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ORIGINAL ARTICLE

Bridging the gaps: an updated mapping of the uses of immersive learning environments

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Abstract
Since publication of the 2020 survey of surveys, "Finding the gaps about uses of immersive learning environments: a survey of surveys," the field of immersive learning environments has experienced substantial growth and diversification. This updated review systematically maps recent developments by analyzing 64 new literature surveys published after the original corpus date, significantly expanding the corpus from 47 to 111 reviews. Through thematic content analysis, our study identifies and integrates five new educational use themes—Games, Observation, Personification, Storytelling, and Student Authoring—and revises existing categories based on recent research. We observed shifts in the prevalence of themes, most notably an increase in uses related to data collection, interactive exploration and manipulation, contextual/media integration, and physical world simulation. We also discussed these changes in relation to recent technological advancements and the influence of emergency remote teaching during the COVID-19 pandemic. Moreover, our results provide an updated representation of immersive learning uses within the conceptual framework of immersion dimensions (system, narrative, agency), updating current research clusters and persistent gaps. By illustrating areas with limited exploration, such as highly interactive narrative experiences, or low-technology interactive uses, this paper informs future research directions and contributes to an understanding of how immersive environments are being employed for learning. This comprehensive mapping thus serves as a resource for researchers and educators aiming to leverage immersive learningenvironments. This paper builds on a shorter version accepted for inclusion in the proceedings of the iLRN 2025 conference, offering expanded results, additional analyses, and extended discussion that clarifies and deepens the original findings.

Keywords Immersive learning · Metaverse · Augmented reality · Virtual reality · Extended reality · Mixed reality

1 Introduction

This paper is an expanded version of our work forthcoming in the Proceedings of the Immersive Learning Research Network 2025 conference (Beck et al., in press). It includes additional results, extended analyses, and further discussion with clarifications that deepen and extend the original findings. Past work, on a survey of surveys, mapped the uses of immersive learning environments accounted for in the literature (Beck et al. 2020). Despite high expectations from initial adoption of immersive technologies in educational contexts, impact studies are often conflicting, revealing the necessity to consider not only the technology itself but its broader context. One way to accomplish this is through an approach posited by information systems research (Fitzgerald 1998), which acknowledges the observer effect (Nguyen et al. 2018) and the complex cause-effect relationships inherent in evaluating technology's impact on learning

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(Lessov-Schlaggar et al. 2016). The analysis in prior work emphasized the importance of understanding actual uses of immersive learning environments (Beck et al. 2020).

Further, we argued that the impact of learning technology extends beyond traditional metrics like academic or skill performance, influencing systemic dynamics and potentially altering learning practices and expectations. Evaluating technology solely based on impacts can be shortsighted, missing out on more transformative potentials (Fitzgerald 1998). Thus, research on immersive learning environments should encompass both evaluation and design & development dimensions, addressing practical and complex problems (McKenney and Reeves 2012). By scoping current empirical research and identifying gaps, we aimed to inform future efforts and set new goals for the research community.

In that earlier work, published in the *Journal of Universal Computer Science* (Beck et al., 2020), we conducted a systematic meta-review of 47 survey papers on immersive learning environments (ILEs) with the specific aim of understanding how these technologies have been used in practice. Unlike prior syntheses that focused primarily on theoretical affordances or system evaluations, our study applied a multi-dimensional immersion framework (Nilsson et al. 2016) to classify and compare reported uses.

Our findings revealed significant fragmentation within the field: few survey authors engaged with each other's work, resulting in disconnected lines of inquiry and thematic redundancy. Across the analyzed literature, several use cases emerged repeatedly—particularly those related to augmented context, simulation, and skill-based training. We also identified critical gaps in the research landscape, including sparse attention to immersive experiences that support perspective switching, emotional and cultural dimensions, data collection, and inclusive accessibility.

Most notably, our framework analysis surfaced three conceptual voids where research was particularly scarce:

1. Mid-system, high-challenge, low-narrative environments (e.g., IoT-integrated smart games),
2. Low-tech, high-narrative, high-challenge formats (e.g., analog role-playing or narrative-driven experiential learning), and
3. Fully immersive, high-challenge, high-narrative experiences that align closely with contemporary visions of the metaverse and embodied simulation.

In this current paper, we continue to inform the field's evolution by identifying underexplored experiential formats and guiding future research efforts. We build upon that earlier framework by systematically mapping recent developments by analyzing 64 new literature surveys published after the original corpus date and integrating five new educational use themes into the previous framework's already robust findings: Games, Observation, Personification, Storytelling, and Student Authoring. Several factors led us to determining a need for this update. First, there was substantial growth and diversification of the field of immersive learning since the last study was completed. The 64 additional literature surveys published across only the short period of two years, are 36% more surveys than those analyzed in the five years span of the previous mapping. Second, we employed Google Trends to examine keyword use and thus to help to determine what might have caused this increase. As is shown in Fig. 3, there was a spike in the use of the term "metaverse" in late 2021, which may account for the large increase in surveys discovered. Finally, in early 2020, lab closures prompted by the pandemic may have pushed researchers to shift focus, consolidating theory and producing a surge of literature reviews across the field. All three of these reasons combined to form a compelling need to update our original survey of surveys.

2 Background

2.1 Immersion

The word "immersion" has come to mean many things to different scholars. Computing literature often ignores all other possible definitions and explains it as an objective characteristic of the technical system features and affordances: the physical ability to look around and experience an alternative virtual world, as if one is part of it (Murray 2017). Others have deemed it the psychological feeling of being present in that virtual world (Witmer and Singer 1998), albeit this feeling is now commonly deemed to be a different concept: Presence (Nilsson et al. 2016). However, other fields of knowledge, such as literature or game studies, have long explored immersion as a phenomenon, revealing the importance of other aspects for it, such as the diegetic narrative (Ryan 2015) or player agency (Frasca 2001). Even studies centered on technical aspects of immersion have demonstrated that interpreting their impacts requires considerations that go beyond providing synthetic virtual representations. Slater, in particular, has pointed out the importance of plausibility for this phenomenon to arise, based on the narrative circumstances and participants' considerations on their levels of possible agency (Slater 2009).

In the last decade, panoramic reviews of the topic have exposed the nature of this faceted phenomenon, particularly the works of Nilsson et al. (2016) and Agrawal et al. (2019). They have collected and contrasted multiple perspectives to provide a theoretical framework towards a more holistic

understanding of immersion. The latter explained immersion as:

> "a phenomenon experienced by an individual when they are in a state of deep mental involvement in which their cognitive processes (with or without sensory stimulation) cause a shift in their attentional state such that one may experience disassociation from the awareness of the physical world" (Agrawal et al. 2019, p. 413).

Nilsson et al. had previously reached a similar understanding, while not making an assertive definition statement such as the one above, by showing how the multifaceted views on immersion could be combined under three dimensions (technological system, narrative, and challenges). They also provided a helpful clarification with the idea of visualizing this phenomenon conceptually, using each conceptual dimension as coordinates of a cube. The relationship of Immersion as a phenomenon with Presence as a sensation is also clarified by several authors synthesized by Nilsson et al. detailing how the abstractness of a challenge could lead to immersion and absence, rather than presence, and as a reader's role or absence in a story could likewise have related effects. Thus, analyzing immersion should not be confounded with analyzing Presence, which itself is a separate construct (Tran et al. 2024).

Armed with this definition of immersion, an immersive environment is then understood as:

> "… the surroundings in which a person may experience immersion. It thus is the locale where the technical, narrative, and challenging aspects occur. Within the immersive environment, the technical system acts and its properties emerge, the narrative content reaches, and the challenges are met. It includes the virtual setting, but also the physical setting; and the contextual conditions of both: the cultural, haptic, organizational, social, logistic, historical, and multifaceted perspectives of reality." (Beck et al. 2020, p. 1045).

Later works renamed the "challenge" dimension as "agency", due to it including operational interventions and tactical and strategic considerations on possible actions (Beck et al. 2021; Pedrosa et al. 2024a, b). In this work we have followed this terminology.

Since our original work, other analytical lens emerged as alternative proposals for the phenomenon, such as Lee (2025) conceptual model of "immersive experience", which he proposes as an alternative for "immersion" to minimize the risk of equivocation with the common use of this term only in the technological sense. Lee combined narrative and physical/tactical agency into an "Involvement" construct and autonomized a construct of "Social/Self Presence" from agency. Alternative viewpoints such as this may provide valuable insights into educational uses of immersive learning environments, but not directly comparable to those of our earlier review.

2.2 Uses, practices, and strategies in immersive learning environments

Under the above definition of "immersion", we define "immersive learning" as the application of that theoretical lens to the complex phenomenon of learning. Hence, when wishing to interpret, describe or plan educational interventions using immersive learning theory, one must identify the theories that comprise their overall learning framework. Thus, immersive learning by itself is agnostic regarding learning, acknowledging the existence of diversified and sometimes conflicting perspectives on the phenomenon.

As we collected the original data for the survey of surveys (Beck et al. 2020), we inductively derived thematic categories to distinguish operational "uses", tactical "practices", and "strategies", defining a three-tiers framework for classifying educational activities (Beck et al. 2024)– here, 'educational activities' refers to observable or designable actions within learning settings, not internal cognitive processes. The latter two categories have explicit pedagogic rationales and are not relevant for this paper. We defined an "account of use" as: "… meaning the literature plainly reports an actual learning activity, rather than its pedagogical-educational rationale, or when that rationale is limited to an intent, without specifying the means to achieve it." (Beck et al. 2020, p. 1046). For instance, any role may be involved in the learning activity: the focus is on accounting for the existence of the learning activity itself. Another example of an account of use would be reporting a learning activity with a vague purpose or hopeful benefits. Following this perspective, to identify educational accounts of uses of immersive environments we sought to distinguish between aspects that have explicit pedagogical rationales from those that do not.

Others have since used this approach for specific areas of interest (Dengel and Maegdefrau 2020; Pedrosa and Morgado 2024) or to conduct reviews of the field and describe it (Mystakidis and Lympouridis 2023; Avila-Garzon et al. 2023). Since the publication of the original survey, Pedrosa et al. (2024a, b) also discovered two additional use themes while conducting literature review on self-regulation in immersive learning environments: "Mobile learning", was adapted as the theme "mobility" and "LMS" was adapted as "learning management" in order to focus on the relevant

affordances of the technology rather than the technology itself.

3 Methods

To perform this update to the previous work, we employed the same goal, "to assemble a panorama of accounts of use of immersive learning environments, and from that panorama extract current research gaps." We express this goal as the following research questions:

RQ1: "*How are immersive environments currently being used for educational purposes, as reported in the literature?*"
RQ2: "*What gaps or underexplored areas are evident from these documented accounts of use?*"

Using the same definition of 'Account of Use' as discussed in Sect. 2.2, we aimed to collect survey papers that focused specifically on actual or proposed uses of immersive technologies in education, rather than on tool evaluation, design theory, or technical development. We also employed the previous work's scope and methods for literature search on Google Scholar, including the keywords, the search strings, and the inclusion & exclusion criteria, and data extraction, for instance using inter-rater vetting among three researchers to identify accounts of use (Beck et al. 2020), only updating the date range. As in that previous study, we did not check which original papers of publication were aligned with each account of use. This means that a single original account may be reported on multiple surveys, potentially biasing the prevalence results for each use, but not their diversity. Analyses of the coverage of diverse research domains by various indexing services indicate that Google Scholar encompasses the majority of sources indexed by alternative platforms (Martín-Martín et al. 2021).

Search Keywords (from Beck et al. 2020):

- Set 1 (for finding surveys):

  survey", "review.

- Set 2 (for finding immersive learning environments):

  immersive learning", "immersive", "environment", "virtual reality", "learning", "augmented", "mixed reality", "education.

Inclusion criteria:

- Survey papers had to be literature surveys or reviews, or systematic reviews.
- The focus needed to be on immersion in educational settings, both using that term or by including virtual reality (VR), augmented reality (AR), or mixed reality (MR).
- The survey papers had to discuss educational use cases for immersive environments, not just technical features or outcomes without association to how environments were used.

Exclusion criteria:

- Papers that focused solely on usability studies, interface design, or software development without addressing instructional use were excluded.
- Editorials, position papers, or papers exploring potential future directions, rather than actual uses, were not included.
- Studies that discussed only theoretical immersion constructs without relating them to practical or proposed classroom use were excluded.

The previous work had mapped literature reviews up until the end of 2019, and we began this update in March 2022, when the search was conducted. This resulted in $n = 64$ new sources found for extracting, meaning the updated results comprised a mapping of $n = 111$ reviews (Fig. 1). The laborious qualitative process was finished in October 2024. As a result, this update does not include any surveys published after March 2022.

