMIL” (Makransky and Petersen 2021)

CAMIL categorized the learning outcomes as factual, conceptual, and procedural knowledge, as well as transfer of knowledge, based on Anderson and colleagues' (2001) revision

of Bloom's taxonomy (Bloom et al. 1956). Factual knowledge has been described as the knowledge about "discrete, isolated content elements" (Anderson et al. 2001, p. 45), such as knowledge of terminology and specific details. Conceptual knowledge refers to "more complex, organized knowledge forms" (Anderson et al. 2001, p. 48), for example, classifications and theories. Procedural knowledge is knowing about "how to do something" and "when to do what" (Anderson et al. 2001, p. 52). Finally, learning that has occurred in one context having an effect on performance in another context is referred to as transfer of learning (Perkins and Salomon 1992; Makransky and Petersen 2021). These learning outcomes have been linked to the usage of VR in student learning (for a review, see Radianti et al. 2020).

Although CAMIL is instrumental in connecting affordances and learning outcomes, it is a generic model for immersive learning. Therefore, we would also like to present the advantages of VR in the context of professional training, based on previous empirical studies in this area (e.g., Ke et al. 2020; Mikropoulos and Natsis 2011; Steffen et al. 2019). First, VR can *recreate* existing aspects of the actual task environment for professional training in a believable fashion, while at the same time reducing resource costs compared to the physical reality. The resources may refer to time, effort, or economical resources (Steffen et al. 2019). Supported by the low-cost HMD, the VR training environments can be distributed efficiently and economically at scale (Kaufman and Ireland 2016). Second, VR could also *create* aspects of the task environment that are either difficult or risky to create in the physical reality. In terms of the difficulty, there are environments that are simply not feasible to construct in real life because of the constraints of the laws of physics. For instance, watching the influence of climate change from underwater (Bailenson 2018) and observing at close distance how the solar wind works (Mintz et al. 2001). And, regarding the risk, many essential tasks in various professions carry with them great

physiological or psychological risks. Military, medical, and aviation applications particularly illustrate this point (Steffen et al. 2019). For instance, even minor maneuver mistakes during pilot training can lead to traumatic and irreversible outcomes if the practice is conducted in the actual physical world (e.g., Kasarskis et al. 2001). Finally, VR can be controlled and configured for stepwise training. As Gray (2002) puts it, VR provides “controlled complexity”—a balance between artificial controllability and naturalistic complexity. The controlled complexity of the VR environment allows for both standardization and individualization of training scenarios. Standardization of setting and procedures is essential for consistent and comparable training results. For instance, surgeons trained at different sites with the identical VR system can be expected to operate on the same patient with abdominal pain in the same way (Larsen et al. 2012). Another application of this feature is the gradual increment in task difficulty and the repetition of the same difficulty, often seen in athlete training (Craig 2013), allowing for appropriate scaffolding at different stages during the training process (Ke et al. 2020).

Due to these affordances, the VR environment has often been considered ideal for training situational, adaptive, and complex skills through deliberate practice in realistic situations (Radianti et al. 2020), and practically, an intermediate step between traditional coursework and the final placement among many professional fields (Rooney and Boud 2019). The same arguments have been applied to teacher education as well. As the unique affordances of VR closely align with the goals of practice-based teacher education (Dieker et al. 2014; Grossman 2018), we are seeing a growing use of VR in teacher education over the last decade (Billingsley et al. 2019; Lamb and Etopio 2020).

Despite the great potential of utilizing VR for teacher education, this rapidly growing field lacks a comprehensive overview of the implementation and evaluation of teacher training

programs that incorporated VR in the last ten years, during which consumer-grade VR has become mainstream. Existing literature reviews share certain overlaps with the scope of the current review. However, the previous reviews have mostly focused on a few specific VR systems (e.g., Hayes et al. 2013; McGarr 2020), an older generation of VR systems (e.g., McGarr 2020), and only initial teacher education (e.g., Peterson-Ahmad et al. 2018) (also see Tab. 1). Other than the fragmental scope, these reviews also have not examined in a systematic fashion what type of VR systems have been used and how they have been evaluated for effectiveness in teacher education. In sum, the field of teacher education calls for a more extensive investigation as to how VR has been implemented and evaluated in all levels of teacher education in the past decade, especially regarding details of implementation, intended outcomes and the effectiveness measures used.

Tab. 1 Summary of Relevant Reviews

Authors	Focus
Hayes et al. (2013)	Pre-service teacher education with one semi-immersive VR system (TLE TeachLivE).
Dieker et al. (2014, 2015)	Teacher education with one semi-immersive VR system (TLE TeachLivE).
Kaufman and Ireland (2016)	Pre-service teacher education with simulations (not necessarily including VR).
Peterson-Ahmad et al. (2018)	Pre-service teacher education with one semi-immersive VR system (Mursion).
Billingsley et al. (2019)	Teacher education with only fully-immersive VR systems.
McGarr (2020)	Training pre-service teachers' classroom management skills with virtual simulations, examined mostly non-immersive VR systems.

1.4 Present Study

In this review, we surveyed the current state of the art in using VR for teacher education from 2010 to 2020, including all types of VR systems used by both pre-service and in-service teachers. We are particularly interested in how teacher education programs utilized VR, in

intended outcomes that are similar to CAMIL's classification of learning outcomes, and how they evaluated its effectiveness in achieving these outcomes. Specifically, we put forth the following research questions:

- a) What are the implementation details of teacher education programs incorporating VR?
- b) What are the intended outcomes of these programs in terms of factual and conceptual knowledge, procedural knowledge, and other outcomes?
- c) Are the trainings effective with regard to its intended outcomes, and what effectiveness measures are included in the evaluation of these programs?

