The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #41514

Use of Theories in Extended Reality Educational Studies: A Systematic Literature Review

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Over the past few decades, the use of extended reality environments for the purpose of teaching and learning has become increasingly popular. Such environments provide an opportunity for perceptual presence and immersion through multisensory experience and interaction and thus mimicking the real-world [1], [2]. Extended reality (XR) encompasses environments and technologies such as Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) [3], [4]. AR overlays information such as images, texts, video and sounds on the real world or the user's viewing device [5]. VR provides an environment for sensory immersion and simulates the real world. It offers an interactive environment where users are immersed in a virtual environment and cannot see the real environment around them [5], [6]. MR uses technology to influence the human perception of an experience. It provides a view of the physical world with an overlay of virtual information where physical and virtual elements can interact [4], [7].

XR environments can help students practice and develop skills that might be difficult to learn in a traditional teaching and learning environment [8]. They also provide an opportunity for students to “see” concepts/structures that are difficult to see and/or are invisible [9] or interact with materials that might be hazardous in real life [10], [11]. Review studies have indicated other benefits of virtual environments such as improved learning outcomes, cognitive, psychomotor and affective skills, as well as enhanced enjoyment, engagement and motivation [12]-[15]. di Lanzo et al. reviewed the use of virtual reality specifically in engineering education [16]. Findings indicated that virtual reality can be beneficial for cognitive and skill-based learning outcomes. However, shortcomings with respect to evaluation metrics and small sample size were noted. The authors further argue that those shortcomings can even question the reported benefits of using VR in engineering education.

Despite recent trends in integrating XR environment in education, there is an absence of theoretical frameworks in studies of XR applications for learning [17]-[20]. Learning theories and educational frameworks, however, can play a key role in supporting educational technology implementation. This paper, thus, seeks to identify, and synthesize theoretical frameworks that support the design and/or implementation and evaluation of XR as a guide for faculty, educational researchers and instructional designers. It will present a systematic review that addresses the following questions:

1. What theoretical frameworks/technological factors are used in educational XR studies?
2. How are theoretical frameworks/technological factors applied in educational XR studies?
3. How is the effectiveness of XR evaluated?

Methods

The review process followed the guidelines by Borrego et al. [21] on systematic literature reviews in engineering education. Specifically, the steps included identifying score and research questions, defining inclusion criteria, finding and cataloging sources, and synthesis. The critical and appraisal step was not fully conducted as details such as sources of bias or missing details were not noted down.

The review process is shown in Figure 1. Scopus and ERIC (Education Resource Information Center) databases were used to carry out the literature search in July 2023. The keywords used for Scopus search included:

- virtual reality OR VR OR augmented reality OR AR OR mixed reality OR MR OR extended reality OR XR
- AND "theoretical framework" OR "conceptual framework"
- AND Learn* OR Teach* OR Educate*

The same keywords were used for ERIC search except the last one where the suggested keywords were used as follow:

- AND education or school or learning or teaching or education system

The results were filtered to cover English publications between 2015 to 2023, which resulted in 363 articles after removing duplicates. 8 review articles were also identified and references within those articles were used as another source.

From this superset of papers, the following inclusion criteria were applied:

- The study was implemented/related to K-12 and University/college
- The study must have included a theoretical framework;
- If theoretical frameworks were used as part of the pedagogical research, it should also include an evaluation of the XR in terms of student learning outcomes or student perceptions;
- The study must have been specific to VR, AR or MR.

The results were not limited to engineering disciplines, as we believe much can be learned about theories and application of those theories in educational studies regardless of the discipline. The studies were first reviewed based on the title and abstract. Next, the full texts of articles were screened against the eligibility criteria and irrelevant studies were excluded. This resulted in thirty articles: nineteen articles from the databases and eleven articles using review articles references.