After data extraction, we initiated qualitative thematic content analysis, employing the process of Vaismoradi

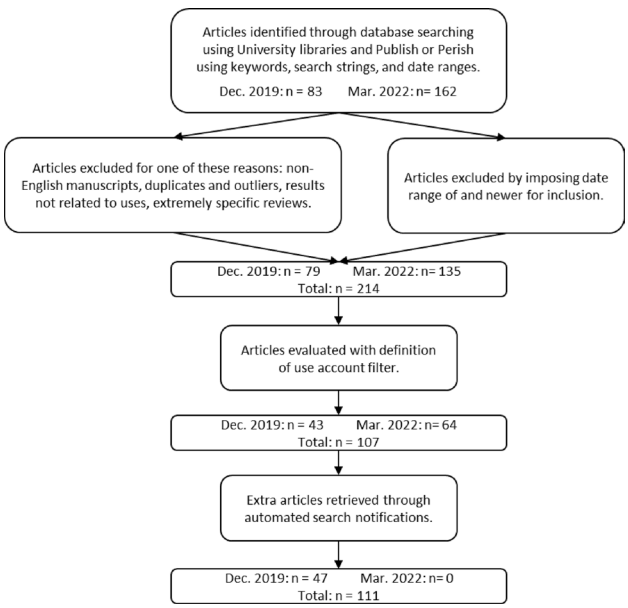

Fig. 1 Overall systematic survey search process, combining the previous one and this update (created with Microsoft PowerPoint)

et al. (2016) for coding each extracted account of use of immersive environments. Our approach for inter-rater coding attempted to improve both the quality and efficiency of the coding process. Training and employing additional human expert coders is a lengthy process, risking the timeliness of this updated review. Hence, we created QUAL-E, an artificial intelligence custom GPT, as a co-intelligent parallel coder (Morgado and Beck 2024): the custom GPT was authored using the ChatGPT interface's paid version, by iteratively developing our set of custom instructions and reference 'knowledge' files, with definitions and examples of our original coding process. Training QUAL-E took about the same amount of time as a human junior researcher, but the coding process was faster and could be repeated as often as necessary, while achieving accuracy comparable to our own (Morgado and Beck 2024).

In short, each researcher individually coded each account of use, and then we compared our codes with those coded by QUAL-E. When codes differed between human coders and QUAL-E, we reconciled them by referring to the specific definition of an account of use of an immersive environment, and checked if the codes aligned to that definition. Any human or QUAL-E codes unaligned to that definition were eliminated. For codes that did follow the definition, regardless of whether they originated from a human coder or QUAL-E, the human coders discussed their adequacy until a consensus was reached. The number of codes per account was determined by saturation, not a preset limit.

We also followed the Vaismoradi et al. process for theme construction which involved classifying, comparing, and labeling. As described in the Background section above, the previous survey had identified 16 themes (Beck et al. 2020) and a later work (Pedrosa and Morgado 2024) had pointed out the relevance of two new themes (LMS and Mobile Learning), so 18 themes in all, with their definitions, already existed and were considered in this process. Many of the codes were classified into those 18 existing themes, but also during the comparison process five new themes were synthesized, defined, and labeled, taking into consideration the definitions of existing themes: Games, Observation, Personification, Storytelling, and Student Authoring.

In the previous survey, we had already coded some accounts as "games". However, during that survey's thematic analysis, we considered that Games was a setting and not an activity, and thus those codes were not synthesized into a theme in the results. Upon further analysis, we determined that our earlier decision to exclude a *Games* theme was inadequate. This was due to the high volume of newly identified codes involving game-based activities and the realization that these codes reflected immersive activities, not just immersive settings—a distinction our previous framework did not fully accommodate. To address this, we established Games as a distinct theme, incorporating both the new accounts and relevant codes from the original dataset. While comparing codes and themes in this process, the emergence of the new theme Storytelling led us to reassign three of the 2019 codes, which were moved from the Augmented Context theme into the new Storytelling theme. The resulting themes and their definitions are presented in Sect. 5, and their prevalence in Sect. 6 (Table 3; Fig. 6).

4 Corpus

Table 1 presents the list of 64 new survey papers used for extraction, the original 47 papers are listed in the original review (Beck et al. 2020).

5 Results

5.1 Overview

As described in the methods section, the thematic analysis process analyzed the new 64 reviews, identifying accounts of educational use of immersive environments. This resulted in 555 new accounts. Together with the 156 accounts of the previous mapping survey, this comprises a total of 711 use accounts. The new accounts were coded, yielding 820 new codes. Since there were 477 codes in the previous survey, the total number of codes underlying these results are 1297. The yearly distribution is shown in Fig. 2. Please note that an educational use account found in a survey paper in year '*x*' was originally published in a paper in a previous year, referenced by that survey.

By performing qualitative theme development on those codes, as described in the methods section, we assigned new codes to the existing themes (the 16 themes by Beck et al. 2020) and the two themes identified since by Pedrosa et al. (2024a, b). We also identified and defined four new educational use themes: "Observation", "Personification", "Storytelling", and "Student authoring". As detailed in the methods section, we also dissented from the earlier mapping, and reckoned that "Games" should not be deemed a setting, but a use. Thus, we now present it as such, with the codes assigned to it in the previous review (57) and the new codes found in this update (13). The definitions for the Games theme and the new themes are provided below in Sect. 5.2. The list of all themes is shown in Table 2, and their prevalence in Table 3, and Fig. 6 illustrates the relative occurrence of uses. Figure 9 illustrates the updated representation of themes in the Immersive Learning Cube, by applying the mapping of the new themes and the new prevalences of Table 3.

Table 1 Dataset of new survey papers resulting from the updated search (_____, in press)

ID	Year	Authors	Title
P48	2020	Tilhou et al.	3D virtual reality in K-12 education: a thematic systematic review
P49	2021	Pathania et al.	A chronological literature review of different augmented reality approaches in education
P50	2021	Dahl	A preliminary scoping review of immersive virtual soft skills learning and training of employees
P51	2022	Godoy Jr	A review of augmented reality apps for an AR-based STEM education framework
P52	2021	Koscielniak	A review of immersive learning technologies featured at EDUCAUSE annual conferences: evolution since 2016
P53	2019	Ziden et al.	A review of research of augmented reality: learning approach and the potential in education
P54	2021	Wulandari et al.	A review of research on the use of augmented reality in physics learning
P55	2020	di Lanzo et al.	A review of the uses of virtual reality in engineering education
P56	2021	Jaiswal et al.	A review on augmented reality in education
P57	2021	Sukirman et al.	A strategy of learning computational thinking through game based in virtual reality: systematic review and conceptual framework
P58	2021	Lau et al.	A systematic literature review of augmented reality used in language learning
P59	2021	Alper et al.	A systematic literature review towards the research of game-based learning with augmented reality
P60	2021	Mystakidis et al.	A systematic mapping review of augmented reality applications to support STEM learning in higher education
P61	2021	Majid et al.	A systematic review of augmented reality applications in language learning
P62	2022	Mazzuco et al.	A systematic review of augmented reality in chemistry education
P63	2021	Rodríguez-Abad et al.	A systematic review of augmented reality in health sciences: a guide to decision-making in higher education
P64	2020	Radianti et al.	A systematic review of immersive virtual reality applications for higher education: design elements, lessons learned, and research agenda
P65	2021	Gómez Rios	Using augmented reality in programming learning: a systematic mapping study
P66	2022	Lai et al.	Adoption of virtual and augmented reality for mathematics education: a scoping review
P67	2022	Özçelik et al.	Augmented reality (AR) in language learning: a principled review of 2017–2021
P68	2021	Theodoropoulos et al.	Augmented reality and programming education: a systematic review
P69	2021	Gutiérrez et al.	Augmented reality for distance education: a systematic literature review
P70	2020	Fan et al.	Augmented reality for early language learning: a systematic review of augmented reality application design, instructional strategies, and evaluation outcomes
P71	2021	Godoy Jr	Augmented reality for education: a review
P72	2020	Ahmad et al.	Augmented reality for learning mathematics: a systematic literature review
P73	2020	Parmaxi et al.	Augmented reality in language learning: a state-of-the-art review of 2014–2019
P74	2020	Sırakaya et al.	Augmented reality in STEM education: a systematic review
P75	2022	Tolba et al.	Augmented reality in technology-enhanced learning: systematic review 2011–2021
P76	2021	Sari et al.	Augmented reality technology as a tool to support chemistry learning: a scoping review
P77	2020	Alzahrani	Augmented reality: a systematic review of its benefits and challenges in e-learning contexts
P78	2020	Nassar et al.	Computer simulation and virtual reality in undergraduate operative and restorative dental education: a critical review
P79	2021	Mystakidis et al.	Deep and meaningful e-learning with social virtual reality environments in higher education: a systematic literature review
P80	2021	Karacan et al.	Educational augmented reality technology for language learning and teaching: a comprehensive review
P81	2021	Cai et al.	Exploring augmented reality games in accessible learning: a systematic review
P82	2020	Weber	Exploring the potential of virtual reality for learning–a systematic literature review
P83	2021	Blair et al.	Immersive 360° videos in health and social care education: a scoping review
P84	2021	Hamilton et al.	Immersive virtual reality as a pedagogical tool in education: a systematic literature review of quantitative learning outcomes and experimental design
P85	2021	Peixoto et al.	Immersive virtual reality for foreign language education: a prisma systematic review
P86	2021	Pellas et al.	Immersive virtual reality in K-12 and higher education: a systematic review of the last decade scientific literature
P87	2020	Di Natale et al.	Immersive virtual reality in K-12 and higher education: a 10-year systematic review of empirical research
P88	2021	Ummihusna et al.	Investigating immersive learning technology intervention in architecture education: a systematic literature review
P89	2021	Lehikko	Measuring self-efficacy in immersive virtual learning environments: a systematic literature review
P90	2021	McBain et al.	Scoping review: the use of augmented reality in clinical anatomical education and its assessment tools
P91	2021	Ratcliffe et al.	Sensorimotor learning in immersive virtual reality: a scoping literature review

Table 1 (continued)

ID	Year	Authors	Title
P92	2021	Pirker et al.	The potential of 360-degree virtual reality videos and real VR for education-A literature review
P93	2022	Urlings et al.	The role and effectiveness of augmented reality in patient education: a systematic review of the literature
P94	2022	García et al.	The use of augmented reality in Latin-American engineering education: a scoping review
P95	2019	Rappa et al.	The use of eye tracking technology to explore learning and performance within virtual reality and mixed reality settings: a scoping review
P96	2021	van der Linde-van den Bor et al.	The use of virtual reality in patient education related to medical somatic treatment: a scoping review
P97	2019	Diao et al.	Trends and research issues of augmented reality studies in architectural and civil engineering education—a review of academic journal publications
P98	2021	Alizkan et al.	Trends of augmented reality in science learning: a review of the literature
P99	2021	Ređep et al.	Use of augmented reality with game elements in education–literature review
P100	2021	Jones et al.	Use of virtual and augmented reality-based interventions in health education to improve dementia knowledge and attitudes: an integrative review
P101	2021	Christian et al.	Virtual reality (VR) in superior education distance learning: a systematic literature review
P102	2021	Scavarelli et al.	Virtual reality and augmented reality in social learning spaces: a literature review
P103	2022	Kruk et al.	Virtual reality as a patient education tool in healthcare: a scoping review
P104	2021	Asad et al.	Virtual reality as pedagogical tool to enhance experiential learning: a systematic literature review
P105	2020	Pirker et al.	Virtual reality in computer science education: a systematic review
P106	2021	Luo et al.	Virtual reality in K-12 and higher education: a systematic review of the literature from 2000 to 2019
P107	2022	Jiang et al.	Virtual reality in medical students' education: scoping review
P108	2021	Mahajan et al.	Virtual reality in presurgical patient education: a scoping review and recommended trial design guidelines.
P109	2021	Huang et al.	Virtual reality in teacher education from 2010 to 2020: a review of program implementation, intended outcomes, and effectiveness measures
P110	2021	Plotzky et al.	Virtual reality simulations in nurse education: a systematic mapping review
P111	2022	Krassmann et al.	What is the relationship between the sense of presence and learning in virtual reality? A 24 years systematic literature review