Particularly, we examined the following implementation details: what the participants' status were (pre- or in-service teachers), the number of participants, the duration of the program, the study design, the VR systems utilized, and the situations simulated in these VR systems. We predefined the categories of intended outcomes and effective measures for a better overview of the themes (see Coding Procedure for details). Specifically, intended outcomes were categorized according to CAMIL's classification of learning outcomes: factual and conceptual knowledge, procedural knowledge, and other outcomes. In order to contextualize and interpret the effectiveness measures, we coded the tendency of evaluation results (effective or not). Effectiveness measures were categorized according to common methods for learning outcome evaluation, such as exam scores, self-reports, and questionnaires (e.g., Radianti et al. 2020), plus any additional measures used in the reviewed studies.

2 Method

2.1 Screening Criteria

As we were specifically interested in the implementation and evaluation of teacher education programs that utilize VR systems, the following criteria were defined before conducting the

literature search (Tab. 2). Generally, we included empirical studies about using VR for teacher education that were published as English-language articles in peer-reviewed journals and conference proceedings during the last decade (2010–2020). We only included peer-reviewed empirical studies that used either qualitative or quantitative methodologies for quality control purposes. Empirical qualitative studies may include narrative research, phenomenology, ethnography, case studies, etc. Empirical quantitative research may include experiments with the random assignment of participants to different conditions, or quasi-experimental and correlational studies (Creswell and Creswell 2017).

Tab. 2 Inclusion and Exclusion Criteria of the Publications for This Review

Inclusion criteria	Exclusion criteria
Must involve actual use of VR systems for teacher education purposes.	Participating teachers didn't have hands-on experiences with VR, such as surveying teachers' attitudes regarding VR (e.g., Graziano 2017).
Must be an empirical qualitative or quantitative study published in peer-reviewed journals or conference proceedings.	Description of how the VR teacher education program is designed or developed without actual implementations, such as an investigation about what should be included in a VR teacher education program (e.g., Paul et al. 2020).
Must be written in English and published between 2010 and 2020.	Description of the design processes or evaluations of VR systems for teacher education purpose but without implementations, such as an evaluation of VR systems using theory-based design principles (e.g., Deale and Pastore 2014)

2.2 Literature Search Strategy

The literature search was conducted in databases including Scopus, ERIC, PsycINFO, Web of Science, and JSTOR. We also used search engines including Crossref, Google Scholar, and Microsoft Academic to ensure the comprehensiveness of the search. During our search, we used the following Boolean search string: (teach* OR educator) AND (VR OR virtual reality OR simulat* OR immersi*) in all databases. This search string covers common keywords for VR (virtual reality, VR, simulation, simulated environment, virtual simulation, simulation-based, immersive environment) and teacher education (teacher training, teacher development, beginning teacher, pre-service teacher, teacher candidate, teacher education, teacher professionalization, teacher expertise, teacher career, teaching, educator).

2.3 Selection Process

The initial literature search yielded 165 documents in the first step. After removing duplicates ($n = 53$), we then read the titles and abstracts and excluded 57 records according to the predefined screening criteria (see Tab. 2) in the second step. We next examined the document's content and excluded 9 documents in the third step due to unoriginal data, a lack of full text, and not being written in English. In the last step, we included 46 articles for the review (see Fig. 3).

Fig. 3 Study Selection Flow Chart

Note: Adapted from the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) flow diagram (Moher et al. 2009)

2.4 Coding Procedure

In this review, we are interested in the implementation and evaluation of VR in teacher education. Therefore, two trained coders each independently examined the following aspects of the included articles: basic article information (country and year of publication), program

implementation details (participant status, number of participants, program length, study design, VR system, simulated situation), intended outcomes, and effectiveness measures (effectiveness, effectiveness measures) (see Tab. 3 for descriptions). The interrater reliability (Cohen's κ) was between .81 (strong agreement) and .97 (almost perfect agreement) for all coding categories (McHugh 2012). Disagreements were resolved through reexamination and discussion of the studies in question.

Tab. 3 Coding Category by Research Questions

Research question	Coding category	Explanation
1. What are the implementation details of teacher education programs incorporating VR?	Participant status	Professional status of the participants of the program, either pre-service or in-service teachers.
	Number of participants	Number of teachers participated in the program.
	Program length	Duration of the training.
	Study design	The design of the study, classified as observational, experimental (with control group), or pre-post designs with/without control group.
	VR system	Name and type (non-, semi-, or fully-immersive) of the VR system used.
2. What are the intended outcomes of these programs?	Simulated situation	The particular situation that the VR system simulated, such as typical classroom instructions or critical situations requiring interventions.
	Intended outcomes	The professional knowledge for which the program was developed. Knowledge is classified into factual and conceptual knowledge, procedural knowledge, and other outcomes.
3. What effectiveness measures are included in the evaluation of these programs?	Effectiveness	Whether the research concluded that VR-based training is successful, categorized as yes, no, or mixed.
	Effectiveness measures	Measures used for evaluation. Categorized as self-report, questionnaire, exam, external observation, physiological response, task completion, and not reported.

3 Results

3.1 Basic Information

Accessible VR technology boomed between 2014 and 2016. Among the 46 studies included in the review, we observed a spike in number of studies published in 2019 and 2020, accounting for 56.5% of all studies. The majority of the included studies were conducted in the United States (57.8%), followed by Germany and Turkey (both 6.5%).