The articles were summarized in an excel file by the first author which included the following information: name of the article, author(s), year published, setting (higher education/K-12), discipline, type of XR intervention, theoretical framework(s) and their application, evaluation method for the intervention, sample size, and a summary of the results where applicable. The summaries were discussed with the second author to confirm the findings. While summarizing the data, it was noticed that other factors such as immersion, presence, interactivity, perceived usefulness, and perceived ease of use have also been applied in some of the studies which are not considered as a theoretical framework. Given the importance of such factors in developing and implementing educational technologies, it was decided to include them as a separate category called *technological factors.*

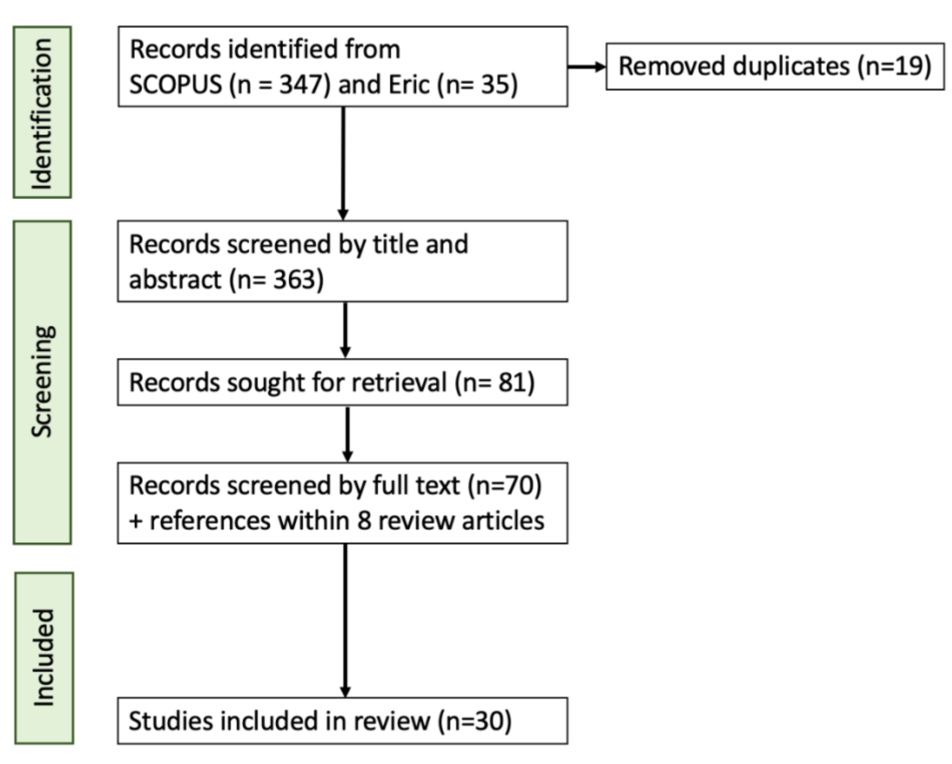

Figure 1. The literature selection process reduced the pool of 363 unique papers down to 30 papers included in the review through iterative application of the selection criteria.

A limitation with this literature search is that only two databases were used, and thus articles in other databases might not have been identified. In addition, other terms and phrases might be used to refer to theoretical frameworks and type of XR environment, which would not have been identified in our search.

Results

Study characteristics

Table 1 provides a summary of the thirty studies. The studies were published between 2015 and 2023 and covered a wide variety of disciplines such as biology, social work, neuroanatomy and skills such as communication and problem solving, which could indicate the potential of XR to be applicable in different contexts. Studies included both STEM (N=18) and non-STEM disciplines (N=11) and took place in University (N=16), and K-12 (N=11). The types of XR environments included VR (N=18), AR (N=11) and MR (N=1). The outcomes measured varied such as acceptability and feasibility of a technology for learning, motivation, learning experience and learning outcomes.

Theoretical frameworks and technological factors: types

Table 1 provides a summary of theoretical frameworks and technological factors/constructs with references cited within the studies. The latter refers to elements such as immersion, presence, interactivity, perceived usefulness, and perceived ease of use. There were thirty-three unique theoretical frameworks and ten unique technological factors/constructs across studies.

The most common theoretical frameworks were situated learning theory (N=7) and cognitive load theory (N=7), followed by experiential learning theory/Kolb's cycle (N=6), and cognitive theory of multimedia learning (N=5). Situated learning theory, also known as situated cognitive theory, indicates that learning is a social process, and it should take place in its intended context. Authentic activities and context are key as learning is specific to the situation in which it is learned [22], [23]. Most studies using this theory indicated that the XR environment provides an authentic context for students to practice and develop skills in an environment similar to the real world.