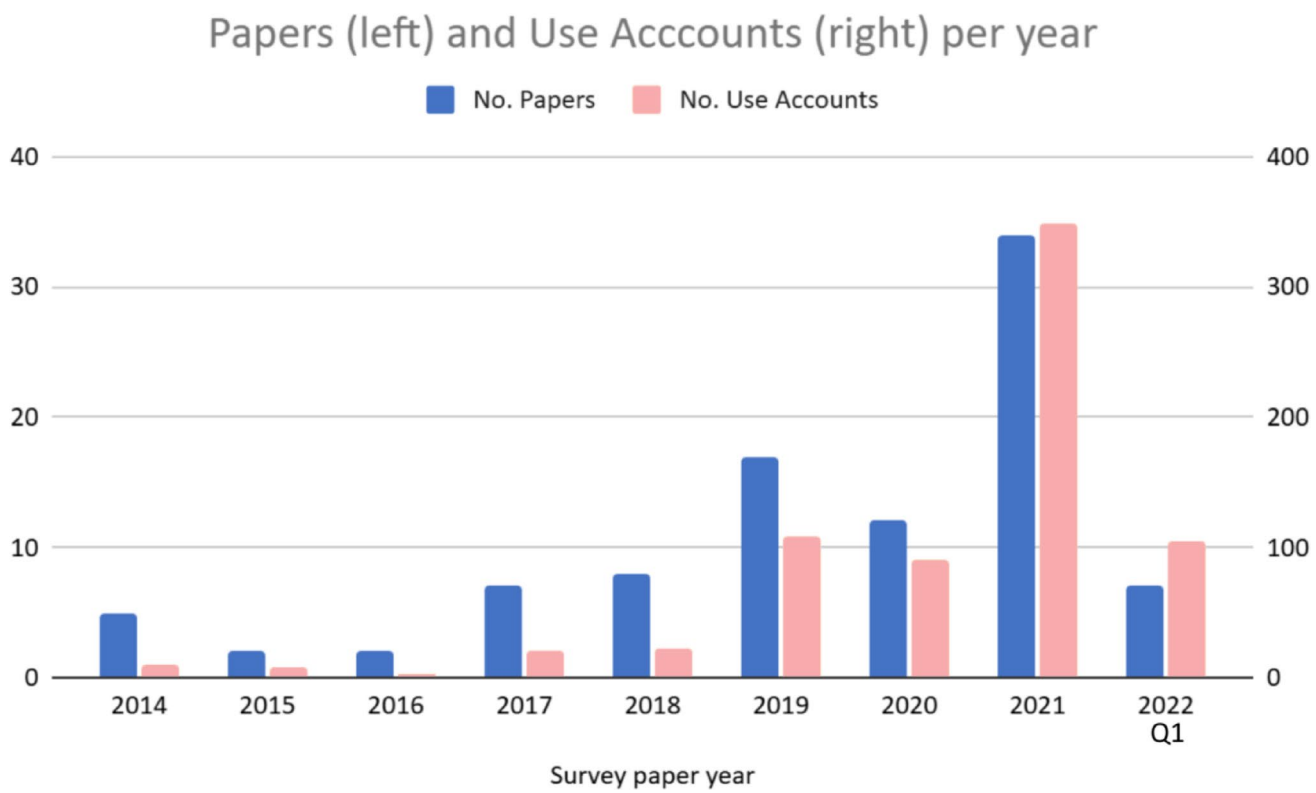

Fig. 2 Survey papers found, per year of publication, and use accounts extracted from them (created with Google Sheets)

Table 2 Outcomes: consolidated list of educational uses of immersive environments and their definitions

Theme	Description: accounts of use of immersive environments for…
Accessibility	… learning activities with the intent to improve accessibility of physical/other settings for people with disabilities.
Augmented context	… learning activities that provide complementary setting-aware information to the users. This includes information based on positioning and nearby items, via overlays or other means.
Changing human behavior	… learning activities designed to alter individuals' physical or attitudinal patterns toward themselves, others, or in response to a specific stimulus.
Collaboration	… for learning activities which involve the social phenomena that characterize group work. This includes the diversity of domains of collaboration, such as live vs. remote, synchronous vs. asynchronous, and situation/contextual factors, etc.
Complement/Combine contexts, media or items	… for learning activities which intend to leverage the combination of physical and traditional digital media with immersive elements as a catalyst for learning. These elements may be in juxtaposition, alternation or mutually impacting each other.
Data collection	… that collect data from the users. This includes data that users actively harvest from their location and data about the users themselves.
Emotional and cultural experiences	… learning activities where non-physical concepts are experienced within context. This includes social, societal and historical situations, but also metacognitive awareness such as one's emotional responses or dangerous situations.
Emphasis	… learning activities to draw the attention of the participants by various means, which may or may not include extra information.
Engagement	… learning activities to support focused attention. This includes enjoyable, motivating experiences.
Games	… that report employing games but without an explicit pedagogic rationale for their use. This includes any of a wide variety of game types, content and technologies, both digital and physical.
Interactive manipulation and exploration	… learning activities based on the learner's active role and agency (acting upon objects or within a space), including cases where the learner is being instructed on how to act.
Learning,anagement	… learning activities to support and structure the learning processes, regardless of the actual activity.
Logistics	… learning activities to coordinate situations involving multiple types of resources or their scarcity (time, equipment, personnel, funding).
Mobility	… learning activities supporting student mobility outside of traditional classroom contexts.
Multimodal interaction	… for learning activities that combine various types of user inputs/outputs. This includes combinations of traditional modalities such as text, images, and audio, but also somatic forms (i.e., haptic, motion, etc.).
Observation	… involving a learner's attentive focus, from its own perspective, on other participants (e.g., their behaviors, emotions, or actions), or the environments (e.g. objects, panorama, setting). This includes activities taking notes of what is being observed or detecting something in that process, and regardless of the synchronous or asynchronous nature of the context. This does not include situations where the observation is intended to change the learner's perspective.
Personification	… learning activities that leverage the presence of synthetic beings. One aspect of this is the use of those beings (a living being or animistic object) to represent an abstract quality or concept. This includes using those synthetic beings, like animated characters or chatbots to drive activities, give instructions, or provide assistance.
Perspective switching	… learning activities to experience different roles, perspectives and viewpoints. This includes embodiment and spatial change.
Seeing the invisible	… learning activities that enable users to see or similarly experience through the senses. This includes the ability to visualize concrete but invisible aspects of the physical world, as well as concrete renderings of abstract concepts.
Simulate the physical world	… for learning activities that imitate or mirror aspects of the physical world. This includes spaces and processes, as well as specific concerns about the fidelity of the environment or process being simulated.
Skill training	… learning activities that provide users with the targeted training they need to gain the knowledge and expertise necessary to fulfil the requirements of a specific ability. This also includes narrow aspects such as providing virtual subjects for interaction or simplifying procedures down to users' current abilities.
Storytelling	… learning activities centered on a developing or overarching story, by any means such as words, actions and/or contexts. This includes their use for driving the dynamics of activities.
Student authoring	… learning activities which leverage students' creativity and provide them with autonomy in the authoring process. This may involve construction of objects, environments, or other artifacts, or even creating their own stories.

5.2 Definitions of new themes

As presented in the background, since the original survey (Beck et al. 2020), two other low-immersion themes were identified by Pedrosa et al. (2024a, b): mobile learning and learning management systems (LMS). In this update, accounts falling within those two themes were also found, but with a wider diversity of topics, which led us to rename them "Mobility" and "Learning Management", focusing on their relevant affordances rather than the technologies. Also, five new themes emerged from the data: Games, Observation, Personification, Storytelling, and Student Authoring. Following the thematic content analysis process (Vaismoradi et al. 2016), we provide below the definition of each theme, with examples.

Table 3 Outcomes: prevalences of uses of immersive environments, and immersion cube categories

Educational use theme	# of codes (2019)	# of codes (2022)	Prevalence (2019)	Prevalence (2022)	System	Narrative	Agency
Accessibility	2	5	0.4%	0.4%	1	0.75	0
Augmented context	102	178	22%	13.7%	0.25	0.75	0.5
Changing human behavior	22	26	4.7%	2.0%	0	0.5	0.5
Collaboration	30	91	6.5%	7.0%	0	0.25	1
Complement/Combine contexts, media or items	26	109	5.6%	8.4%	0.75	0.25	0
Data collection	3	14	0.6%	1.1%	0.5	0	0.5
Emotional and cultural experiences	19	29	4.1%	2.2%	0	1	0.25
Emphasis	9	16	1.9%	1.2%	1	0.25	0
Engagement	17	25	3.7%	1.9%	0	0	1
Games	N/A	70	N/A	5.4%	0.50	0.50	0.75
Interactive manipulation and exploration	18	83	3.9%	6.4%	1	0	1
Learning management	N/A	7	N/A	0.5%	0.25	0	0
Logistics	15	50	3.2%	3.9%	1	0.75	0.75
Mobility	N/A	14	N/A	1.1%	0.50	0	0
Multimodal interaction	34	59	7.3%	4.5%	1	0	0.5
Observation	N/A	5	N/A	0.4%	0.50	0.25	0.25
Personification	N/A	11	N/A	0.8%	0.50	0.75	0.25
Perspective switching	16	53	3.4%	4.1%	1	1	0
Seeing the invisible	26	55	5.6%	4.2%	0.5	0.75	0
Simulate the physical world	68	261	14.7%	20.1%	1	0.5	0.5
Skill training	57	107	12.3%	8.2%	0	0.5	1
Storytelling	N/A	8	N/A	0.6%	0	1	0
Student authoring	N/A	21	N/A	1.6%	0.25	0.25	1
Totals	**464**	**1297**	**100%**	**100%**	–	–	–

Bold is simply to facilitate the reading and identification of the totals

Mobility. This theme involves accounts of use of immersive environments for learning activities supporting student mobility outside of traditional classroom contexts. For example:

- "an AR-based mobile learning system" (cf. paper 99).
- "mobile version (…) allowed access to the same information [that was in the collaborative.
- learning environment with virtual reality] with significantly limited functionality" (cf. paper 102).

This includes ambitious mobile-based concepts, like ubiquitous or pervasive learning activities, which combine multiple devices or sensors:

- "integration of ubiquitous games" (cf. paper 99).

Learning management. This theme involves accounts of activities to support and structure the learning processes, regardless of the actual activity, e.g.:

- "Role management [design element framework] The VR application offers different functionalities for different roles. A distinction is made between the role of a student and the role of a teacher. For a teacher, the VR application offers extended functionalities, such as assigning and evaluating learning tasks or viewing the learning progress of students." (cf. paper 64). This excerpt was coded as Learning Management because it illustrated how immersive environments can facilitate instructional oversight and learning coordination, irrespective of the specific learning activity.
- "a MOOC entitled (…) the immersive learning content is delivered for distant learners" (cf. paper 92). We applied the code Learning Management if the platform served a clear role in organizing or supporting access to the learning experience. In this case the excerpt referenced a MOOC delivering immersive content to distant learners. While no specific instructional actions were mentioned, the platform itself was interpreted as a management structure supporting the learning process at scale.

Games. The theme "games" represents accounts of use of immersive environments that report employing games but without an explicit pedagogic rationale for their use. This includes any of a wide variety of game types, content and technologies, both digital and physical. In our current results, augmented reality games dominated this theme, with several codes emphasizing the use of AR based immersive

game environments, either as a whole, or as a small part of an overall AR immersive experience. These AR games also emphasized various means of interaction in the AR environment, as well as common use of a specific location (e.g. Pokemon Go, cf. papers 67, 70, 99).

- "Mobile game using multiple interaction forms (touchscreen interaction, accelerometer) and a combination of AR with non-AR mini-games." (cf. paper 6).

Most of these AR games focused on the interaction of physical and digital materials. This means that the codes for games often were associated with accounts which were also coded for the theme "Complement/Combine contexts, media or items", for instance:

- "AR offers the opportunity to participate in games using real-world learning objects (e.g., maps, books, and tools)" (cf. paper 6).
- "ARGBL using a graphic book in combination with 3D physical objects and 3D virtual objects" (cf. paper 27).

Also, sometimes games were mentioned with a pedagogic intent, but not the rationale of how that intent would be pursued. For example:

- "utilized (…) a popular AR-infused game, to improve vocabularies regarding characteristics and appearance" (cf. paper 25).
- "[AR application] (…) to (…) visualize [matching quiz games about] music phenomena" (cf. paper 49).

Still within our current results, a minority of games were not AR-based. They tended to be simulation games and/or targeting complex skills, such as mathematics or puzzle-solving:

- "modeling simulated realistic with high representational fidelity learning tasks in (…) games" (cf. paper 86).
- "Students can have access to VR narrative-driven environments as fully instructional-guided or gamified experiences or in a mode of free exploration (…) using (…) games" (cf. paper 86).
- "The virtual game was a pot-shooting task, in which the trajectory of a flying rock was used to simulate the properties of a quadratic function, which has a parabola graph. The VE consisted of a wall with grid lines on a basketball court, with Cartesian coordinates marked to provide location information and two pots on the wall to provide the coordinates of the target point." (cf. paper 87).
- "a virtual jigsaw puzzle" (cf. paper 84).
- "Solving collaborative puzzles together within VEs (e.g. virtual escape room)" (cf. paper 102).

Observation. The theme "observation" represents accounts of use of immersive environments involving a learner's attentive focus, from its own perspective, on other participants (e.g., their behaviors, emotions, or actions), or the environments (e.g. objects, panorama, setting). This includes activities taking observational notes of what is being observed or detecting something in that process, and regardless of the synchronous or asynchronous nature of the context. This does not include situations where the observation is intended to change the learner's perspective. Some of the use codes from our corpus focused on passive observation, where the user was merely watching something occur in an immersive environment. For example:

- "(…) used passive observation to learn [content] (…) through VR" (cf. paper 65).
- "allowed students to observe a virtual lecture" (cf. paper 86).
- " students were able to watch predefined specific educational content (…) the main student interaction.
- in a CAVE was head movement to different directions to see different aspects of a virtual world or.
- walked and observed them apparently" (cf. paper 86).