3.2 Program Implementation

Among 46 studies, we found that 80% of the investigations targeted pre-service teachers. VR training session mostly served as a supplemental element of existing teacher training courses or workshops. Program lengths varied greatly due to the course schedule (from an hour to a semester), but the VR session, which only took place several times during the program, usually occupied less than half an hour, ranging from 10 minutes to 2 hours. The research designs of included studies ($n = 46$) were classified as observational (45.7%), experimental (19.6%), pre–post with control group (10.9%), and pre–post without control group (23.9%). Observational studies involved researchers observing participants' behaviour without intervening or manipulating them. Experimental investigations entail the manipulation of an independent variable, the measurement of a dependent variable, and the random assignment of participants to conditions. While the pre–post design employed the same measures both before and after the participants were exposed to a condition, with or without a control/comparison group (VandenBos and American Psychological Association 2007).

An array of VR systems with varying degrees of immersion and interaction were employed in the reviewed studies ($n = 46$): 41.3% of studies used fully-immersive, 34.8% used semi-immersive, and 23.9% used non-immersive VR systems (see Tab. 4 for descriptions).

Technology used in these systems ranged from traditional input/output devices like a mouse and keyboard to sensor-based input/output devices including a haptic controller, head movement tracker, and motion sensor (see Fig. 1 in Features of Virtual Reality for details about different VR systems).

Tab. 4 VR Systems

System name	Categorization	Features	Sample publication
Second Life	Non-immersive (desktop) VR	Online multiplayer game in which users can create their own avatars and interact with other users through text messaging in a 3D environment.	Lybeck et al. (2011) among four others.
TLE TeachLive	Semi-immersive VR	Users teach in front of a TV display with simulated student avatars operated as puppets by a trained actor.	Dicker et al. (2019) among seven others.
Mursion	Semi-immersive VR	Based on TLE TeachLive but with professional level graphics.	Dalinger et al. (2020) among three others.
OpenSimulator	Semi-immersive VR	Open source virtual college classrooms with both autonomous virtual students and avatars controlled by other users.	Ke et al. (2020) among three others.
Self-developed VR system: Breaking Bad Behavior	Fully-immersive VR	VR classroom with semi-autonomous virtual students that allow an external supervisor to give feedback while the trainee is teaching.	Lugrin et al. (2016) among one other study.
Self-developed VR system: eChalk	Fully-immersive VR	Open source program with functions such as configurable classroom layouts, controllable student behavior either externally, or with a predefined script.	Huang et al. (2021)
Self-developed VR system: 360-degree video	Fully-immersive VR	Classroom videos shot with 360-degree cameras are presented in HMD.	Gold and Windscheid (2020) among six others.

Note: $n = 46$. For other VR systems please see Appendix Table

The situations that participating teachers could experience in these VR systems converged on several themes that were closely related to teachers' work lives, such as creating a lesson plan, giving a lesson, dealing with student disruptions, intervening in bullying, conversing with colleagues and parents, and reflecting on teaching practices (see Tab. 5 for details). Among 46 studies, teachers were most frequently instructing a group of student avatars in a virtual classroom (coding category of instructional situations: 60.9%), and often with heightened level of disruption (42.9% of instructional situations). Interactive events other than instructions were also simulated, such as dealing with critical situations (8.7%) and communicating with colleagues/parents (6.5 %). In these interactive situations, avatars would display verbal confrontations or aggressive behaviors, requiring teachers to make quick decisions. Seventeen percent of situations also addressed professional tasks unrelated to students or other individuals, such as lesson planning (13%) and reflection on teaching (4.3%). Teachers were also exposed to VR lessons that provided them with new information, such as metacognition and dyslexia, in a smaller proportion (6.5%).

Tab. 5 Simulated Situations in Reviewed Studies ($n = 46$)

Category (number of studies)	Explanation	Sample publication
Instructional situations (28): Instruction in classroom (13) Instruction with disruptions (12) Instruction with special needs students (2) Instruction in laboratory (1)	Teachers taught in typical classroom situations.	Ye et al. (2019) used interactive 360-degree videos presented in VR to help pre-service teachers detect and react to misbehaviors in typical elementary classroom scenarios.
Lesson design situations (6): Lesson plan (4) VR application (2)	Teachers designed learning activities and materials for their subjects and their student groups.	Nussli et al. (2015) conducted workshops with pre-service teachers to design activities for social skill practice in Second Life or other virtual worlds, specifically for students who struggle with social skills.
Critical situation (4): Diversity issues (2) Homelessness (1) Substance usage (1)	Teachers were involved in high-risk situations that require their immediate interventions.	Stavroulia and Lanitis (2020) used a self-developed fully-immersive VR system and presented a scenario regarding racial diversity and verbal bullying for in-service teachers.
Communicative situations (3): Communication with colleagues (2) Communication with parents (1)	Teachers had verbal communications with colleagues and parents.	Spencer et al. (2019) used TLE TeachLivE for training pre-service teachers to have difficult conversations with a reluctant coteacher.
Learning situations (3): Metacognition (1) Geography (1) Dyslexia (1)	Teachers were regarded like students and were exposed to new ideas.	Passig (2011) used a self-developed fully-immersive VR system to simulate the cognitive experience of dyslexic students in order to increase teachers' understanding of dyslexia.
Reflectative situations (2)	Teachers reflected on classroom events and instructional practices.	Walshe and Driver (2019) used a fully immersive VR system to show 360-degree classroom recordings and asked pre-service teachers to reflect.