Cognitive load theory emphasizes the importance of instructional design to avoid overloading working memory as it has a limited capacity. New information is first processed in working memory before it can be stored in long-term memory. If the learning tasks requires cognitive processing exceeding that of learner's cognitive system, it results in cognitive overload [24]. The cognitive overload can also happen in a multimedia learning environment. Thus, drawing on cognitive load theory, dual coding theory and working memory, Mayer proposed the cognitive theory of multimedia learning [25] providing guidelines to reduce cognitive load in a multimedia environment. Considerable cognitive processing is required for a meaningful learning experience specifically in a multimedia environment, which can exceed the limited capacity of working memory [25]. Thus, multimedia design principles have been proposed for combining texts, pictures, audio and animations, as well as other guidelines such as providing opportunities for feedback, reflection and controlling the pace of the presented material [25], [26]. These guidelines can help design XR environments to prevent cognitive overload for students.

Experiential learning considers learning by doing. According to Kolb [27], learning involves four stages of concrete experience, reflective thinking, abstract conceptualization and active experimentation. XR environment can provide an environment for students to learn by doing while moving through the four stages of Kolb's cycle.

Among technological factors, presence was the most common one reported in 6 studies, followed by immersion (N=5). Presence refers to the concept and feeling of "being there" [28], or "being perceptually present" in a virtual environment [29]. Presence is dependent on media characteristics and user characteristics [30]. The media characteristics include the extent of sensory information which is dependent on immersion and control factors. The user characteristic refers to different amounts of presence experienced by different individuals [28], [30].

Immersion was not defined well across studies. Lanzieri et al., [31] and Cheng and Tsai [21] did not provide a clear definition of immersion. Immersion was indicated as an objective feature of the delivery technology that depends on the extent of sensory information presented in [19] and [33]. Sukirman et al. defined immersion as "user's perception of being physically present in a non-physical world like a digital environment" which can be generated using visual displays and sounds to influence the perception [29]

Table 1. Summary of theoretical frameworks and technological factors/other constructs of included studies

Author(s), Year	**Educational Technology**	**Discipline/Skills**	**Theoretical Frameworks**	**Technological Factors/Other constructs**	**Application of theoretical frameworks/technological factors**
Araiza-Alba et al., 2021 [34]	VR with HMD	Problem solving	Embodied cognition [58]; Interest theory [59], Cognitive load theory [60]; Cognitive theory of multimedia learning (59)	Presence [61]	Rationalize the use of VR; Implementation and evaluation of intervention
Bacca Acosta et al., 2019 [35]	AR	Chemistry	ARCS motivation model [62]; Universal design for learning [63]; Co-creation [64]	N/A	Design of technology; Implementation and evaluation of intervention
Baumann and Arthurs, 2023 [36]	AR	Topographic map-reading skills	Situated cognitive theory [23]	N/A	Rationalize the use of AR
Chang et al., 2016 [37]	AR	Socio-scientific issues	Situated cognition [65]; Constructivism [66]; Multimedia design principles [26]	N/A	Design of technology
Chen and Yuan, 2023 [38]	VR with HMD	Second language vocabulary learning	Situated learning; Immersive learning [67]; Sociocultural learning	N/A	Development of a theoretical framework; Implementation and evaluation of intervention
Cheng and Tsai, 2020 [32]	VR with HMD	Science learning	Motivation including motivational beliefs and learning strategies [68]	Immersion [69]	Implementation and evaluation of intervention

De Back et al., 2021 [39]	VR CAVE	Neuroanatomy	Dalgarno and Lee framework [70]; Fawler framework [71]; Cognitive load theory [24], [26]; Collaborative learning [72]; Gamification [73]	N/A	Design of technology
Han, 2019 [40]	VR with HMD	Literacy	N/A	Presence [74]	Implementation and evaluation of intervention
Hill and Preez, 2021 [41]	VR with HMD	Taxation	Technology Acceptance Model [75]; Educational framework for immersive learning [76]	N/A	Not clear- appear to be used to put the methodology in context
Hsu (2017)[42]	AR	English vocabulary	Cognitive load theory [24]; Flow state [77]; Self-directed learning and task-based learning; Learning styles [78]	Foreign language learning anxiety [79]	Design of technology; Implementation and evaluation of intervention
Hsu and Liu, 2023 [43]	AR	Oral communication skills	Constructivist learning [66]; Social constructivist learning [80]; Situated learning; Self-regulated learning	N/A	Development of a theoretical framework
Hu et al., 2021 [44]	AR	Basic structural systems	UI/UX design considerations; Situated learning theory [65]	N/A	Design of technology; Implementation and evaluation of intervention
Huang et al., 2016 [45]	AR	Ecological education	Kolb’s cycle [27]	N/A	Design of technology

