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Finding the Gaps about Uses of Immersive Learning Environments: A Survey of Surveys

Dennis Beck
(University of Arkansas, Fayetteville, AR, U.S.A.
ORCID: 0000-0003-1771-3237
debeck@uark.edu)

Leonel Morgado
(Universidade Aberta, INESC TEC, CIAC, & LE@D, Coimbra, Portugal
ORCID: 0000-0001-5517-644X
Leonel.Morgado@uab.pt)

Patrick O'Shea
(Appalachian State University, Boone, NC, U.S.A.
osheapm@appstate.edu)

Abstract: Advancing the field of research in Immersive Learning Environments requires avoiding the pitfalls of previous educational technologies. Studies must consider the actual use of these environments and the context where it occurs, not simply the technocentric perspectives on these environments. This paper provides an overview and analysis of surveys on this topic, in order to map the field and find out which information on actual uses of Immersive Learning Environments are reported, and hence which gaps need to be covered towards a robust, encompassing knowledge on their relationship with learning. Collected accounts of use were clustered via thematic analysis and contrasted with research areas in learning and technology, highlighting the gaps in the field and serving as a blueprint for research agendas on uses of immersive learning environments.

Keywords: uses, practices, strategies, immersive, immersive learning, immersive learning environments, augmented reality, virtual reality, mixed reality, extended reality, XR, AR, VR
Categories: A.1, L.3.0, L.3.6, L.5.0, L.5.1

1 Introduction

Given the current enthusiasm about immersive learning environments, one might expect their usage to be clear, stemming from rich practice accounts and empirical results. Alternatively, one might expect them to be charting a similar course to that of earlier learning technologies, such as computers, edutainment, programming languages for novices, or serious games, to name a few: initial adoption alongside high expectations, followed by impact studies that focus on the new technology as if it were an environmental, chemical or medical remedy; and then conflicting outcomes. After this process, of course, comes the inevitable conclusion: that to analyze the impact of technology in learning it is necessary to consider not just technology itself, but its overall context.

This perspective is neither new nor specific to learning technologies. It is commonplace in information systems and information technology research, which advocates for multidimensional analysis, including second-order dependencies and effects at social, political, and organizational levels (Fitzgerald, 1998). It is also not restricted to information technologies and emerges in fields where different agents can intervene with initiative - where agency occurs. This stems from two aspects. The first is the observer effect (sometimes called the Hawthorne Effect), "the modification of activity when individuals are aware that they are being observed" [Nguyen, Miller, Sunderland and McGuiness 2018]. The second is the complex, cause-effect relationships involved: Research that tries to establish an effect from a single variable when the cause is complex has incurred in the complex cause fallacy [Lessov-Schlaggar, Rubin and Schlaggar 2016]. This has been reported often in learning research, such as "the contemporary trend to primarily emphasize the final stage of the research cycle - testing claims of causality" [Nieveen, McKenney and Akker 2006] and is sometimes called technocentrism or infocentrism [Bronfman 2007]. Therefore, research on the evaluation of immersive learning environments needs to consider the actual practices, the physical settings, and the broader contexts (organizational, normative, social, etc.).

Further, the impact of learning technology is not simply an end-of-line output such as academic grades, retention rates, or skill performance. There are (or can be) systemic impacts: technology can impact not just details in current learning activities, but also their dynamics and the empowerment levels of participants; it can lead to novel practices or render feasible different ones, even learning expectations and goals may be changed. Again, this is not a specific aspect of learning technology, but of information technology in general. In organizations, for instance, evaluating technology merely on its impacts on current operations is short-sighted: "a strict financial evaluation (...) will potentially miss out on what might be more worthwhile projects that cannot be justified on efficiency criteria alone" (Fitzgerald, 1998). Ultimately, using technology leads to organizational change, and change must be managed at a diversity of levels [Stouten, Rousseau and De Cremer 2018].