3.3 Intended outcomes

We classified the intended outcomes of VR-based teacher education programs into four categories, roughly based on the categorization of learning outcomes in CAMIL (see Tab. 6 for descriptions). Five out of 46 studies were targeting two intended outcomes, added up to 51 reported outcomes. First, 5.9% of reported outcomes ($n = 51$ from 46 studies) utilized VR simulated environments to teach facts and conceptual frameworks. In these cases, VR technology was employed as a tool for distance learning, for instance, for teaching about metacognition (e.g., Gregory and Masters 2012).

Second, 74.5% of reported outcomes were classified as procedural knowledge related to tasks in teachers' work environment. Several themes emerged from this category, the most common one was classroom management (15.7% of 51 outcomes), such as noticing and reacting to student misbehaviors (e.g., Ye et al. 2019). These programs also frequently addressed skills useful for particular subjects (15.7%), such as a framework called Collaborative Strategic Reading (CRS) for language teachers (Ely et al. 2018). Another popular theme regarded communicative skills (11.8% teacher-student interaction, 7.8% teacher collaboration), teachers were trained to interact with students, parents, and co-teachers in high-stake situations that are difficult to replicate in real life (e.g., Spencer et al. 2019): for instance, talking to students with substance abuse issues or behavioral and psychological disorders (e.g., Stavroulia et al. 2019). Digital literacy was mentioned in 11.8% of all reported outcomes, implying that teachers may need to employ VR for instructional purposes in their job, such as how to design and implement a lesson in VR (e.g., Huh 2020).

Lastly, we also identified a few uncategorizable intended outcomes (19.6% of the 51 outcomes) which include improving teachers' self-efficacy (e.g., Bautista and Boone 2015), resilience and motivation.

Tab. 6 Intended Outcomes of Reviewed Studies

Category (number of studies)	Explanation	Sample publication
Factual and conceptual knowledge (3): Knowledge development (3)	Knowledge of both isolated and more organized content elements.	Gregory and Masters (2012) used Second Life for learning activities that may improve pre-service teachers' knowledge about metacognition.
Procedural knowledge (38): Classroom management (8) Instructional practices (8) Teacher-student interaction (6) Digital literacy (6) Teacher collaboration (4) Noticing and interpreting events (3) Lesson planning (1)	Knowledge about "how to do something" and "when to do what".	Ely et al. (2018) used TLE TeachLivE to improve preservice teachers' knowledge of evidence-based comprehension practices embedded in Collaborative Strategic Reading (CSR) for students with disabilities.
Other outcomes (10): Self-efficacy (7) Motivation (3) Resilience (1)	Other knowledge and skills that are hard to categorize.	Bautista and Boone (2015) used TLE TeachLivE for improving science teachers' self-efficacy in science teaching and outcome expectancy belief.

Note: n = 51 (5 out of 46 studies had two intended outcomes). For all included articles with coding please see Tab.

7 in Appendix.

3.4 Effectiveness Measures

Among the reviewed articles, only one study reported negative result (Lybeck et al. 2011), while two others had mixed results in terms of intended outcomes (Dalgarno et al. 2016; Gold et al. 2020). Among 10 studies that provided the effect size (Cohen's d) of their positive results, a range from .31 to .51 were reported (medium to large effect) (Cohen 1992). It is also worth noting that only three studies investigated the transfer of VR training outcomes back into physical realities.

There is a variety of measures included for demonstrating the effectiveness of VR training programs. We categorized the measures used for evaluating the outcomes as: task completion (able to finish a certain task in VR or actual life), exam (score on a formal exam), self-report (teachers reported that the VR training was effective either through interview or survey), questionnaire (used a validated scale or measurement), external observation (teachers' behaviors in VR were recorded and coded), and physiological responses such as heart rate and EEG. Among 46 studies (60.9% used multiple effectiveness measures), we found that the effectiveness of these VR training programs was mainly measured by teachers' self-reports (75.6%) and questionnaires (48.9%) (see Fig. 4).

Fig. 4 Effectiveness Measures Used in the Included Studies ($n=46$)

Note: Twenty-eight studies used multiple effectiveness measures.

4 Discussion

In this comprehensive literature review of empirical studies on the topic of VR and teacher education published from 2010 and 2020, we focused on the implementation and evaluation of VR systems in teacher education. Specifically, we investigated program implementation,

intended outcomes, and effectiveness measures included in the reviewed studies. We discuss the findings in each of the three areas and offer suggestions for future implementation and research.

First, after reviewing the implementation specifics of how VR was employed in the included research, we found that most training programs were implemented with pre-service teachers. The affordances of VR, such as providing a safe environment for experimenting with courses of actions that are high-stake in real-life, are not only beneficial for initial teacher education, but also for the professional development of in-service teachers. For instance, many in-service teachers are not equipped with the expertise needed to conduct inclusive instruction (Keppens et al. 2019). Studies that we reviewed already demonstrated the effectiveness of engaging teachers in high-risk situations, such as interacting with students with substance abuse issues (Stavroulia et al. 2019) or students on the Autism spectrum (Garland et al. 2015). With the increasing accessibility of VR technology, we would propose that VR-based teacher education programs should include more diverse teachers' groups at different career stages.

We also identified numerous VR systems with varying degrees of immersion that had been applied in teacher education. The diversity of systems used in the current field may pose a challenge in comparing teachers' experience and outcomes in these trainings. Our finding that 58.7% of VR systems utilized in the present literature were not fully immersive highlighted the insufficiency of employing VR systems with high degrees of immersion. According to CAMIL, the benefits of VR experiences in terms of learning outcomes originate largely from technological aspects like immersion; hence, fully-immersive VR systems could be favored over semi- and non-immersive systems in the future. Additionally, although VR hardware is becoming increasingly affordable, the VR software as we identified in the review is still mostly developed by for-profit organizations and companies and is highly proprietary (including

Mursion, Second Life, and MaxWhere). This heavy reliance on certain commercial software could be an obstacle for the distribution and further development of VR training environments as educational resources.