However, some of the observation was more specific, with a focus on specific audio and visual experiences or 3D learning artifacts:

- "[in VR] students were immersed in music performance [observation] of different genres, such as.
- classical, country, jazz, and swing, navigating inside several musical rooms" (cf. paper 86).
- "observe objects, such as numerous art exhibitions or artistic design works" (cf. paper 65).
- "using (…) a 3D artifact in a CAVE (…) [students] watched the artifact via the three-dimensional.
- immersive facility" (cf. paper 87).

The final two use codes were unique in that they involved the observation of another human being who was active in the virtual reality environment:

- "after each participant had observed the virtual bystanders' positive attitude towards their virtual peers.
- in the English class" (cf. paper 89).
- "Parents were able to watch via a computer what the child was watching in real time" (cf. paper 96).

Personification. The theme "personification" represents accounts of use of immersive environments for learning activities that leverage the presence of synthetic beings. One aspect of this is the use of those beings (a living being or animistic object) to represent an abstract quality or concept. This includes using those synthetic beings, like animated characters or chatbots to drive activities, give instructions, or provide assistance.

The visual characteristics of the avatars were often discussed:

- "animated virtual characters" (cf. paper 82).
- "animated-virtual actors" (Flat, Cartoon, and Lifelike-3D)" (cf. paper 86).

Also, how users were represented as avatars in the immersive learning environment was also an issue:

- "the integration of avatars in the learning materials" (cf. paper 85).
- "educational simulation AR-SEE to include virtual human inhabitants" (cf. paper 99).
- "the virtual reality device of avatars provides a training environment " (cf. paper 104).

Finally, the use of avatars as chatbots, non-player characters (NPCs) or pedagogical agents, or virtual assistants was discussed:

- "[therapeutic platform with] an AR avatar which children can customize and which acts as a guide and chatbot" (cf. paper 93).
- "Overlays of AR graphics, animations and a chatbot" (cf. paper 93).
- "In the paediatric setting, an animation character was used to explain the preoperative procedure in detail " (cf. paper 96).
- "information conveyed visually through pedagogical agents" (cf. paper 95).
- "an Optical Head-mounted display (OHMD) learning assistant" (cf. paper 102).

Storytelling. The theme "storytelling" represents accounts of use of immersive environments for learning activities centered on a developing or overarching story, by any means such as words, actions and/or contexts. This includes their use for driving the dynamics of activities. Some examples follow:

- "(…) app for kids that uses AR to transform ordinary spaces into extraordinary stories (…)" (cf. paper 80).
- "the use of linear educational narratives using the same experience" (cf. paper 92).
- "students listened to pre-recorded narratives about the causes, processes, and effects of ocean acidification on their HMD headphones while exploring a virtual coral reef." (cf. paper 106).
- "Context-aware storytelling and science learning games." (cf. paper).

Some of the accounts focused on the visualization aspect of the stories being told:

- "VR (…) visualization and simulation of narratives and true-to-life scenarios via its 3D virtual environment in (…) a biodiversity topic, objects such as flowers, trees, rivers, hills, birds, butterflies, for science course topics" (cf. paper 86).
- "VR (…) visualization and simulation of narratives and true-to-life scenarios via its 3D virtual environment in (…) different views of an external heart (cardiac anatomy) using 3D images with 360° views of active heart function (physiology) in real time and haptic feedback of heart rate" (cf. paper 86).

And one of the environments discussed how the narrative helped to direct students through the immersive environment:

- "Students can have access to VR narrative-driven environments as fully instructional-guided or gamified experiences or in a mode of free exploration (…) using 360° videos" (cf. paper 86).
- "using narrative across both virtual and physical museum contexts" (cf. paper 102).

Student authoring. The theme "student authoring" represents accounts of use of immersive environments for learning activities which leverage students' creativity and provide them with autonomy in the authoring process. This may involve construction of objects, environments, or other artifacts, or even creating their own stories. For example:

- "Assembling objects [design element framework] Students can select virtual objects and put them together, including the creation of new objects by assembling several individual objects" (cf. paper 64).
- "an AR authoring environment designed for children, which (…) [leverages] simple interaction metaphors." (cf. paper 68).
- "students (…) were tasked with designing an architectural space (…) with the assistance of an I-VR design tool" (cf. paper 84).

A particular form of authoring that is included is the customization of avatars or creation of virtual characters:

- "Online multiplayer game in which users can create their own actress and interact with other users through text messaging in a 3D environment." (cf. paper 109).
- student-customizable guide.
- "[therapeutic platform with] an AR avatar which children can customize and which acts as a guide and chatbot" (cf. paper 93).

This theme also includes non-modelling authoring, like apps, or 360-degree video:

- "students created 360-degree resources using (…) cameras and the (…) editing studio. " (cf. paper 52).
  - " learners developed their own AR applications and studied on them (…)" (cf. paper 67).

This also includes authoring of computer programs and other automations, for instance:

- "(…) an AR authoring environment designed for children [to learn programming]" (cf. paper 68).
- "Learners can draw finite state machines and navigate between states [visually in VR]" (cf. paper 105).
- "[therapeutic platform with] an AR avatar which children can customize and which acts as a guide and chatbot" (cf. paper 93).

6 Discussion: themes per immersion definition

6.1 Publication trends

In the results section, we detailed how there was a large increase in literature reviews in our corpus, particularly since 2021, with this year more than doubling the number of reviews of 2019, and the first quarter of 2022 seeing half as many as in the full year of 2019 (Fig. 2). We employed Google Trends to help determine what might have caused this increase. It should be noted that Google Trends tracks keywords used on the Internet as a whole and not only in research publications. These metrics provide a rough understanding of the increase in general interest of these topics. As is shown in Fig. 3, there was a spike in the use of the term "metaverse" in late 2021, but although that may explain the increase in the corpus after that point, it does not explain the increase before that date. Other terms did not exhibit

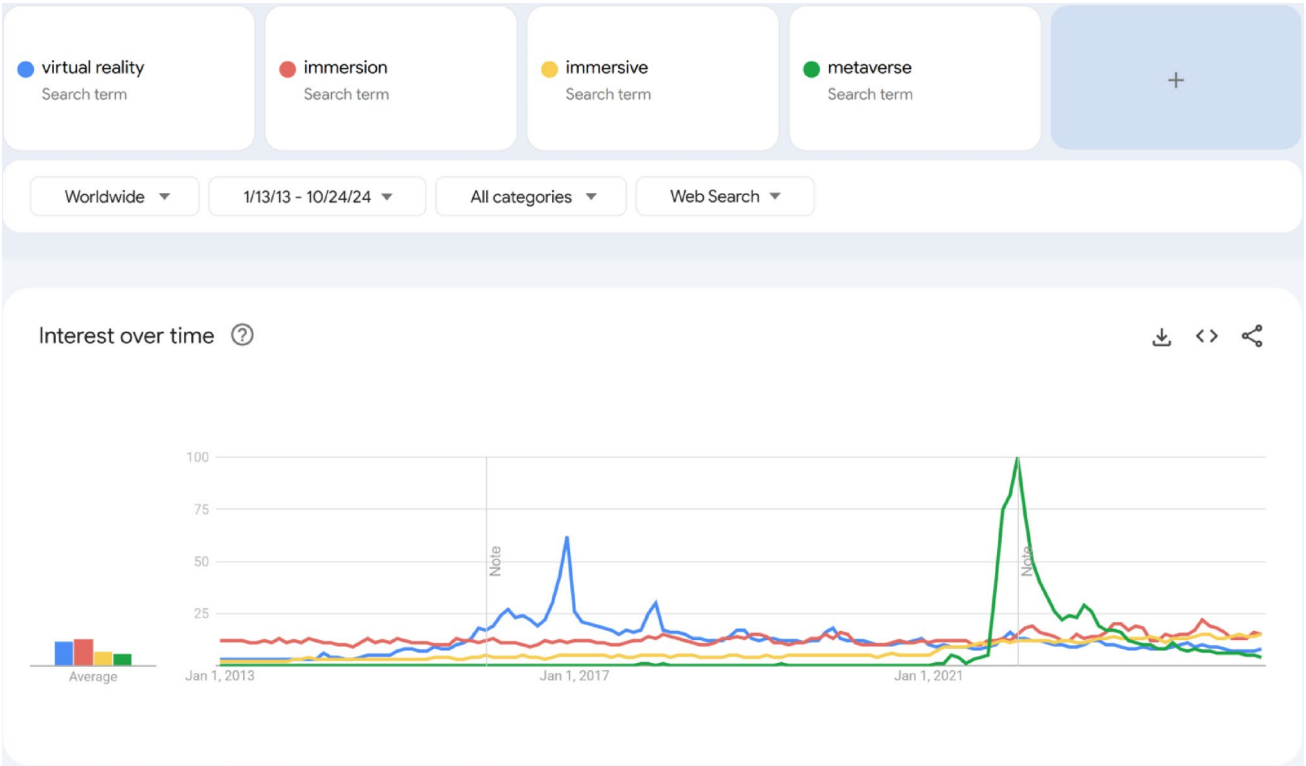

Fig. 3 Google Trends search keyword interest 2013–2024 for "virtual reality", "immersion", "immersive", and "metaverse" (screenshot from Google Trends)

visibly-different changes in overall interest over this period. Anecdotally, we know that throughout 2020 many researchers experienced a pandemic closure of laboratory facilities in which they normally practiced research. Thus, it may be that the onset of the pandemic in early 2020 led researchers to find different ways to pursue their activities, taking the opportunity to consolidate theory, leading to an increase in literature reviews in the field.

6.2 Types of immersive technologies used

By considering the diversity of immersive technologies that are the focus of the corpus, we can see that VR and AR comprise the overwhelming majority of the focus areas of the papers (see Fig. 4). This is unsurprising, given mainstream interpretations of what "immersive" technologies are in education in general. It reveals a gap in the area of uses of MR, which is one of the keywords we used.

The results also included surveys focusing on other technological environments beyond those included in our keywords: Extended Reality or XR (an umbrella term for MR, Rauschnabel et al. 2022), 360° videos (recorded videos that let the viewer look around, for instance up, down, or side to side, and possibly click on hyperlinks, but not move within space), and Alternate Reality, referring to employing the world as a game or learning platform with fictional or layered elements (Hu et al. 2016) delivered for instance through websites, emails, physical clues, or social media.

This also indicates that our perspective may be neglecting to include reviews addressing other perspectives on immersion like the aforementioned 360° videos, and particularly those relying more on narrative immersion and agency immersion than technology, like Alternate Reality, if they are not using "immersion" itself as a keyword or descriptor.

6.3 Influential reviews

To clarify the context of the corpus, we begin by identifying which literature reviews have most shaped the field. This provides both a characterization of our sample and a foundation for addressing RQ2, by highlighting areas of concentrated and neglected scholarly attention.

We used LitMaps (https://www.litmaps.com/) to analyze the connections between the corpus papers by their citations and references. This is shown in Fig. 5. The publications are arranged from the earliest, starting in 2014 on the left, to the most recent on the far right. Papers on the left are influencing the papers linked to their right (which cite them). The more connections to the right, the greater a paper's influence within this corpus. The overall number of citations a paper received in the overall literature increases from bottom to top, so a paper further up is more influential on the overall

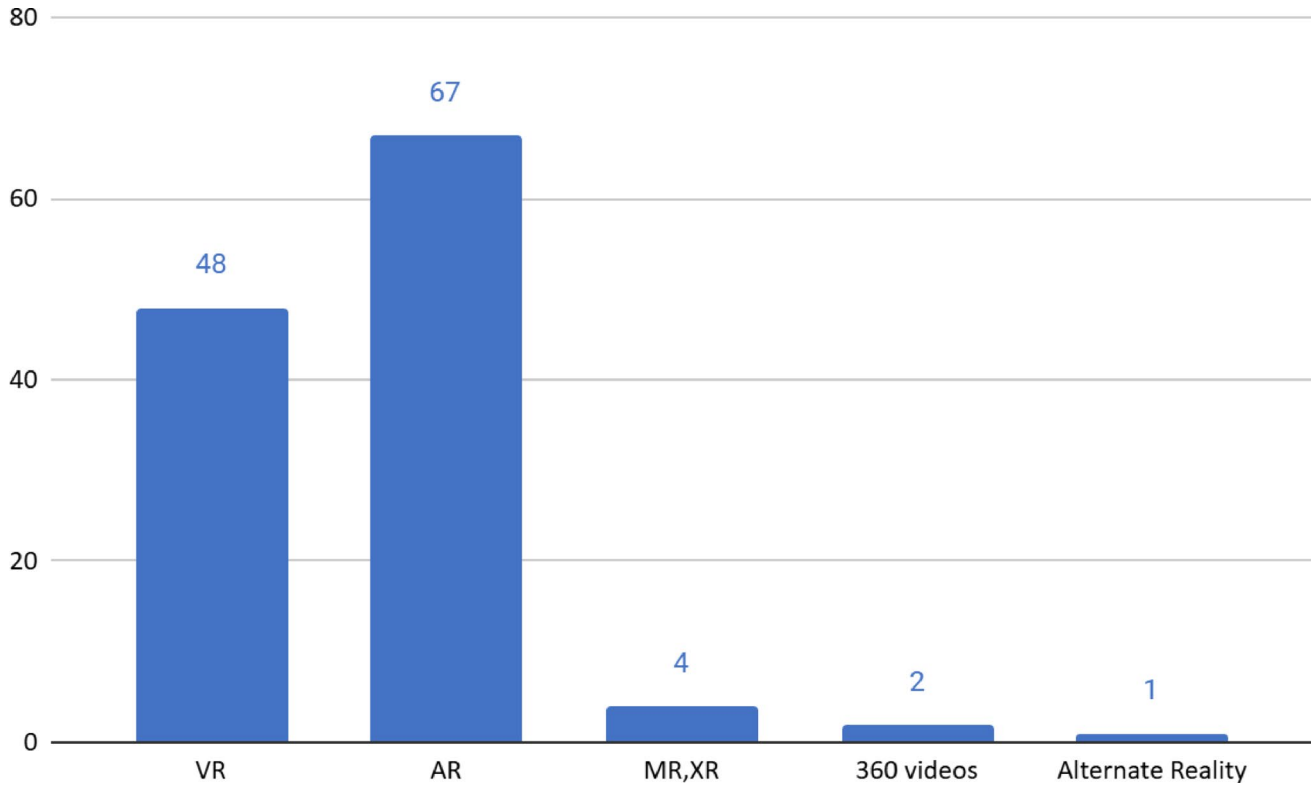

Fig. 4 Types of immersive technologies used in each paper in the corpus. The total is > 111 because some papers address more than one technology (created with Google Sheets)