The field of research on immersive learning environments needs to tackle a diversity of dimensions: Evaluation research (i.e., "effects", "impacts", "outcomes"), which requires clarification and accounting for the complex nature of what is being evaluated as stated above; but also design & development research, concerned with the "development of solutions to practical and complex (...) problems" [McKenney and Reeves 2012].

As a result, we sought to inform future research efforts on immersive learning environments by scoping out how current research is grounded in actual empirical facts about their use, rather than collecting stated outcomes or prospective reflections. The resulting panorama revealed relevant gaps grounded in the current knowledge, thus contributing to the establishment of future goals for the research community.

To find the gaps, we set out to identify accounts of actual uses of immersive learning environments in the various surveys conducted in the field. There have been dozens of surveys in the last few years, as shown in the following sections, and our rationale is that this creates a corpus of knowledge likely suitable to ascertain an overall panorama. The survey selection process identified relevant surveys and accounts of use, which were then subjected to citation analysis, thematic analysis, and finally scrutinized to identify gaps and draw future research recommendations.

2 Background

2.1 Immersion

Immersion is a multifaceted concept, often approached without clarification in technology-centric literature, but for which recent reviews have provided a structured theoretical perspective [Agrawal, Simon and Bech 2019]. Over the past decades, works in this field typically approached the concept of immersion solely from the two main perspectives: immersion as an objective characteristic of the technical system features and affordances [Slater 2009] and the perspective of immersion as a psychological state characterized by one's perceptions of presence and interaction [Witmer and Singer 1998]. However, those recent reviews have not only brought to light the theoretical complementarity of these perspectives, but also clarified that they are in fact the minority of perspectives in the literature. Those reviews state that indeed immersion is a psychological state, emerging from the technological affordances of the system but also from two other aspects: the narrative and its ability to originate "a degree of mental absorption or intense preoccupation with the story, the diegetic space, and the characters inhabiting this space" [Nilsson, Nordahl and Serafin 2016]; and the challenges one faces, leading to "absorption brought about by the experience (...) requiring mental or sensorimotor skills" (ibid.). We follow this recent syncretic perspective of immersion, stated by Agrawal et al. 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". And we follow the perspective by Nilsson et al. that this phenomenon can be envisioned as arising from three dimensions: the technology, the narrative, and the challenges (see Figure 1). Thus, a given immersion case can be envisioned as a three-dimensional placement within the conceptual space of immersion (as we later do in section 7).

2.2 Immersive Learning Environments

With immersion being defined in terms of the experience of a phenomenon by an individual, an immersive environment is 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. The technical aspects of an immersive environment may include, for example, a video game and the hardware used to play it. The narrative content in an immersive environment would include the story/plot, geographic features, characters, relationships, and interactions between those characters. The physical setting involves where the individual is physically experiencing immersion and under what conditions. For example, is the person playing the videogame alone or with a group? Playing with people they know, or strangers? What time of day is it? What is their level of fatigue? Where are they playing the game? Is the game hip or old-fashioned? Part of educational activities or not? In a hurry or relaxed? Costly or free?

A family tradition or a break from societal customs? All these questions and more compose the context of the immersive environment where one experiences immersion. Thus, an immersive environment is described by the a) technical system and its properties, b) narrative content; and c) encompassing context (setting and its contextual conditions).