Jiang et al., 2022 [46]	VR	Business negotiation	Experiential Learning Theory [27]	N/A	Design of technology; Implementation and evaluation of intervention
Kardong-Edgren et al., 2019 [47]	VR with HMD	Health care education	Overlearning [81]	N/A	Rationalize the use of VR
Kyza and Georgiou, 2019 [48]	AR	Reflective inquiry in outdoor education	Kolb's cycle [82]	N/A	Rationalize the use of AR
Lai et al., 2018 [49]	AR	Science reading	ARCS motivation model [62]; Cognitive load theory [83]; Multimedia principles [84]	N/A	Implementation and evaluation of intervention
Lanzieri et al., 2021 [31]	VR	Social work education	Situated learning theory [22], [65]; Multimedia design principles [25], [85]	Immersion [6], [86]; Presence [87], [88]	Design of technology; Implementation and evaluation of intervention; Rationalize the use of VR
Lo et al., 2021 [5]	AR	Environmental Education	Technology Acceptance Model [75]	N/A	Implementation and evaluation of intervention
Makransky and Petersen, 2021 [19]	VR	N/A	Intrinsic motivation [89]; Self-efficacy [90]; Embodiment [91]; Cognitive load theory [60], [83]; Self-regulation [92]	Presence [28], [30]; Immersion [28], [30]; Representation fidelity [70]; Control factors [94]; Agency [94]; Situational interest [95]	Development of a theoretical framework

Mejia-Puig and Chandrasekera, 2022 [50]	VR with HMD	Spatial skills and idea development	Sense of embodiment [91]; Cognitive load theory [24], [60]	Presence [96]	Implementation and evaluation of intervention
Parong and Mayer,2021 [33]	VR with HMD	History	Cognitive load theory [60]; Cognitive theory of multimedia learning [84]	Immersion	Implementation and evaluation of intervention
Quaid et al., 2020 [50]	VR with HMD	English learning	Technology Acceptance Model [75]	N/A	Implementation and evaluation of intervention
Roberson and Baker, 2021 [52]	VR with HMD	Social work education	Experiential learning Theory [27]	N/A	Rationalize the use of VR
Scarparolo and Mayne, 2022 [53]	MR	Communication skills	Kolb's cycle [27]; Self-efficacy theory [97]; Reflective practice [98]	N/A	Design of technology; Implementation and evaluation of intervention; Rationalize the use of VR
Southgate, 2019 [54]	VR with HMD	Biology	Deeper Learning Theory	N/A	Implementation and evaluation of intervention; Rationalize the use of VR
Sukirman et al.,2021 [29]	VR	Computer thinking skills	N/A	Game elements (Playability, interactivity, enjoyment); VR features (Enjoyment, presence, immersion)	Development of a theoretical framework (note: This is referred to as conceptual framework in the paper. For the purpose of this review study, it is referred to as theoretical framework)

Ye et al., 2022[55]	Desktop VR	Biology	Stimuli-organism-response framework [99]	N/A	Implementation and evaluation of intervention;
Zhou et al., 2020 [56]	VR	Math	Based on the framework of Lee et al.,2010. [100]	N/A	Implementation and evaluation of intervention
Zhu et al., 2015 [57]	AR	Health care education	Situated Learning theory [22]; Experiential learning theory [27]; Transformative learning [101]	N/A	Design of technology

Application of theoretical frameworks and technological factors

Tables 1 shows the application of the theoretical frameworks and technological factors which were coded in four categories:

1. Informed the implementation and evaluation of the XR intervention by:
    - Informing the hypothesis/conceptual framework and/or
    - Informing the methods and/or
    - Interpreting the results
2. Informed the design of XR;
3. Developed a theoretical framework;
4. Rationalized the use of XR technology.

Frameworks were used to inform the implementation and evaluation of the XR intervention in eighteen studies. For example, Quaid et al. investigated students' behavioral intention to use a high immersion VR system for the purpose of learning paragraph structure [51]. The Technology Acceptance Model (TAM) was adopted to develop a conceptual framework and the hypothesis. A survey aligned with TAM was used to determine student perceptions, and the results were further interpreted with respect to factors in TAM. Cheng and Tsai [32] used motivation theory and immersion to investigate the relationship between student self-efficacy, intrinsic value and self-regulation with perceived immersion and attitudes in a VR learning environment. The motivation constructs and technological factor of immersion informed the hypothesis as well as data collection and analysis by using surveys aligned with the constructs and factors.