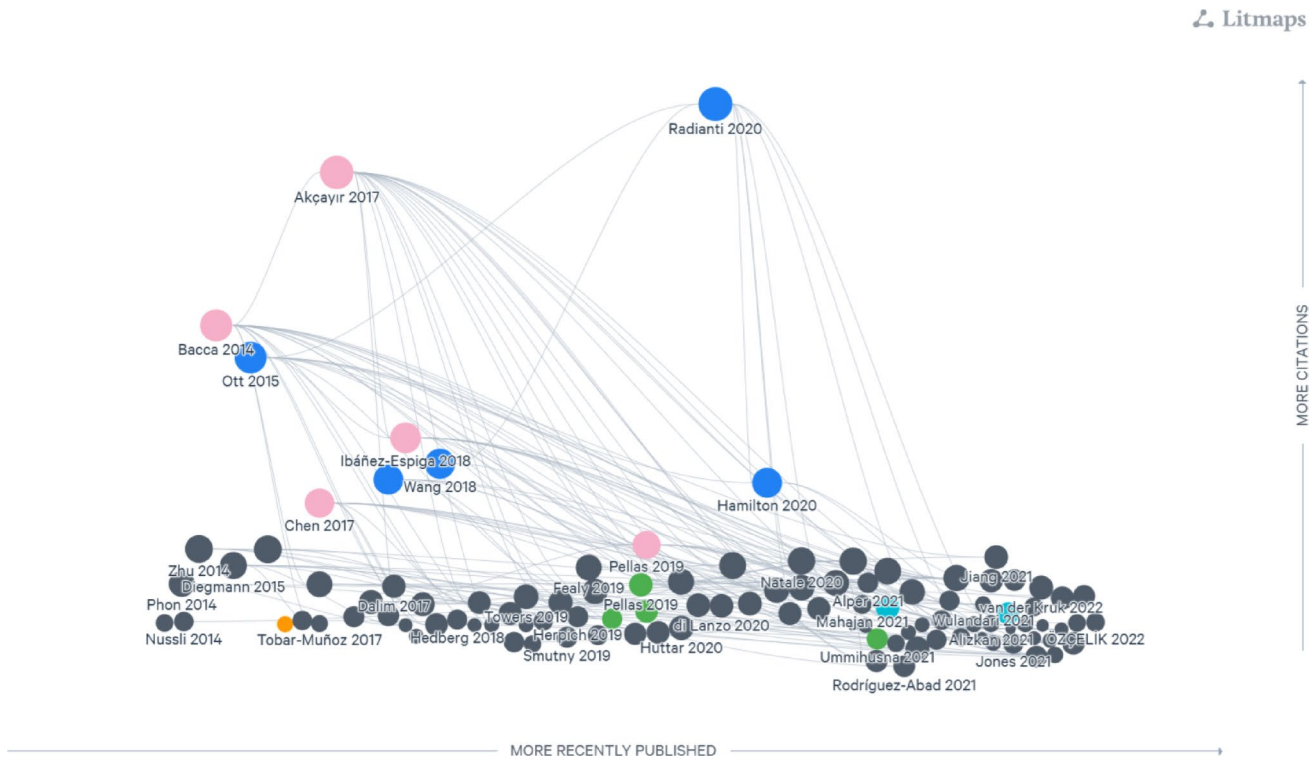

Fig. 5 Influential literature surveys on AR (pink) and VR (blue). Papers addressing other technologies are not being cited as often (orange = Alternate Reality, green = MR & XR, Cyan = 360º video). Created with Litmaps.com

literature. In Fig. 5 we have highlighted the most influential survey papers in our corpus, which are surveys focusing on either Augmented Reality (pink) or Virtual Reality (blue). Other technologies, such as Alternate Reality (orange), MR & XR (green), or 360° video (cyan) are not being cited as much by subsequent papers in this field, both with this corpus or at large.

Bacca et al. (2014) and Akçayır et al. (2017) were widely cited within our corpus, both addressing Augmented Reality (the latter cites the former). This may be because AR technologies were used more widely in educational contexts prior to widespread adoption of VR and other immersive technologies. They surveyed a broad range of contexts (not limited to a specific educational context or subject area) and considered aspects of immediate concern to both practitioners and researchers, such as outcomes, challenges, and features of the uses of AR. Both were also published in high profile journals, ranked in the first quartile (Q1) of Scopus.

Three other AR-focused papers emerged that were noteworthy, although a lower level of influence than the two papers discussed above. Ibáñez et al. (2018) cited both Bacca et al. and Akçayır et al. This review focused on a specific subject area (STEM), without further restricting application contexts. It focused on the instructional strategies and design features of AR environments and recommendations for them. Another, which did not cite either of those earlier influential reviews, was Chen et al. (2017). It was similarly broad in scope, and focused on a wide range of aspects, from uses and features to advantages and outcomes. It was published in Springer proceedings of the third edition of a conference which is organized by a well-connected network of experts around the world. Finally, Pellas et al. (2019a), which cited three of these influential papers (Bacca et al., Akçayır et al., and Chen et al.), was published two years later and was similarly influential despite having a more limited educational scope (primary and secondary) and application context (game-based learning). It is also a precursor to other similar reviews that limit educational and subject matter focus, and considers aspects of immediate concern regarding the use of AR such as effectiveness and instructional affordances. Similar to the others, Pellas was published in a Q1 journal, but for Software and related technical topics, not education or educational technology.

As for Virtual Reality, the most influential reviews within our corpus that focus on it were Freina and Ott (2015) and Radianti et al. (2020) (the latter cites the former). Freina and Ott (2015) focused on a general audience over a very limited time period (2 years, 2013–2014) that followed the emergence of the Oculus Rift VR headset in 2012. It also addressed a wide range of factors such as the advantages, disadvantages, and potentials of VR use education. It was published in a long-standing conference (11th edition) albeit

with non-indexed proceedings (university publisher). The authors themselves were part of a well-known institute. Radianti et al. (2020) was the most widely cited paper in our corpus overall by a large margin, in spite of being published much more recently than others. It cites Freina and Ott and another influential review in our corpus (Wang et al. 2018). Although limited in its educational scope (higher education), it addresses the full range of VR technologies (both high-end and budget headsets) and was published in a Q1 journal. Radianti et al. (2020) took the perspective of mapping the field, showing connections between features of the identified research: application domains and design elements to learning contents. In doing so, they uniquely identified several research gaps across multiple application domains.

As was the case in AR-focused papers, there was also a second tier of influencing papers among VR-focused surveys: Kavanagh et al. (2017), Wang et al. (2018), and Hamilton et al. (2021). Kavanagh et al. approached the broad theme of VR in education, focusing on identifying motivations for its use and reported problems, and proposing avenues to address the problems they identified. It was published in a long-standing but non-indexed journal. Wang et al. focus on the narrow application area of construction engineering education and training, analyzing its publications about VR over 10 years, reporting on technologies and applications. It was published in a Q2 journal from a different field (environment & health). Hamilton et al. focused on surveying quantitative learning outcomes from experimental studies, contrasted with more conventional methods.

Other technologies did not exhibit exemplars of greater impact: papers focusing on MR & XR (Barrie et al. 2019; Pellas et al. 2019b; Rappa et al. 2022) were mostly published in the same year within the corpus, with a single later one (Ummihusna and Zairul 2022). These authors do not exhibit a clear pattern of influencing papers: Ummihusna et al. (2022) cites Wang et al. (2018), which is one of the influential VR surveys in this corpus, but does not cite any of the AR-based surveys in the corpus (they do focus exclusively on a narrow topic area, architecture education). Pellas et al. (2019b) cite themselves (Pellas et al. 2019a), albeit a very highly cited AR paper in the corpus, but do not cite any of the VR surveys in the corpus (they do limit their focus to primary and secondary education). Rappa et al. (2022) doesn't cite anyone in our corpus (their focus is eye tracking technology). The one MR & XR survey that does cite both VR and AR previous surveys is Barrie et al. (2019) (they focus on medical education), which cites Kavanagh et al. (2017) (VR) and Zhu et al. (2014) (AR). The former is one of the influential surveys in this corpus, but the latter is one with lesser influence.

As for 360º video, the two surveys on this topic are both from the same year. One of them does reference two of the most influential VR surveys (Kavanagh et al. 2017; Hamilton et al. 2021). The single survey paper focusing on Alternate Reality (Hu et al. 2016) is neither referenced nor referencing other surveys in this corpus.

6.4 Growth in uses of immersive environments

The significant increase in the number of new literature surveys yielded nearly triple the original number of codes for accounts of use of immersive environments. As shown in Table 3, there were 464 codes in the 2019 survey, and 833 new ones, totaling 1297 codes used in this update. The numbers of new codes in Table 3 reflect the data procedures described in the Methods section.

"Simulate the physical world" and "Augmented Context" remain the two primary uses, but have switched places in terms of common use, as shown in Fig. 6: the former is now the most common use, overtaking the latter. "Augmented context" was reduced in prevalence from 22 to 13.7%. This was most likely due to the extraction of "Games" codes into a theme of its own, which included quite a few augmented reality games. The rankings by total number of codes can be found in Fig. 6. The rate of growth is shown in Fig. 7.

An interesting pattern emerged when examining the themes by how fast they grew since the original survey was completed. These are the themes that at more than doubled the number of found codes: "Data collection", "Interactive manipulation and exploration", "Complement/Combine contexts, media or items", "Logistics", "Perspective switching", "Accessibility", "Seeing the invisible" and "Collaboration". Figure 8 reveals that the fast growth themes are all in mid-to-high System areas except for "Collaboration". This possibly reflects significant advancements in the technologies behind these uses or in the ease with which they are deployed. For example, the creation and use of virtual reality environments during the pandemic gave birth to multiple, novel technology offerings, such as Virbela, FrameVR, Decentraland, or Mozilla Hubs. It may also simply reflect the pandemic phenomena known as Emergency Remote Teaching, or "… a temporary shift of instructional delivery to an alternate delivery mode due to crisis circumstances." (Hodges et al. 2020). During the pandemic, instructors and educational administrators focused on changing the delivery mode of their instruction to new technologies that had not been thoroughly tested or deployed in a learning context. Thus, uses of immersive learning environments during this period focused on the technology itself, rather than in more demanding approaches of creating narratives or planning for agency.