Regarding the situations simulated in VR, we found that despite the great potential of exhibiting any situations in VR, the current training programs were mostly sticking to recreating traditional classroom scenarios in which teachers carry out instructions. As we summarized in the introduction to VR affordances, this technology allows not only for the recreation of existing aspects of the actual teaching environment, but it also allows for a) the creation of task environment that are either difficult or high-risk in the physical world; and b) configurable stepwise training. We would therefore argue that current VR-based teacher education programs have not fully utilized the technology's full potential in these two areas. For starters, only a few existing VR systems are interactive in the sense that the avatars respond to teachers' behavioral and/or verbal cues. Mursion, for example, employs professional actors to control avatar's gesture and speech as if manipulating a puppet (Dalinger 2020). This mixed-reality approach allows for a flexible reaction to varied input from teachers. However, the costs associated with training the actors and implementing such systems limit the scalability of this type of technology (Peterson-Ahmad 2018). The bulk of VR systems are still not truly interactive, which means that student avatars are controlled by pre-programmed scripts and respond little to teacher activities. The overall absence of interactivity impedes both presence and agency associated with the current VR systems. Second, situations that are rare yet high-stake in teachers' work environments should be emphasized more, as only 8.7% of the existing simulations showed crucial situations that required instructors to make decisions in the heat of the moment. Third, the existing VR simulations were mostly a brief and singular experience, as shown in the short program duration

ranging from 10 minutes to 2 hours. Limited attempts in the existing literature had been made to gradually evolve the simple situation to approximate the level of complexity in real-life teaching through repeated practice—an effective approach often seen in sports training (Craig 2013). To summarize, the simulated situations in VR might be enhanced further by simulating infrequent but critical events, as well as increasing the training time, interactivity, and task complexity for stepwise training in teacher education.

Second, we examined the intended outcomes of the existing literature. VR has been utilized most frequently to cultivate procedural knowledge, but less often for factual and conceptual knowledge. This finding is to be expected given VR's distinct affordances of presence and agency. Individuals are empowered to practice deliberately when they feel physically present in a situation and are able to perform actions in accordance with their will (Gray 2002). For this precise reason, VR has also been utilized in other professional fields mostly for training procedural and situational knowledge such as “how to do something” and “when to do what” (Jensen and Konradsen 2018). In this sense, classroom instruction has been elevated to the level of piloting a fighter jet or performing surgery. Although VR is naturally suited for training procedural knowledge, we would like to emphasize that the potential of VR could be equally great for training factual and conceptual knowledge in specific subject areas, as evidenced by the large body of immersive learning literature aimed at students in higher education (e.g., Hamilton et al. 2020; Radianti et al. 2020).

Another finding in intended outcomes is that it was common to assess changes in self-efficacy and motivation alongside knowledge development. Consistent with the hypothesis of CAMIL, self-efficacy and motivation are positively associated with VR experience which may continue to affect learning outcomes (e.g., Eccles and Wigfield 2002; Harackiewicz et al. 2016).

Besides these affective and motivational factors, cognitive factors such as cognitive load and self-regulation are also crucial factors that link affordances of VR and learning outcomes according to CAMIL. Future investigations on teachers' cognitive experience may lead to a deeper understanding of the learning process in VR.

Finally, the majority of the reviewed studies reported positive results regarding the intended outcomes, with 10 of them reported medium to large effect sizes. This universal positive evidence spoke in support of the use of VR in teacher education programs aiming for a variety of objectives, and for both pre- and in-service teachers. Despite the majority of positive outcomes, one methodological flaw in the evaluated studies is that they typically measure the effectiveness of VR using instructors' self-reports rather than objective and external observations.

It is also worth mentioning that a lack of research on knowledge transfer into real-world classrooms casts doubt on the validity of considerably increasing the use of VR-based teacher education programs in the future. Although the ecological validity of VR environments are often claimed to be comparable to real-life teaching, due to the strong sense of presence they are able to invoke, validation studies that compare teacher's performance in VR and real classrooms need to be conducted in order to establish the ultimate effectiveness of VR environments for teacher education and eventually include student outcome measures.

4.1 Implications

We would want to return to the CAMIL framework (Fig. 2) to highlight potential directions for bringing the research ahead. As illustrated in Fig. 2, the hypothesized effect of VR training stems from its technological characteristics and affordances and has an indirect impact on learning outcomes via the mediation of psychological factors involved in learning experiences, such as

motivation or cognitive load. As discussed earlier, we found that the reviewed studies had often used non-immersive VR system that might be low in presence and agency; and assessed only knowledge-related outcomes and emotional factors (self-efficacy). In order to construct a comprehensive model that connects VR affordances with learning/training results, we would recommend future research to choose VR systems that maximize presence and agency, and assess both emotional and cognitive factors in connection to VR experience.