Ten studies used frameworks to inform the design of technology. For example, De Back et al. expanded the frameworks of Dalgarno and Lee [70] and Fowler [71] by incorporating cognitive load, collaborative learning and gamification theoretical frameworks [39]. Recommended design strategies to optimize cognitive load include implementing pretraining, fostering generative actions using embodiments, and providing clear instructions. Strategies to foster collaborative learning include building active participation into the instructional design and providing discussions through learner interactions. The authors further recommend leveraging platform-specific affordances such as embodiments, voice and avatars to benefit learning. Lastly, gamification elements using levels and scores are suggested to increase motivation and learning. Bacca Acosta et al. used the theories of motivational design and universal design learning to inform the design of motivational AR applications through inclusion of student scaffolding, and real time feedback [35]

Frameworks were used in eight studies to rationalize the use of technology as learning interventions. For example, Roberson and Baker [52] explained that VR was chosen in the study as it can lead students through the full learning cycle of experiential learning theory. Southgate [54] used the deeper learning theory and argued that virtual environments can be used to promote deeper learning theory by providing an authentic environment to learn various skills, and hence rationalizing the use of VR.

Four studies proposed a broader theoretical framework. For example, Makransky and Petersen proposed the cognitive affective model of immersive learning [19]. The framework includes immersion, control factors and representational fidelity as technological factors and presence and agency as VR affordances, which can affect affective and cognitive factors such as interest, motivation, and cognitive load. These lead to learning outcomes which are categorized as factual, conceptual, procedural knowledge and transfer of learning. Sukirman et al. reviewed literature on game-based learning in VR environment and proposed a theoretical framework compromising several factors which can be used as a guide to develop and implement the learning of computer thinking skills using VR [29]. The theoretical framework includes game elements (playability, interactivity) and VR features such as presence and immersion. Enjoyment is another factor which is generated by a combination of both game elements and VR features. Hsu and Liu [43] developed a theoretical framework consisting of five phases of need analysis, learning system and materials development, detailed scaffolding and clear guidance, investigation and reflection. The theories such as social constructivist learning and situated learning informed the last two phases of the framework by providing an authentic context, facilitating collaborative learning-by-doing activities and group discussions.

Approaches to evaluating the effectiveness of XR

Tables 2 summarizes the evaluation methods of the XR interventions in twenty-four studies which ranged from student perceptions, student learning or a combination of both. Two studies investigated student intention to use or continue using the technology for the purpose of learning [51], [55]. Kardong-Edgren et al. conducted a system usability test of a VR game [47]. Lo et al. investigated user adoption patterns [5]. The impact of different conditions of virtual body (e.g. 1st person and 3rd person) on developing spatial abilities and eliciting idea generation was studied by Mejia-Puig and Chandrasekera [50]. Zhou et al. investigated the optimal 3D display technology for virtual learning [56].

The most common type of evaluation approach was quasi experimental design (N=7), post-intervention student experience/learning (N=7), and randomized experimental design (N=4). Only six studies included qualitative data collection and analysis such as interviews (N=3), student reflections (N=2) and focus group (N=1).

In terms of student learning, eight studies reported significant increase as the result of XR intervention compared to the control group. Baumann and Arthurs [36] reported an increase in student learning for the experimental group, but the difference was not statistically significant from the control group. There were significant differences in motivation, interest and enjoyment for students using XR technologies in studies by Araiza-Alba et al. [34], Bacca Acosta et al.[36] and Lai et al. [49].

In the study by Chang et al. the effect of VR vs. simulation on student learning was compared [37]. The results indicated that both resulted in an increase in student learning but the two were not statistically different from each other. Another interesting result was obtained by Parong and Mayer where the effect of video and VR on retention and transfer was investigated [33]. Findings indicated the video resulted in a significant increase on transfer test, while there was no statistically significant difference between the two interventions for the retention test. The VR lesson was also found to result in higher emotional arousal and lower cognitive engagement. The authors suggested that the excessive emotional arousal caused by VR high immersion distracts the learner from cognitive processing of the information. On the other hand, Lai et al. results indicated that students using AR perceived a significantly lower extraneous cognitive load compared to those who learned with conventional multimedia [49].