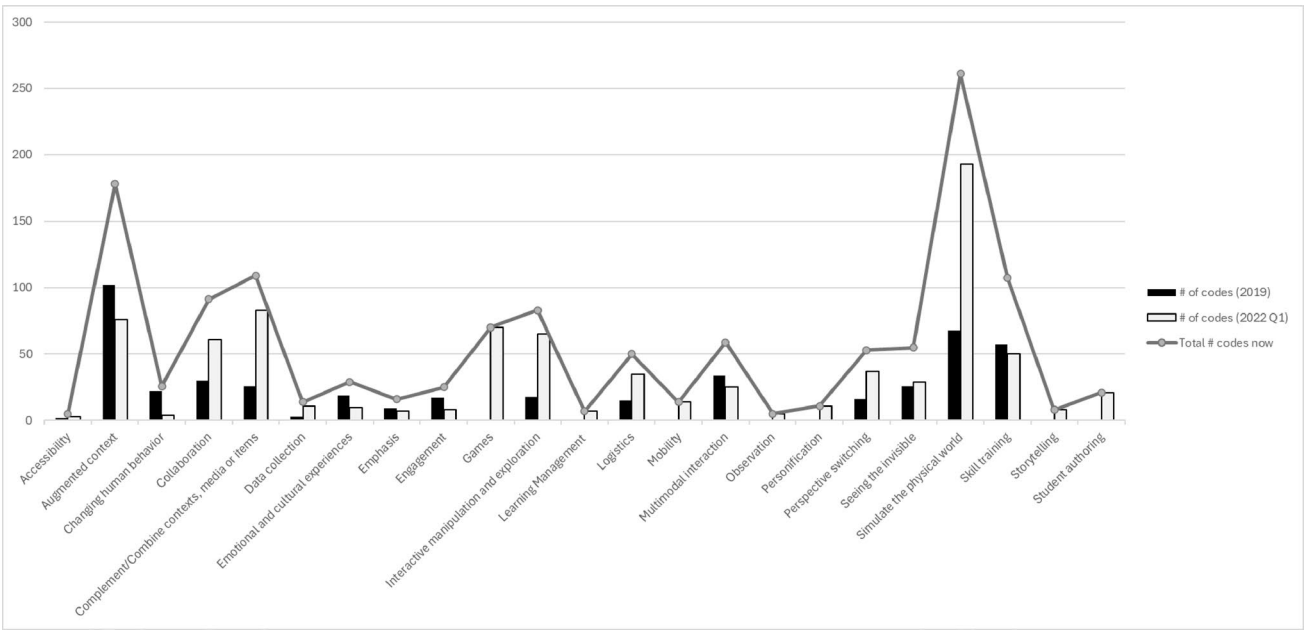

Fig. 6 Educational uses of immersive environments, combining old and newly found codes (created with Google Sheets)

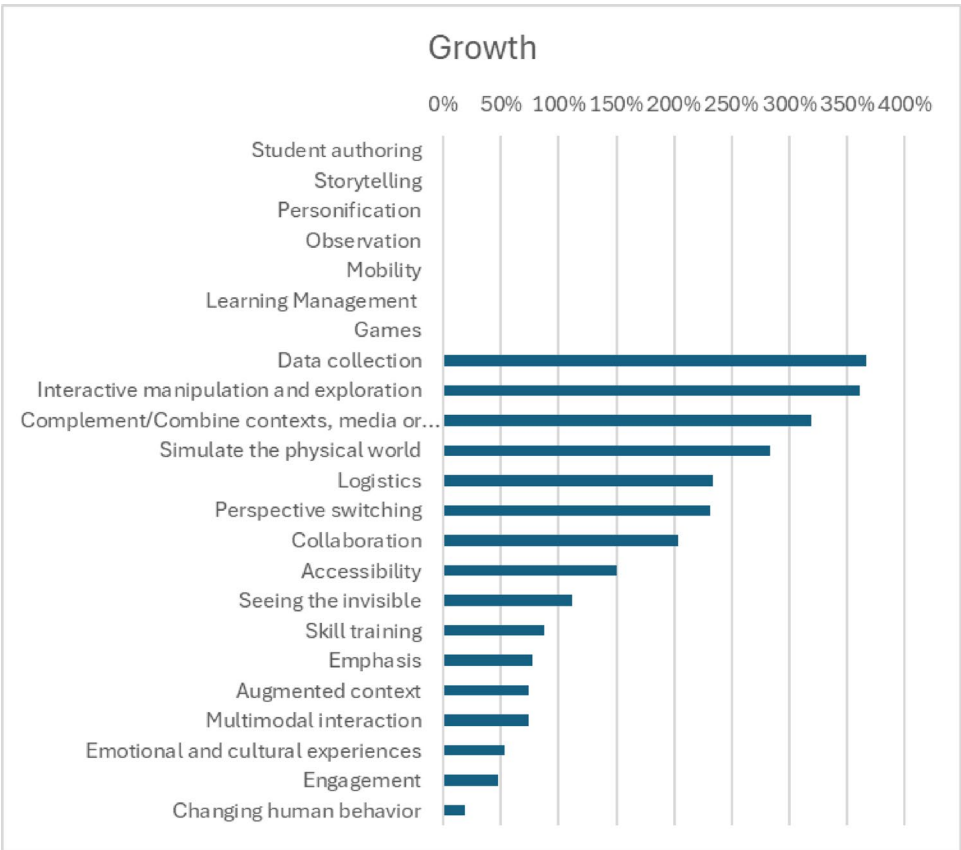

Fig. 7 Educational uses of immersive environments by rate of growth of new codes (created with Google Sheets)

The only use with high growth and low System immersion, "Collaboration", also points in this direction, which is also most likely related to the Emergency Remote Teaching phenomenon (Hodges et al. 2020). During the pandemic teachers and students were no longer in physical contact, and thus needed technologies that facilitated collaboration.

The single fastest-growing theme was Data Collection, which grew by 367% between our initial mapping of

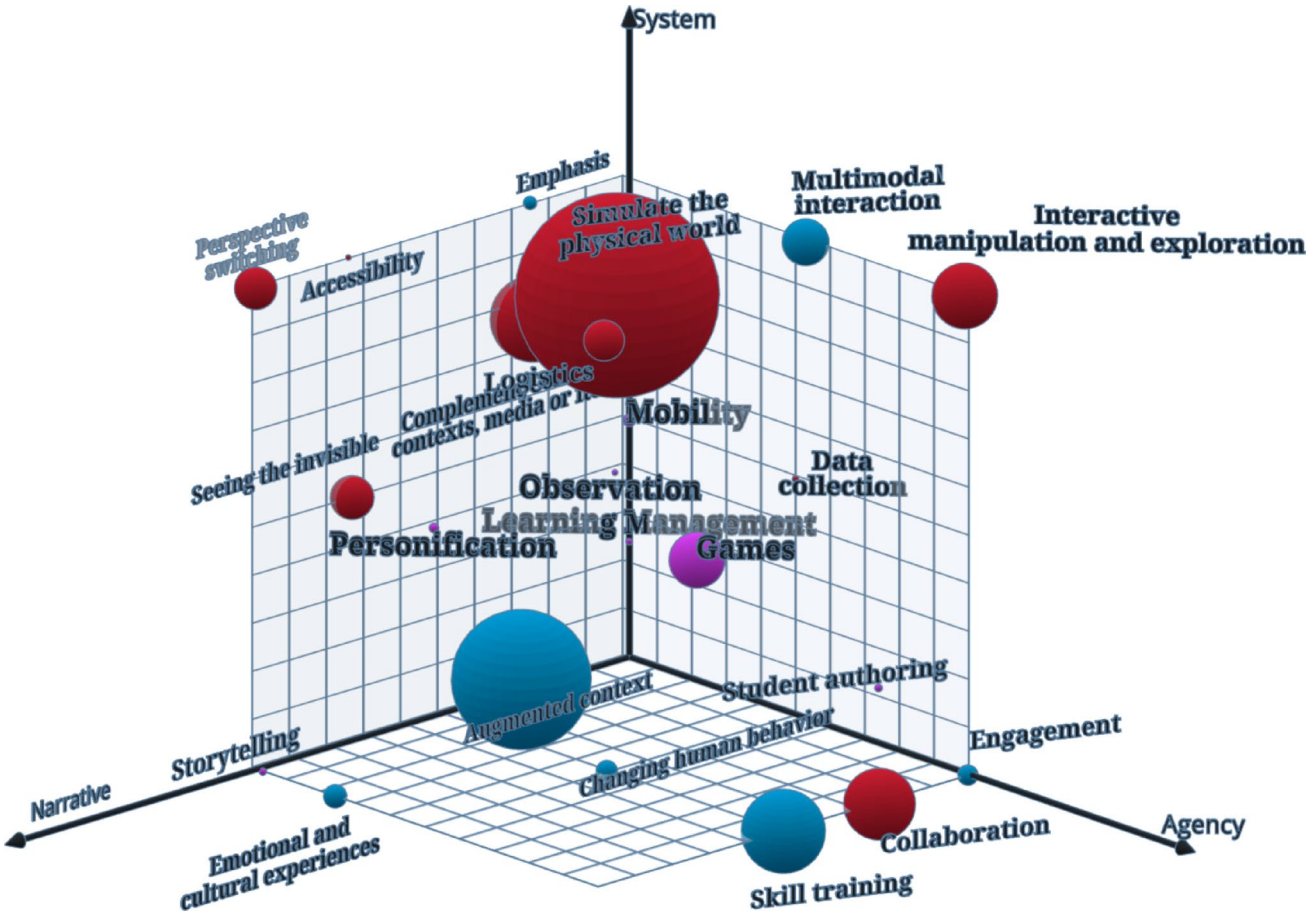

Fig. 8 Rate of growth of the themes: fast growth, more than doubling the number of codes (red) vs. slow growth (blue). New themes are in violet (created with Tinkercad.com)

surveys and this update. In our initial mapping, data collection encompassed a mere three accounts of use, related to collecting data about users and users collecting location-based data. In this update, the theme greatly expanded with 11 new accounts, reflecting a more diverse panorama. The update found more accounts of data collection about users or by users, in various levels of granularity and diversity of interactions, but it also found entirely different approaches. For instance, we found accounts that focused on data about activities, rather than users. Or on data collection supporting different modes of analysis, like remote or longitudinal data collection. There was even an account regarding immersive educational assessments for applicants, i.e. collecting data for administrative phases of education, not just pedagogical. One potential reason for this growth may be the proliferation and availability of data collection technologies involved in immersive learning. For example, smartphone ownership by children and adults in the U.S. increased significantly between 2015 and 2021 (Rideout et al. 2022). The timeframe of our initial mapping collected surveys published between 2014 and 2019, that is, based on papers published earlier. This update thus reflects accounts from an era where smartphones are prevalent in society, and given their role in augmented reality, this likely influenced our growth in data collection uses.

6.5 Updated immersion cube of uses of immersive environments

The above analysis enables us to answer the research questions stated in the methods section. RQ1 is answered as follows. In the original survey (Beck et al. 2020), we classified use themes according to the conceptual dimensions of immersion proposed by Nilsson et al. (2016). Here, we use the same dimensions ("System", "Narrative", and "Agency") as defined and argued in the background section. However, there remains no established process for evaluating these dimensions rigorously. Therefore, we replicated the inter-rater process described in that original survey paper, with subsequent suggestions and criteria for this classification in the Immersive Learning Case Sheet method (Beck and Morgado 2025). Two researchers independently classified each theme on the scale 0–1, based on their reliance on system, narrative, and agency immersion, with ratings

assigned in 0.25 intervals. They then discussed their classifications to reach consensus. We followed this process for the new themes and for reconsidering older themes, resulting in the classifications presented in Table 3. The only previous theme where we disagreed with the prior classification was Multimodal Interaction, previously classified as (System, Narrative, Agency) = (1, 0, 0), and now as (1, 0, 0.5).

As an example of the consensual rating, the theme "Observation" represents accounts of use of immersive environments involving a learner's attentive focus, from its own perspective, on other participants (e.g., their behaviors, emotions, or actions), or the environments (e.g. objects, panorama, setting). This includes activities taking notes of what is being observed or detecting something in that process, and regardless of the synchronous or asynchronous nature of the context. This does not include situations where the observation is intended to change the learner's perspective (see Table 2). The researchers' bilateral judgment from this description was that it was relatively reliant on System immersion (rating 0.5), since the ability to observe phenomena depends to a certain extent on the technological capabilities of the environment, but does not require full spatial envelopment by that environment (for instance, some cases involved observing using desktop screens). Also, it had minimal emphasis on narrative and agency immersion, but not null (rating 0.25 for both), since observation requires little in the way of story or the ability to interact with the environment, but there is the need for interpreting meaning (narrative) and have both the action of observing and the tactical/strategic considerations and initiative of how to direct one's attention. As another example, the theme "Student authoring" represents accounts of use of immersive environments for learning activities which leverage students' creativity and provide them with autonomy in the authoring process. This may involve construction of objects, environments, or other artifacts, or even creating their own stories (see Table 2). The researchers' bilateral judgment from this description was that it was focused minimally on technological and narrative aspects of immersion (rating 0.25), but highly reliant on agency immersion (rating 1), since personal intervention and tactical/strategic considerations about it, are a paramount requirement of performing student authoring.

The themes from this study are presented in Fig. 9, based on Nilsson et al.'s proposed representation of the conceptual dimensions as a cube. In this "immersive learning cube", the use themes are represented spatially by their coordinates of System, Narrative, and Agency.