Although the current review focuses on the way of implementation and evaluation of VR systems used for teacher education purposes, we want to raise the point that the application of VR in educational science is not restricted to teacher training. Besides serving as an environment for practicing teaching skills, VR is also ideal for eliciting and measuring teachers' behavior in experimental conditions for research purposes. The realism and experimental controllability of the VR environment has already presented itself as an ideal setting for studying human behavior in several branches of research, such as consumer behavior, human perception, and social behavior (e.g., Kim et al. 2020). In the context of teaching, VR is capable of not only providing a compelling experience, but also ensuring standardized and meticulous controls that are impossible to achieve in real-life classrooms. For instance, in the VR environment, researchers can strategically manipulate the frequency and duration of a variety of situations that are unpredictable in real-life classrooms. Classroom features such as group size, layout, student characteristics, and the number and types of events can also be defined and controlled.

Multiple empirical studies regarding the influencing factor of teachers' behavior have already attested the potential value of using VR as an experimental test-bed (e.g., Heitzmann et al. 2019; Kaiser et al. 2013). For instance, in a VR classroom, Krämer and Zimmermann (2019) found that besides the actual exam, virtual students' misbehaviors affected teachers' judgments

about their grades. Another study that employed a VR classroom as an experimental environment investigated whether classroom complexity features affected the likelihood that student teachers would notice disruptions and how they reacted after noticing (Huang et al. 2021). In sum, this exciting possibility of controlling a lifelike classroom will enable researchers to answer questions that have not previously been possible to investigate.

4.2 Limitations and Conclusions

The present review is unique in that it covers the field of VR and teacher education over the last ten years. Despite its comprehensiveness, this review also suffers from two limitations. First, we acknowledge that as we included all types of VR systems and teacher communities, the broad focus of this review may have blunted the specific details about the studies. For instance, we did not code for details such as number of avatars or the type of sensors, due to the great diversity of each of the included studies. Second, although the current review describes the effectiveness measures used in the included studies, we did not carry out analyses to reach a synthesis of study results. In sum, a meta-analysis with an even narrower window of publication years or a more specific thematic focus would be beneficial for the field.

Overall, this review aggregated the prosperous research effort from the last decade in applying VR for teacher education. Based on investigations into three areas of the VR-based teacher education program (program implementation, intended outcomes, effectiveness measure), we concluded that VR has been universally beneficial for the intended outcomes, using various VR systems that simulated a great range of education-related situations, for both pre- and in-service teachers. The use of VR in teacher education may be enhanced in all three areas, and the research field could benefit from incorporating theoretical models and reframing VR as an experimental lab.

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Appendix

Tab. 7 Articles Included in the Review and the Corresponding Coding

ID	Author	Title	Country	Participant status	No. of participants	Program length	Study design	VR system	Simulated situation	Intended outcomes	Intended outcomes descriptions	Effectiveness	Effectiveness measures
1	Huh (2020)	360° virtual reality project to inspire future educators to be creators	United States	pre-service teachers	missing	2 weeks	observational	360° (fully-immersive)	lesson design (VR application)	procedural	digital literacy	yes	self-report, questionnaire
2	Lybeck et al. (2011)	A discussion about Second Life and virtual reality as a tool in online teacher education	United States	pre-service teachers	25	1 year	observational	Second Life (non-immersive)	instruction (classroom)	procedural	teacher collaboration; instructional practices (teaching English as a second language)	no	self-report
3	Md Shamsudin et al. (2019)	A framework of virtual reality learning system for teacher's trainee programme at Malaysian higher education	Malaysia	pre-service teachers	30	missing	observational	Self-developed VR (non-immersive)	lesson design (lesson plan)	procedural	implement safety measures	yes	questionnaire
4	Dalinger et al. (2020)	A mixed reality simulation offers strategic practice for pre-service teachers	United States	pre-service teachers	94	single session	observational	Mursion (semi-immersive)	instruction (classroom)	other	knowledge transfer; self-efficacy	yes	self-report
5	Nussli and Oh (2015)	A systematic, inquiry-based 7-step virtual worlds teacher training	United States	in-service teachers	18	4 hours per week for 1 semester	pre-post without control group	Second Life (non-immersive)	lesson design (lesson plan)	procedural	digital literacy	yes	external observation, self-report, questionnaire
6	Stavroulia et al. (2020)	Addressing the cultivation of teachers' reflection skills via virtual reality based methodology	Cyprus	in-service teachers and pre-service teachers	33	single session	pre-post without control group	Self-developed VR (fully-immersive)	critical (diversity)	procedural	reflection	yes	questionnaire
7	Stavroulia and Lanitis (2019)	Assessing the emotional impact of virtual reality-based teacher training	Cyprus	in-service teachers	25	5 min	pre-post without control group	Self-developed VR (fully-immersive)	critical (substance use)	procedural	teacher-student interaction (understanding of student's problematic situations related to substance use)	yes	physiological response, self-report
8	Lugin et al. (2016)	Breaking bad behaviors: A new tool for learning classroom management using virtual reality	Germany	pre-service teachers	22	1 session of 40-60 minutes during 1 semester	observational	3B (fully-immersive)	instruction (disruptions)	procedural	classroom management	yes	questionnaire
9	Ye et al. (2019)	Classroom misbehaviour management: An SVVR-based training system for preservice teachers	China	pre-service teachers	62	95 minutes	experimental	TrainCM2 (fully-immersive)	instruction (disruptions)	procedural	classroom management	yes	exam, questionnaire, task completion
10	Ely et al. (2018)	Classroom simulation to prepare teachers to use evidence-based comprehension practices	United States	pre-service teachers	22	one semester	experimental	TLE TeachLivE (semi-immersive)	instruction (classroom)	procedural	instructional practices (reading)	yes	questionnaire, external observation
11	Spencer et al. (2019)	Comparing the efficacy of virtual simulation to traditional classroom role-play	United States	pre-service teachers	90	5 sections of an inclusive education course	experimental	TLE TeachLivE (semi-immersive)	communication (colleagues)	procedural	teacher-teacher communication	yes	questionnaire
12	Bucher and Grafe (2018)	Designing augmented and virtual reality applications with pre-service teachers	Germany	pre-service teachers	19	1 semester	observational	Self-developed VR (fully-immersive)	lesson design (VR application)	procedural	digital literacy	yes	self-report, exam
13	Walsh and Driver (2019)	Developing reflective trainee teacher practice with 360-degree video	United Kingdom	pre-service teachers	23	10 min	observational	360° (fully-immersive)	reflection	procedural	reflection (lesson excerpts)	yes	self-report
14	Walsh and Driver (2019)	Developing trainee teacher understanding of pedagogical content knowledge using 360-degree video and an interactive digital overlay	United Kingdom	pre-service teachers	23	30 min	observational	360° (fully-immersive)	reflection	procedural	reflection (pedagogical decisions)	yes	self-report