There were mixed results in terms of student preference. While students preferred the AR more in [37] and [49], projection-based VR with TV screens was found to be preferred by students in the study by Han [33]. Hill & Preez's [41] longitudinal study also indicated that student positive opinions towards VR declined throughout the academic year, though not significantly. This could indicate that novelty effect could have an impact on student perceptions about XR environment.

Table 2. Evaluation approaches and summary of the results for included studies.

	Purpose	**Evaluation approach**	**Data collection method**	**Summary of results**
Araiza-Alba et al., 2021 [34]	Investigating the effect of VR on students' problem-solving skills, Student perceptions	Randomized experimental design (3 groups: board game, tablet, VR)	Performance outcome, Questionnaire, Knowledge transfer test	The percentage of students who completed the problem-solving game was higher in VR group compared with those using the tablet or board game. VR group also scored significantly higher on interest and enjoyment.
Bacca Acosta et al., 2019 [35]	Effect of AR on students' motivation	Quasi experimental design	Questionnaire	The experimental group significantly had higher positive response for the attention and confidence dimensions of motivation. The control group had significantly higher positive response for the satisfaction dimension.
Baumann and Arthurs 2023 [36]	Effect of AR on students' topographic map-reading skill, Student perceptions	Quasi experimental design	Questionnaires, Pre-post test, Instructor observation, Student feedback	The experimental group scored higher on post-test compared to the control group, but the difference was not statistically significant.
Chang et al., 2016 [37]	Comparison of AR with a simulation on students' learning, Student perceptions	Randomized experimental design	Pre-post test, Questionnaire	There was a significant increase between pre and post-test for both the AR and simulation group. There was no significant difference on post-test between the AR and simulation groups.

Chen and Yuan, 2023 [38]	Effect of VR on students' second language vocabulary learning, student perception	Randomized experimental design	Pre-post and delayed post-test, Questionnaire, Interview	The experimental group significantly scored higher on post-test and delayed post-test. Students had a positive learning experience using VR.
Cheng and Tsai, 2020 [32]	Students' self-efficacy, intrinsic value and self-regulation relation to perceived immersion and attitudes in VR	Post-intervention student experience	Questionnaire	Intrinsic value and self-regulation were found to impact students' learning attitudes in VR environments. Students' immersive experiences of attention and enjoyment significantly mediated their learning.
Han, 2020 [40]	Effect of immersive VR on presence; student perception	Mixed method within subject	Questionnaire, Student reflections	Significant enhancement in virtual presence with immersive VR compared to projection-based VR with TV screens. However, students preferred learning using the projection-based VR.
Hill and Preez, 2021 [41]	Student perceptions on using VR for learning	Longitudinal mixed-method design	Questionnaires, Student written reflection	Student positive opinions towards VR declined throughout the academic year but not significantly.
Hsu, 2017 [42]	Effect of self-directed and task-based learning VR on cognitive load, flow state, foreign language learning anxiety and learning effectiveness	Quasi experimental design	Post-test, Questionnaire	Both the self-directed and task-based AR resulted in high learning outcomes. However, the self-directed AR group had significantly higher scores on flow experience.

Hu et al., 2021 [44]	Effect of AR on student understanding of basic structural systems, Student perceptions	Quasi experimental design	Pre-post Test, Questionnaire	The experimental group significantly scored higher on post-test. Authentic context and user interface were found to be important design considerations influencing students perceived achievement of learning outcomes.
Huang et al., 2016 [45]	Impact of learner emotion on experiential learning and learning performance using the AR	Randomized experimental design	Post-test, Questionnaire, Interview	The experimental group had significantly higher learning outcomes and positive emotions. Students found the AR to be more interesting and helpful to their learning.
Jiang et al., 2022 [46]	Effect of VR on student learning, Student perceptions	Quasi experimental design	Post-test, Questionnaire	The experimental group significantly scored higher on post-test compared to the control group. Students had a positive learning experience.
Kardong-Edgren et al., 2019 [47]	System usability test of a VR game	Post-intervention student experience	Questionnaire	The System Useability Score was 64.03. Seventy-five percent of participants rated the game as positive overall.
Kyza and Georgiou, 2019 [48]	Development and investigation of a scaffolded, location-based AR platform	Quasi experimental design	Pre-post test	The experimental group significantly scored higher on historical empathy and learning growth compared to the control group.