As stated above, the six new educational use themes were: "Mobility", "Learning Management", "Observation",

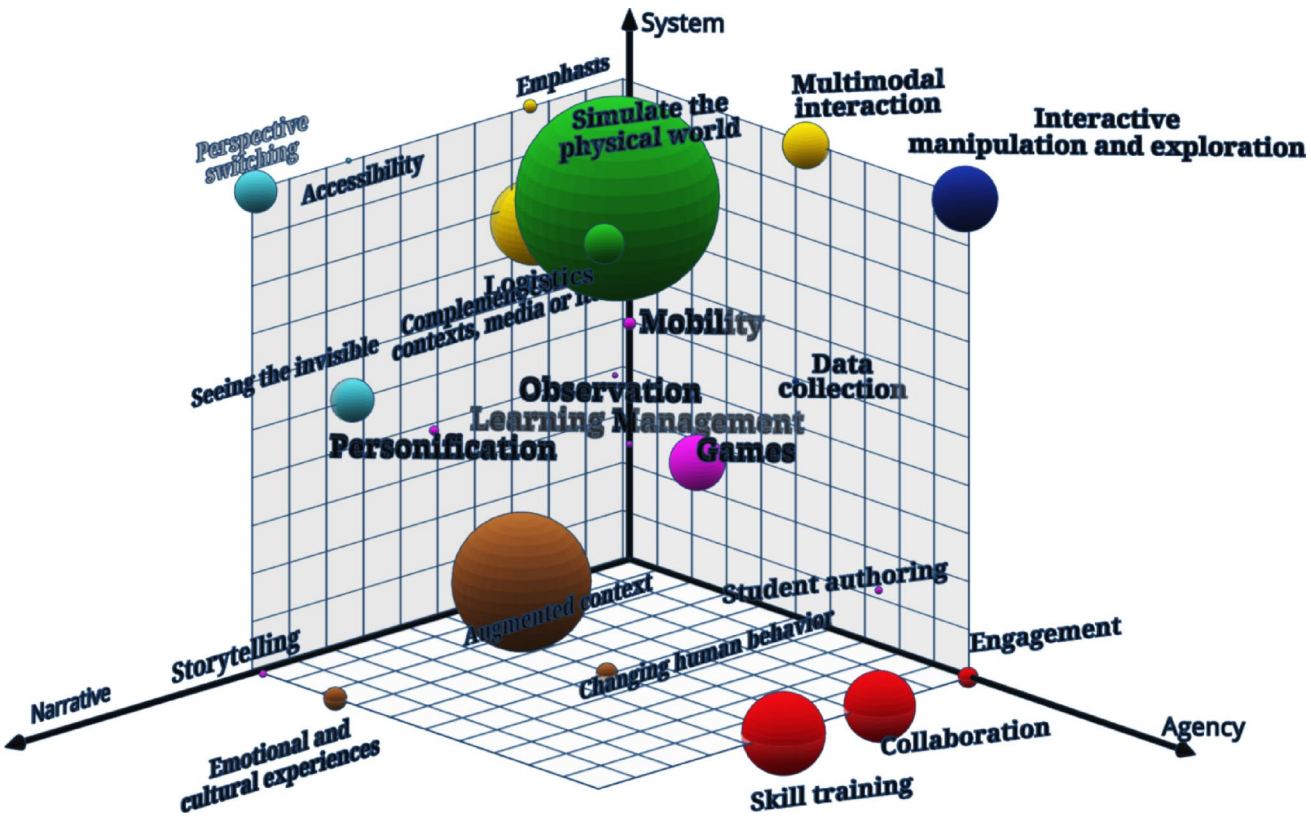

Fig. 9 Updated immersive learning cube with the new themes in violet and the new relative sizes (created with Tinkercad.com). Remaining colors representing clusters are from the original survey, the updated clusters and colors labels are shown in Fig. 10

"Personification", "Storytelling", and "Student authoring". These new themes are presented in violet color in Fig. 9, for easier location amidst previously-existing themes.

Most of the new themes represented extremes on the immersion cube:

- Student authoring is high in agency and low in narrative and system;
- Storytelling is high in narrative and low in system and agency;
- Mobility is mid level in system and very low in narrative and agency;
- Learning Management is low in system and very low on narrative and agency.

These new uses at extremes of the cube are types of well-established educational activities. However, in previous reviews there were no accounts about them, unlike now. Two of our new uses, however, represented more nuanced combinations:

- Observation is mid level in system and low in narrative and agency;
- Personification is high in narrative, mid in system, and low in agency.

The first of these, Observation, is also a well-established educational activity. The second, however, reflects unique new affordances of immersive technology, since it involves leveraging the presence of synthetic beings.

One possible explanation for the appearance in our results of well-established educational activities may simply be the case that as more people get acquainted with immersive learning technologies, they initially attempt to use them in their established practice. The Diffusion of Innovation theory (Rogers et al. 2008) explains this phenomenon: as individuals become aware of immersive environments and their uses for education and learning, some of them become persuaded and decide to adopt them. That decision leads to implementation with varying degrees of innovation, and eventual continuation or abandonment of it. Initial implementation tends to be minor modifications rather than outright transformations. This would lead us to expect what we have found in this review update: as people adopted immersive environments, accounts emerged of their use in established activities. Those established activities are more often than not adopting a mundane, one-dimensional aspect of immersion: they are narrative, they are agentic, they are about providing a spatial context, but they are not often about a combination of several of these.

Case in point: The new Student Authoring theme. It is a form of student-centered learning, at the center of pedagogical thought and innovation at least since Dewey's My Pedagogic Creed at the turn of the XIX century (Dewey 1897). Teachers have the ambition to deploy student centered learning, but often struggle with fully adopting this approach due to multiple challenges, such as student diversity and the need for differentiation of instruction, and the lack of resources to do so (Fufa et al. 2023). That leads to the minimization of changes to their instruction, since major changes to an educational process have been shown to deprive teachers of multiple aspects of their situational awareness (De Lima et al. 2021). Hence, student authoring is typically centered on agentic aspects: the authoring. This is not to say that accounts do not exist where narrative or system immersion have a role, but rather that the typified concept of Student Authoring as an activity is mostly agentic. Yet nearly every student has a smartphone device that empowers them to respond, at their own pace, to teacher-led inquiries, and even initiate their own. Thus, it is unsurprising that teachers try to adopt those affordances to fulfil ambitions of implementing student-centered learning - including Student Authoring. Thus, they implement but with caution and within the responsibilities of their professional contexts. Teachers employ the devices in ways that enable them to retain situational awareness, some familiarity with the challenges and outcomes of their educational processes. This means that the original one-dimensional (agentic) aspect of Student Authoring is retained, even though innovation adoption is taking place.

The new theme of use, "Personification", involves a leveraging of a new affordance of immersive environments: the presence of synthetic beings. Their use to represent abstract concepts or to drive activities, give instructions, provide assistance, is highly associated with narrative immersion along its three aspects (Ryan 2015): contextual interpretation of space (that is, interpretation of how avatars are present relative to the other participants: near, far, at a meaningful location, etc.), of time (the sequence, the before and after of the avatars actions) and of emotion (attachment to characters and to narrative outcome). The presence of synthetic beings is also related to system immersion, in that the technical system may enable it by simply displaying the beings to other participants. There are cases, however, where the display is not really the focus of the situations, as in the use of flat characters or more obviously in the use of chatbots as personas, hence less prevalent use of system immersion than narrative immersion. Finally, the presence of a synthetic being enables some aspects of agency immersion, in that participants may commit to meaning in new forms of interaction (this includes choosing which personal digital body e.g. avatar with which one can "clothe" ourselves). This may also be explained by Diffusion of Innovation: as individuals become more acquainted and comfortable with

the use of immersive technology, they will start to leverage its potential for innovation. So, it is to be expected that as time progresses more novel forms of use emerge - as indeed Personification now emerged in this update of the survey.

Conducting a visual analysis of the use themes, we identified several clusters, by determining which themes were closer to one another than to any of the others. We also named each cluster as a mnemonic. The clusters of the former survey remained, with the new themes being found to be part of one of them or emerging as new clusters by themselves, as detailed below. The notable exception was that the emergence of "Observation" and its positioning near "Data collection" led to the formation of a new cluster, with the latter thus being removed from its previous membership of the "Exploring" cluster. Also, the new coordinates for "Multimodal interaction" led it to be reallocated to the "Exploring" cluster.

The resulting list of clusters and their membership is as follows, and represented visually in Fig. 10:

- **Cluster 1: High System**, **Low Narrative**, **Low Agency**, **"Complementing"**.
  (Combined prevalence: 9.6%: ↓↓ from 14.8%)
  ○ Emphasis.
  ○ Complement/Combine contexts, media or items.
  (REMOVED: "multimodal interaction").
- **Cluster 2: High System**, **Mid-to-High Narrative**, **Mid-High Agency**, **"Simulating"**.
  (Combined prevalence: 24%: ↑ from 17.9%)
  ○ Simulate the physical world.
  ○ Logistics.
- **Cluster 3: High System**, **Low Narrative**, **Mid-to-High Agency**, **"Exploring"**.
  (Combined prevalence: 10.9: ↑↑ from 4.5%)
  ○ Interactive manipulation and exploration.
  ○ Multimodal interaction **(moved)**.
  (REMOVED: "data collection").
- **Cluster 4: Low System**, **Mid-to-Low Narrative**, **High Agency**, **"Engaging"**.
  (Combined prevalence: 18.7%: ↓ from 22.5%)
  ○ Skill training.
  ○ Engagement.
  ○ Collaboration.
- **Cluster 5: Low System**, **Mid-to-High Narrative**, **Mid Agency**, **"Experiencing"**.
  (Combined prevalence: 18.5%: ↓↓ from 30.8%)
  ○ Augmented context.
  ○ Emotional and cultural experiences.
  ○ Changing human behavior.
  Storytelling (new).
- **Cluster 6: Mid-to-High System**, **High Narrative**, **Low Agency**, **"Accessing"**.
  (Combined prevalence: 9.4%: = unchanged)
  ○ Perspective switching.
  ○ Accessibility.
  ○ Seeing the invisible.
  Personification (new).
- **Cluster 7: Mid System**, **Mid Narrative**, **Mid-to-High Agency**, **"Gaming"**.
  (Prevalence: 5.4%: new.)
  ○ **Games**.

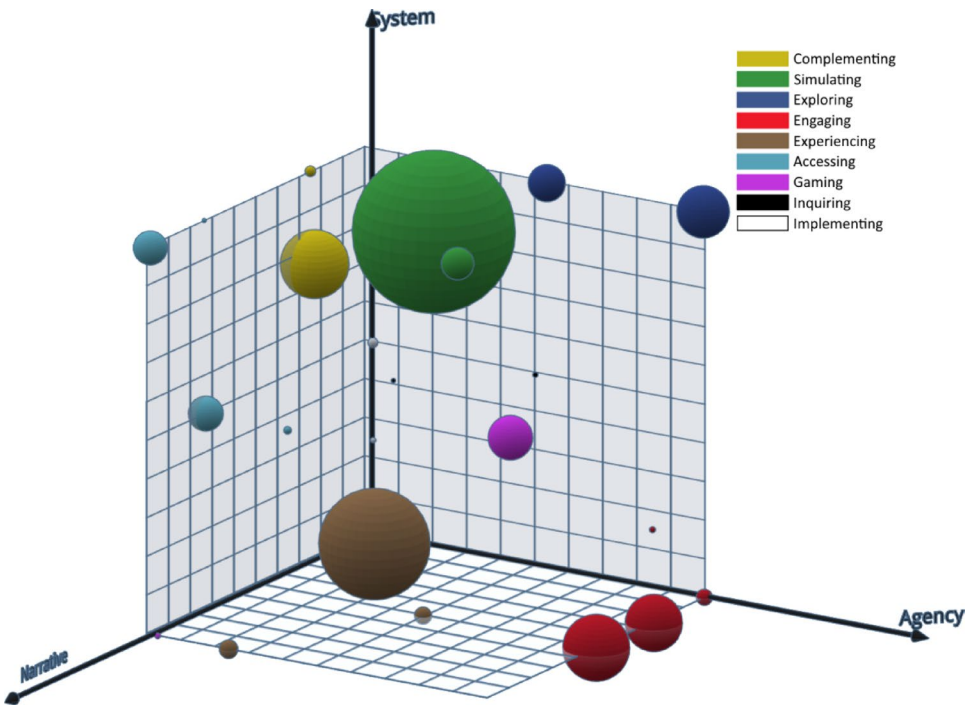

Fig. 10 Updated immersive learning cube with the new theme clusters (created with Tinkercad.com)