15	Artun et al. (2020)	Effects of virtual reality enriched science laboratory activities on pre-service science teachers' science process skills	Turkey	pre-service teachers	54	one semester	experimental	Google Expeditions app with HMD (fully-immersive)	instruction (laboratory)	procedural	science process skill	yes	exam, self-report
16	Garland et al. (2012)	Efficacy of individualized clinical coaching in a virtual reality classroom for increasing teachers' fidelity of implementation of discrete trial teaching	United States	in-service teachers	4	6 sessions	pre-post without control group	TLE TeachLivE (semi-immersive)	instruction (special needs)	procedural	teacher-student interaction (with students with Autism spectrum disorder)	yes	external observation, self-report
17	Bautista et al. (2015)	Exploring the impact of TeachMET TM Lab virtual classroom teaching simulation on early childhood education majors' self-efficacy beliefs	United States	pre-service teachers	62	one semester	pre-post without control group	TeachME Lab (semi-immersive)	instruction (disruptions)	other	self-efficacy	yes	questionnaire, self-report
18	Yun et al. (2019)	Exploring the influences of immersive virtual reality pre-service teacher training simulations on teacher efficacy	South Korea	pre-service teachers	75	missing	experimental	Self-developed VR (fully-immersive)	instruction (disruptions)	other	self-efficacy (classroom management)	yes	questionnaire
19	Barab et al. (2016)	Gaming up the practice of teacher education: Quest2teach	United States	pre-service teachers	3500	2 years	observational	Ques2Teach (non-immersive)	instruction (classroom)	procedural	teacher collaboration; teacher-student interaction	yes	self-report
20	Garland et al. (2015)	Individualized clinical coaching in the TLE TeachLivE Lab: Enhancing fidelity of implementation of system of least prompts among novice teachers of students with autism	United States	in-service teachers	6	one semester	pre-post without control group	TLE TeachLivE (semi-immersive)	instruction (special needs)	procedural	teacher-student interaction (with students with Autism spectrum disorder)	yes	questionnaire, self-report
21	Ke et al. (2020)	Investigating educational affordances of virtual reality for simulation-based teaching training with graduate teaching assistants	United States	graduate teaching assistants	17	2 hour session	pre-post without control group	OpenSimulator (semi-immersive)	instruction (classroom)	procedural	instructional practices (teaching assistant)	yes	external observation, self-report
22	Dawson et al. (2017)	Meaningful practice: generalizing foundation teaching skills from TLE TeachLivE TM to the classroom	United States	pre-service teachers	4	1 semester	pre-post without control group	TLE TeachLivE (semi-immersive)	instruction (disruptions)	procedural	classroom management	yes	questionnaire, self-report
23	Gold and Windscheid (2020)	Observing 360-degree classroom videos – Effects of video type on presence, emotions, workload, classroom observations, and ratings of teaching quality	Germany	pre-service teachers	59	3 rounds (each 1 semester)	experimental	360° (fully-immersive)	instruction (classroom)	procedural	noticing and interpreting classroom events (professional vision)	mixed	questionnaire, external observation
24	Dalgarno et al. (2016)	Practising teaching using virtual classroom role plays	United States	pre-service teachers	82	two hour sessions - one for introduction and one for the role play	observational	Second Life (non-immersive)	instruction (classroom)	procedural	instructional practices	mixed	questionnaire, self-report
25	Hudson et al. (2019)	Preservice teacher experiences implementing classroom management practices through mixed-reality simulations	United States	pre-service teachers	25	1 semester (3 times)	pre-post without control group	Mursion (semi-immersive)	instruction (disruptions)	other	self-efficacy (classroom management)	yes	questionnaire, self-report
26	Kosko et al. (2020)	Preservice teachers' professional noticing when viewing standard and 360 video	United States	pre-service teachers	33	one semester	experimental	360° (fully-immersive)	instruction (classroom)	procedural	noticing and interpreting classroom events (professional vision)	yes	self-report, external observation
27	Gregory and Masters (2012)	Real thinking with virtual hats: A role-playing activity for pre-service teachers in second life	United States	pre-service teachers	96	2 years	experimental	Second Life (non-immersive)	learning (metacognition)	factual and conceptual	knowledge development (metacognition)	yes	external observation, questionnaire
28	Hartley et al. (2011)	Second Life for special educators: Using virtual reality in a teacher education program	United States	pre-service teachers	54	2x2 hours	observational	Second Life (non-immersive)	communication (colleagues)	procedural	teacher collaboration	yes	self-report
29	Gundel et al. (2019)	Self-efficacy in mixed reality simulations: Implications for preservice teacher education	United States	pre-service teachers	53	1-3 semesters (each 30 minutes of exposure)	pre-post with control group	Mursion (semi-immersive)	instruction (disruptions)	other	self-efficacy	yes	questionnaire