Lai et al., 2018 [49]	Effect of AR on students learning, student perceptions	Quasi experimental design	Pre-post test, Questionnaire	The experimental group had significant gain in learning and motivations compared to the control group with conventional multimedia learning and a significantly lower perceptions on cognitive load compared to the control group.
Lanzieri et al., 2021 [31]	Effect of VR on student learning, Student perception	Pre-post intervention design	Pre-post test, Questionnaire	Significant increase in average scores between pre and post-test . Guided reflective questions combined with immersion in an authentic community context were among the features students found most useful
Lo et al., 2021 [5]	User adoption patterns for AR	Post-intervention student experience	Questionnaire, Interview	Age affects perceived usefulness and perceived ease of use of AR applications. Perceived ease of use positively affects perceived usefulness of AR and application use attitude. Perceived usefulness positively affects app use attitude. For more results, please refer to the paper.
Mejia-Puig and Chandrasekera, 2022 [50]	Assess the impact of embodied VR on developing spatial abilities and eliciting idea generation by implementing three different conditions of virtual body within the VR	Between group experimental set up	Student final product evaluation, Questionnaires, Pre-post mental rotation test	A more embodied virtual body (i.e., first person) resulted in a higher level of presence but also increased cognitive load. VR interactions aided participants to develop spatial skills and allowed idea generation.1st person point of view had higher levels of creativity of the outcomes.

Parong and Mayer, 2021 [33]	Effect of VR on student learning, Student perceptions	Between group experimental set up (2x2)	Pre-knowledge test, Post-test, Questionnaire	The video lesson group significantly scored higher on the transfer test compared to the VR group. There was no statistically significant difference on retention scores. The VR lesson resulted in higher emotional arousal and lower cognitive engagement.
Quaid et al., 2020 [51]	Investigating students' behavioral intention to use a high immersion VR system for the purpose of learning paragraph structure	Post-intervention student experience	Questionnaire	Students' intention to use VR was determined by its usefulness rather than perceived ease of use.
Scarparolo and Mayne, 2022 [53]	Effect of MR on student preparedness for parent-teacher	Post-intervention student experience	Focus groups	The MR provided an authentic experience, valuable in helping students to prepare for future, increased student self-efficacy
Southgate, 2019 [54]	Effect of VR to enhance student learning	Post-intervention student learning	Student exemplar	Student exemplar showed elements of deeper learning theory such as content mastery, effective communication, and critical thinking.
Ye et al., (2022) [55]	To investigate learner's intention to continue using VR for learning	Post intervention student experience	Questionnaire	Eudaemonic factors (perceived utility, curiosity, and superior influence) influence students' cognition (cognitive absorption and reflective thinking) and learner's intention to continue to use VR for learning.

Zhou et al., 2020 [56]	To identify the optimal 3D display technology for virtual learning	Single-factor within-subject experimental design	Questionnaire, Performance within the VR	Different display technologies significantly affected users' visual comfort, interaction experience, learning experience, and outcome in experiential learning. User ratings on these aspects for the VR HMD were significantly higher than those for the 3D projection and AR HMD.

4. Discussion and recommendations

This review study identified a range of theoretical frameworks and technological factors in XR educational studies. The situated learning theory, followed by cognitive load theory, experiential learning and cognitive theory of multimedia learning were among the most common types of frameworks. Presence and immersion were also the most common type of technological factors. This diversity of theoretical perspectives is also echoed in other literature reviews related to virtual environments [20].

4.1 Design of XR environment

The application of frameworks and technological factors included informing the design of technology, implementation and evaluation of the intervention, development of a theoretical framework and rationalizing the use of technology. However, most studies used theoretical perspectives to conduct pedagogical research to evaluate the XR environments with less to inform the design of XR environment. The same trend was observed by O'Conner et al. in their review study of the use of technology in nursing education [20]. Though their study included all types of e-learning interventions, the results indicated that theories are mostly applied to guide pedagogical research. However, the design of technology is as important when it comes to student learning [17]. Noteworthy design theories emerged from review include cognitive overload theory and the multimedia design principles which could serve as a guide to design XR environments to minimize student cognitive overload. Multimedia design principles such as eliminating extraneous material (i.e. coherence principle), breaking content into smaller, manageable segments specifically could guide the design of XR environments. In addition, given these design principles were created for non-immersive learning environments, research can be done to expand the guidelines for immersive learning environments.