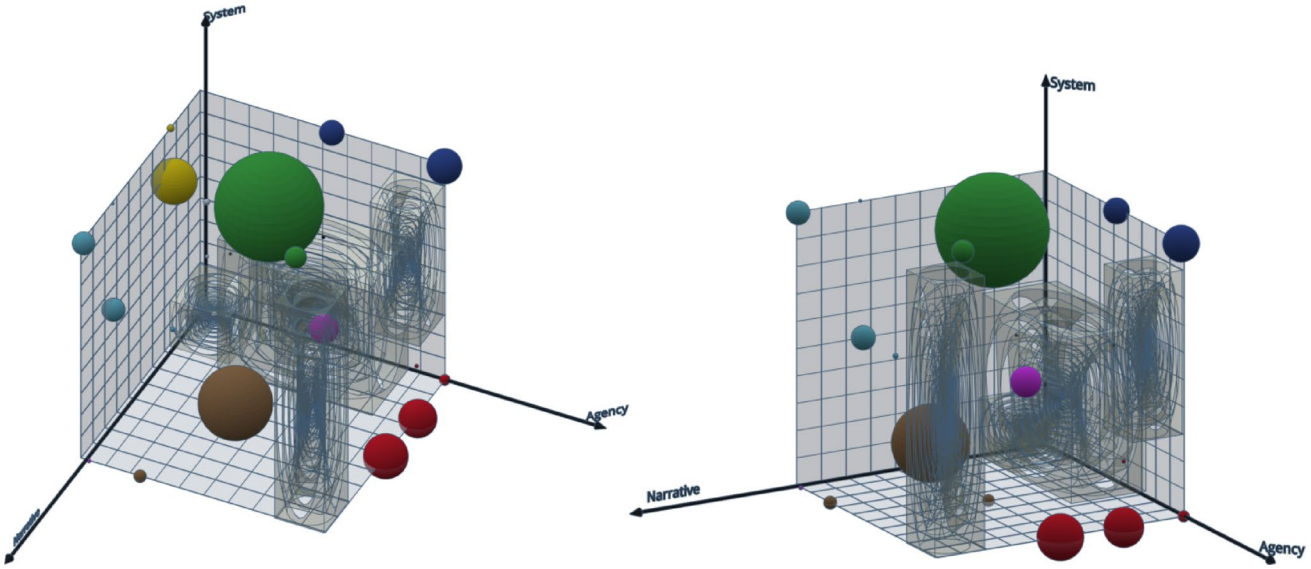

Fig. 11 Updated visualization of the voids of use (different perspectives) (created with Tinkercad.com)

- **Cluster 8: Mid System**, **Low Narrative**, **Low-to-Mid Agency**, **"Inquiring"**.
  (Combined prevalence: 1.5%: new.)
  ○ **Observation (new)**.
  ○ Data collection **(moved)**.
- **Cluster 9: Low-to-Mid System**, **Low Narrative**, **Low Agency**, **"Implementing"**.
  (Combined prevalence: 1.6%: new.)
  ○ **Mobility (new)**.
  ○ **Learning Management (new)**.

These clusters represent the updated main trends of use of immersive learning environments reported by this mapping of surveys of the literature.

To answer RQ2, we consider that opportunities for least-explored research directions are represented by the least-explored clusters. Researchers should consider these as fertile ground for their future research. Areas where there are no clusters at all represent a complete absence of empirical data, or what we call a "Void" (see Fig. 11):

- Void 0: Low System, Low Narrative, and Low Agency (i.e., almost non-immersive).
- Research during the time period between the original study and this update has differentiated themes more finely, identifying the Learning Management and Mobility themes as part of the new "Implementation" cluster, which resulted in the overall reduction of this void.
- Void 1: Mid-Low Narrative, Mid System and the full span of Agency.

  (i.e., immersion via agency with some technology, rather than narrative)

  Research during the time period between the original study and this update has differentiated themes more finely, identifying "Games", "Observation", and "Student Authoring" as new themes that resulted in the overall reduction of this void.

- Void 2: The full span of System and High Narrative, High Agency.
- (i.e., strong interactive storylines, regardless of the technology environments)
- This void combines two voids (2 & 3) from the original survey, which had no themes separating them, and thus did not warrant a separation. It has not seen any new developments.

7 Conclusions

From the results we can see that the trajectory of uses in immersive learning environments has changed significantly during the time period between the original study and the update. "Observation", "Personification", "Storytelling", and "Student Authoring" were added as new themes, and Mobility and Learning Management were adopted as themes (Pedrosa & Morgado 2024). The major themes from the original study remained strongly represented in the literature, although some waxed or waned in their representation. "Student Authoring" was the most prevalent of the new themes, also emphasizing the increase in more readily available VR authoring environments for practitioners. The most interesting of these major themes is that "simulate the physical world" increased to 20.1% while the previous

strongest theme decreased to 13.7% of the use codes. We consider that this is likely due to the increase in more readily available VR simulation environments for practitioners: VR platforms that offer realistic, interactive environments for educational use. Over the past few years, we've seen a surge in widely available VR tools. Also, this may be related to the parallel emergence of the "games" theme, since many immersive environments now gamify simulation-based learning, integrating challenges, feedback loops, and scoring systems that align with gameplay mechanics. Some papers reported in the surveys may have elected to highlight the simulation aspects of those tools, others the gaming aspects. In other words, as simulation tools became more accessible and pedagogically viable, beginning to blur with game-based learning approaches, this may explain both the rise in simulation uses and the parallel growth of "games" as a distinct thematic category, something only an in-depth analysis of the data might reveal, beyond the goals of a mapping.

We should also note that *Void 0* and *Void 1* both reduced in size due to the introduction of new use themes to the corpus. *Void 0* (Low System, Low Narrative, and Low Agency) was reduced due to more literature reviews included in the corpus surrounding the "Implementing" cluster. This cluster contained the themes "mobility" and "learning management" which focused on supporting deployment aspects of learning activities, and thus partially addressed the Low System, Low Narrative, and Low Agency of Void 0. For example, the theme learning management involved uses related to activities which supported structuring the learning process, and mobility involved those uses supporting student mobility outside of the traditional classroom context. Neither of these themes are particularly high in System, Narrative, or Agency, and thus they helped to address Void 0.

Also, Void 1 (Mid-Low Narrative, Mid System and the full span of Agency) was reduced due to more use accounts included in the corpus surrounding the "Gaming" use theme, which formed its own cluster. This focused on the use of immersive environments that report employing any of a wide variety of game types, content and technologies, including both digital and physical games, and thus partially addressed *Void 1*. This void was also reduced due to more use themes included in the corpus surrounding the "Inquiring" cluster. This cluster contained the themes "Observation" and "Data collection" which focused on the use of immersive environments that collect data from the users whether for the express intent of collecting data, or for some other purpose. Neither of these themes involve much in the way of system and narrative, yet they could encompass a wide range (low to high) of agency. As a result, the "Inquiry" cluster partially addressed other areas of *Void 1*. The voids point to the need to consider new keywords to find out what is happening in immersive learning in those areas that we may be missing. For example, our criteria need to consider keywords that capture non-VR forms of immersive learning better.

The resulting map of clusters and voids points towards the need for more immersive learning environments research on the area of *Void 2*: The full span of System and High Narrative, High Agency. In other words, we need accounts of use of immersive environments with strong interactive storylines, regardless of the technology environments. These types of immersive learning environments can be extremely challenging to create, so it is no wonder that this area experienced little change from our original study. Still, they do exist, and the continued existence of this void of research accounts points to the need for revisiting this area. For instance, the use of traditional game books, role-playing games, educational theatre, and board games should be deemed as part of this area, but it is entirely absent from our corpus. This indicates this research is not being analyzed under the lens of immersion, which poses an opportunity for novel perspectives and insights. Additionally, we need to continue to address *Void 1* with more research applying immersion theory to activities with some reliance on the envelopment provided by digitally-enhanced physical spaces. An example of such spaces is the smart board game *Chronicles of Crime*[1], which uses QR codes and smartphone app-based interfaces including AR and VR to blend tactile play with narrative progression and environmental scanning. Similarly, educational escape rooms and similar environments can have embedded IoT sensors (e.g., RFID-triggered content, pressure sensors, etc.) or leverage city locations and GPS sensors (Schlemmer et al. 2025). Also, recent natural language AI chat systems like ChatGPT, Alexa Classroom, and experimental voice-interactive NPCs in educational VR spaces demonstrate how AI-driven dialogue can serve as a responsive learning partner, enabling role-play, feedback, or adaptive scaffolding. Such examples signal a growing interest in technology-integrated learning spaces that remain underexplored through the lens of immersion.

One challenge in analyzing analog immersive formats—such as game books, role-playing games, educational theatre, and board games—within our current framework is finding them, since we cannot rely on technological obvious keywords. A field survey would be recommended as a first step to establishing the diversity of these formats, leading to subsequent literature review and analysis. A benefit of using Nilsson et al. as a framework, as we did, is that it already accounts for non-technological forms of immersion. However, since these analog experiences often achieve

[1] https://luckyduckgames.com/usa/game/1-chronicles-of-crime.

high narrative immersion and high agency but do so without the digital envelopment typically associated with system immersion, more detailed criteria may be necessary to adequately classify those experiences. For instance, future adaptations of the framework might clarify how to grade "system" immersion to encompass rule structures, physical environments, and embodied interaction—not just digital fidelity.

8 Limitations and future work

This is a tertiary study. A limitation of this type of study is that we only analyzed review or surveys of the literature and not actual primary studies. Thus, our study relies on second-hand information of the description of each of the primary studies, which may have omitted or misinterpreted information from the original study. Furthermore, the current work relies on identifying accounts of use of immersive environments using our keywords and criteria. The absence of non-technical terminology in the keywords is likely contributing to the research gaps of Void 2 (absence of traditional game books, role-playing games, educational theatre, and board games). The low prevalence of reviews dealing with 360° video (2 reviews) and Alternate Reality (1 review) and their isolation from the main body of our corpus may reflect something akin to this: these fields do not include either "immersion" or "immersive" in their titles and abstract. As a result, a search of the literature specifically for these fields may open new interpretations if seen under the theoretical lens of immersion.

Another limitation stems from our classification method. There remains no established process for evaluating rigorously the three dimensions of immersion (system, narrative, agency). Our inter-rater process provides an early approach, as does the sharing of qualitative criteria for this classification (Beck and Morgado 2025), but conducting a wider survey of experts, validating those criteria, and analyzing their use for classification, may result in different organization of the uses in the cube. More rigorous classification methods could include thematic analysis of specific system, narrative and agency-related terminology used in each paper in the corpus, followed by a quantitative comparison of the number of terms used in each immersion dimension. Additionally, future researchers should consider training future coders of accounts of use in immersive environments in using validated questionnaires for system (Jennett et al. 2008), narrative (Busselle and Bilandzic 2009), and agency (Bellotti et al. 2009).

Also, as we stated earlier, immersive learning research needs to look at what works and how it works in specific contexts, as well as how to design and develop immersive learning experiences. As a result, we are also developing the analysis of this corpus focusing not only on uses, but on the update to the mapping of surveys on practices and strategies in immersive learning environments published in 2024 (Beck et al. 2024). Other research is still needed to pinpoint where specific pieces of current knowledge are located, simplify concepts, confirm the importance of criteria and dimensions used, and identify possible questions for future literature reviews, which can then provide even stronger, evidence-based overviews of current knowledge on immersive learning environments. For instance, future research could consider extracting the learning subjects and target populations from our corpus in an effort to better understand how they may be related to the accounts of use. To support further research, we will make our data publicly available, as we did with the previous review data (Sousa et al. 2022).

Finally, the large number of new reviews included in our updated corpus (64) present a time-intensive and consistency challenge for a continuous mapping of the literature. Our use of QUAL-E (Authors) to code the uses of immersive learning environments provides a promising option for opening new avenues to standardizing qualitative criteria application among research teams, possibly enabling more regular and diversified approaches to achieving overviews of the current knowledge in the field. There are also many innovative literature research tools, such as LitMaps or Research Rabbit, which may provide new insights on how to identify relationships in the corpus and change our research voids and clusters.

We believe that by providing a framework of the existing uses of immersive environments, in concert with higher-order descriptive frameworks of practices and strategies, the research and practice community may better compare and contrast their experiences and cases, leading to more solid conclusions for this field. A potential next step would be to build on this conceptual foundation to support mapping from use settings and pedagogical intentions to the types of learning activities supported by immersive environments. In sum, this updated mapping of immersive learning use cases provides both researchers and educators with a practical resource. For researchers, the clarified thematic trends and identified voids offer a roadmap for future inquiry, helping to prioritize studies that address underexplored intersections of system, narrative, and agency. For educators and instructional designers, the framework serves as a reflective tool to assess current practices and inspire new approaches to curriculum design. Finally, for institutional decision-makers, this mapping can guide more informed technology adoption, encouraging choices that support meaningful instructional methods rather than novelty-driven implementation. By bridging empirical synthesis with actionable insight, this

work supports the continued evolution of immersive learning toward richer, more inclusive educational experiences.

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Author contributions All authors contributed to the study conception and design. Preparation, corpus selection, data extraction, and classification, and theme development, and analysis were performed by Leonel Morgado, and Dennis Beck. The data classification was reviewed by Patrick O'Shea. The first draft of the manuscript was written by Leonel Morgado, and Dennis Beck, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The dataset generated by the mapping of the uses research during and/or analyzed during the current study are available upon request to the authors, and will be subsequently provided openly in the INESC TEC research data repository. https://rdm.inesctec.pt/.

Declarations

Competing interests The authors are Steering Committee and/or Board members of the Immersive Learning Research Network, a non-profit organization, and received support to present a shorter version of these results at this organization's 2025 annual conference. The License to Publish of these conference proceedings authorizes us "to publish an expanded version of their Contribution provided the expanded version (i) includes at least 30% new material (ii) includes an express statement specifying the incremental change in the expanded version (e.g., new results, better description of materials, etc.)."

Human and animal rights This research did not involve any human participants.

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