30	Cohen et al. (2020)	Teacher coaching in a simulated environment	United States	pre-service teachers	105	3 sessions over several months	pre-post with control group	Mursion (semi-immersive)	instruction (disruptions)	procedural	classroom management	yes	external observation, questionnaire
31	Thompson et al. (2019)	Teacher Moments: A digital simulation for preservice teachers to approximate parent-teacher conversations	United States	pre-service teachers	24	one semester	observational	Teacher Moments (non-immersive)	communication (parents)	procedural	teacher-parent communication	yes	questionnaire, self-report
32	Lorenzo (2014)	Teacher's skill improvement by role-play and simulations on collaborative educational virtual worlds	Spain	in-service teachers	20	one school year	pre-post without control group	Self-developed VR (non-immersive)	critical (diversity)	procedural	teacher-student interaction (related to diversity)	yes	questionnaire, self-report, observation
33	Haghanikar and Hooper (2020)	Teaching about homelessness through multicultural picture books and virtual reality in preservice teacher education	United States	pre-service teachers	46	one semester	observational	Self-developed VR (fully-immersive)	critical (homeless)	procedural	instructional practices (about homelessness)	yes	self-report
34	Ke et al. (2016)	Teaching training in a mixed-reality integrated learning environment	United States	pre-service teachers	23	two one hour sessions	observational	OpenSimulator (semi-immersive)	instruction (classroom)	procedural; other	self-efficacy; instructional practices; teacher-student interaction; classroom management	yes	observation, self-report, questionnaire
35	Hursen and Beyoğlu (2020)	The effect of geography teaching curriculum enriched with virtual reality applications on teacher candidates' interest for the course, achievement and the tendencies to utilise information technologies	Turkey	pre-service teachers	27	6 weeks (3 hours a week)	pre-post without control group	Google Classroom app with HMD (fully-immersive)	learning (geography)	procedural; other	motivation; digital literacy	yes	questionnaire, self-report
36	Passig (2011)	The impact of immersive virtual reality on educators' awareness of the cognitive experiences of pupils with dyslexia	Israel	in-service teachers	80	20min	pre-post with control group	Self-developed VR (fully-immersive)	learning (dyslexia experience)	factual and conceptual	knowledge development (dyslexia)	yes	questionnaire, self-report, observation
37	Judge et al. (2013)	The use of visual-based simulated environments in teacher preparation	United States	pre-service teachers	6	around 11 weeks with 3 sessions (5-10 minutes per session)	observational	TLE TeachLivE (semi-immersive)	instruction (disruptions)	procedural	classroom management	yes	self-report, external observation, questionnaire
38	Theelen et al. (2019)	Using 360-degree videos in teacher education to improve preservice teachers' professional interpersonal vision	Netherlands	pre-service teachers	141	three two hour sessions	observational	360° (fully-immersive)	instruction (classroom)	procedural	noticing and interpreting classroom events (professional vision)	yes	task completion, self-report, questionnaire
39	Kelleci and Aksoy (2020)	Using game-based virtual classroom simulation in teacher training: user experience research	Turkey	pre-service teachers	16	14 weeks	observational	SimInClass (non-immersive)	instruction (disruptions)	procedural	classroom management	yes	self-report
40	Mouw et al. (2020)	Using virtual reality to promote pre-service teachers' classroom management skills and teacher resilience: A qualitative evaluation	Netherlands	pre-service teachers, school-based teacher educators	6	5 months	observational	3B (fully-immersive)	instruction (disruptions)	procedural; other	classroom management; resilience	yes	self-report
41	Dieker et al. (2019)	Using virtual rehearsal in a simulator to impact the performance of science teachers	United States	in-service teachers	102	four 10 minutes sessions	pre-post with control group	TLE TeachLivE (semi-immersive)	instruction (disruptions)	procedural	instructional practices	yes	external observation
42	Nissim and Weissbluth (2017)	Virtual reality (VR) as a source for self-efficacy in teacher training	Indonesia	pre-service teachers	10	missing	observational	Self-developed VR (fully-immersive)	lesson design (lesson plan)	procedural; other	self-efficacy; motivation; digital literacy; teacher collaboration	yes	self-report, external observation
43	Kustandi et al. (2016)	Virtual reality based on media simulation for preparing prospective teacher education students	Hungary	pre-service teachers	missing	missing	observational	MaxWhere (non-immersive)	instruction (classroom)	procedural; other	digital literacy; motivation	yes	missing
44	Bujdosó (2020)	Virtual reality in teacher training - developing presentations in virtual reality	United States	graduate teaching assistants	42	3-hour session	observational	OpenSimulator (semi-immersive)	lesson design (lesson plan)	procedural	digital literacy; lesson planning	yes	questionnaire, external observation

45	Ke and Xu (2020)	Virtual reality simulation-based learning of teaching with alternative perspectives taking	United States	pre-service teachers	54	3 hours with 3 VR-Sessions	pre-post with control group	360° (fully-immersive)	instruction (classroom)	procedural	instructional practices (chemistry)	yes	external observation, physiological response, questionnaire
46	Lamb and Etopio (2017)	Virtual reality: A tool for preservice science teachers to put theory into practice	Israel	pre-service teachers	176	8 hours in one semester	experimental	OpenSimulator (semi-immersive)	instruction (classroom)	factual and conceptual	knowledge development	yes	self-report