Presence and immersion in XR environments could also have a profound effect on student learning. Immersion, specifically, as indicated by Parong and Mayer [33] could diminish learning by distracting students from cognitive processing of learning. On the other hand, as Makransky and Petersen [19] argue presence arises from immersion and that higher presence could result in enriched learning. Therefore, more research is needed to determine the interaction between presence, immersion, cognitive overload and learning to determine the 'optimal' level of immersion.

4.2 Evaluation of the intervention

The evaluation approach of most studies with a significant increase in student learning included comparison to a control group without the use of XR. However, when XR was compared to other types of multimedia environments such as simulation and videos, there was either no difference or a decrease in students learning outcomes. Cognitive overload generated by XR, and the novelty effect could distract students from learning [36]. Thus, more research is needed to compare the effect of XR to other multimedia environments such as simulations and videos which might be easier and more cost effective to create and implement, especially in large class sizes.

Most studies also included one-time interventions. However, the study by Hill and Preez [41] clearly demonstrates the benefits of longitudinal studies as students' positive perception towards XR environments could diminish after a while. This could be related to the novelty effect which is when “people show increased effort and attention when dealing with media that are new to them” [102]. In addition, many studies reported students' positive experiences for XR using self-reported surveys. However, as Suh & Prophet [103] argue self-reported evaluation of system use and perceptions can be influenced by social desirability bias [104]. Thus, a recommendation for researchers and instructors is to implement longitudinal studies and repeated trials with respect to student perceptions and learning outcomes to determine the long-term effect of XR on student knowledge and skills. The evaluation should also go beyond just student enjoyment and perceptions to include long-term retention and knowledge transfer.

There was more emphasis on quantitative methodologies among the studies, with only six studies using qualitative methods. Qualitative studies could provide a more in-depth picture of student perceptions on the affordances and challenges of using XR for learning. Think-aloud experiments could also provide us with a better understanding of student experiences while they use the technology. Data acquired from physiological sensors such as electroencephalogram (EEG) or functional near-infrared spectroscopy (fNIRS) could be used to provide a more detailed picture of cognitive load and affect within XR environments.

4.3 Noteworthy frameworks

A framework which may be warranted for consideration by instructors and instructional designers is the Cognitive Affective Model of Immersive Learning (CAMIL) proposed by Makransky and Petersen [19] which is a comprehensive framework to describe the process of learning in immersive VR environments. Presence and agency are identified as the general psychological affordances of learning in VR. Immersion, control factors and representational fidelity facilitate these affordances. The model further includes six affective and cognitive factors that can lead to learning outcomes including interest, motivation, self-efficacy, embodiment, cognitive load, and self-regulation. These factors can lead to factual, conceptual and procedural knowledge acquisition and knowledge transfer. The authors emphasize that immersion, representational fidelity and control factors are important design considerations in VR to increase presence and agency. At the same time, it is important to consider cognitive load and self-regulation by reducing extraneous processing through multimedia design principles [25]. The framework distinguishes between different types of knowledge which is an important consideration as most studies reviewed focused on factual and conceptual knowledge. Thus, this comprehensive framework can be used as a starting point to design XR interventions based on the type of learning outcomes and knowledge required of students.

Situated cognition also emerged as one of the most common type of frameworks. The theory can be used to guide the design of the XR interventions by developing ‘real-world’ scenario for students to practice and improve their skills/knowledge. It could also be used to guide the evaluation approach by informing data collection methods and analysis.

Conclusion

This study reviewed theoretical frameworks and application of them in XR educational studies from 2015-2023 across thirty studies. Thirty-three unique frameworks and ten unique technological factors/constructs were identified across studies. The most common theoretical perspectives were situated learning theory, cognitive load theory, experiential learning theory and cognitive theory of multimedia learning. Presence and immersion were the top technological factors identified across studies. Results further demonstrate that while there is an emphasis on application of theories to implement and evaluate the XR technology, fewer studies used them to design the intervention. In addition, longitudinal, repeated trials and other types of methods such as qualitative data and use of physiological sensors such as EEG and fNIRS could provide a richer and more accurate description of the effect of XR on student cognitive and affective values.

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