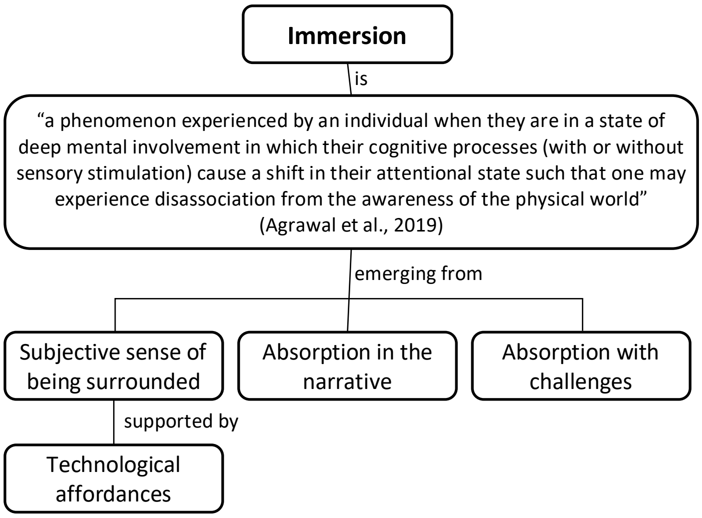

Figure 1: Syncretic perspective on Immersion (Agrawal et al. x Nilsson et al.)

Finally, an immersive learning environment, in the context of this survey, is an immersive environment analysed from the perspective of its relationship with learning phenomena. This can mean an immersive environment designed specifically to foster learning, but also the learning that occurs in immersive environments not specifically designed for that purpose.

3 Survey methodology and criteria

3.1 Goals and concepts

Our focus in this survey of surveys was to assemble a panorama of accounts of use of immersive learning environments, and from that panorama extract current research gaps. "Accounts of Use" meaning the literature plainly reports an actual learning activity, rather than its pedagogical-educational rationale, or when that rational is limited to an intent, without specifying the means to achieve it.

In order to establish whether a specific account of use of an environment refers to an immersive learning environment, one must extract elements about its immersion phenomena alongside the three Nilsson et al. dimensions, as put forth in the previous section. However, the brevity of accounts provided in surveys, give minimal details about their source papers. This puts into question, for many of the accounts, whether they fall within our scope or not. Thus, one must consider the global scope of each survey to determine whether one can assume that their reported accounts can be associated with immersive learning environments.

For this reason, we limited this survey of surveys to those focusing on environments where the technology being used was developed with the specific intent of eliciting immersion, because that would be unequivocal (i.e., augmented reality, virtual reality, or mixed reality). This excluded cases such as surveys on generic educational technology, on games in education, on training technology contexts, and on similar generic themes combining technology & learning, since their reported accounts would combine aspects originating from immersive and non-immersive learning environments, without enough details for us to tell them apart. By restricting ourselves to surveys whose environments employed immersive technology, we hope to have improved the data quality of the collection of use accounts of immersive learning environments from current surveys in the area. This approach manages to include possible surveys focusing on narrative and/or challenge-based aspects of immersion, albeit only if those aspects are occurring in environments with a relevant presence of immersion technology. A limitation of this approach is that any uses that are more prevalent in immersive learning environments with low technology or repurposing non-immer

3.2 Search process

Figure 2 provides a visual overview of the search process. In order to find surveys focusing on immersive learning environments where the technology being used was developed with the specific intent of eliciting immersion, we combined two sets of keywords for searching in titles:

Set 1: Keyword for finding surveys

survey, review

Set 2: Keyword for finding immersive learning environments

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

The two sets of keywords were combined to focus search outcomes. For instance, combining "survey" and "education" would yield a too broad selection of outcomes, as would "review" and "environment". Thus, in each search string an extra keyword from Set 2 was always used to provide more focus. Table 1 lists all the search strings used, listed as "First pass". The timespan selected was the last 20 years. While the search was conducted in late 2019, the date span was 2000 to 2020, to enable inclusion of possible preprints. We have not included any search string with the keyword "immersive learning", because any such results would have already been collected in the search for "immersive" AND "learning".

We then complemented the output of these searches with a narrower search for the "immersive learning" keyword combined with extra keywords for surveys: "scoping" and "systematic", as a safeguard against possible surveys self-designated neither as "survey" nor as "review" (e.g., "systematic study", "scope of the field", etc.). These complementary searches are listed in Table 1 as "Second pass" and restricted to the last 10 years (since 2009).

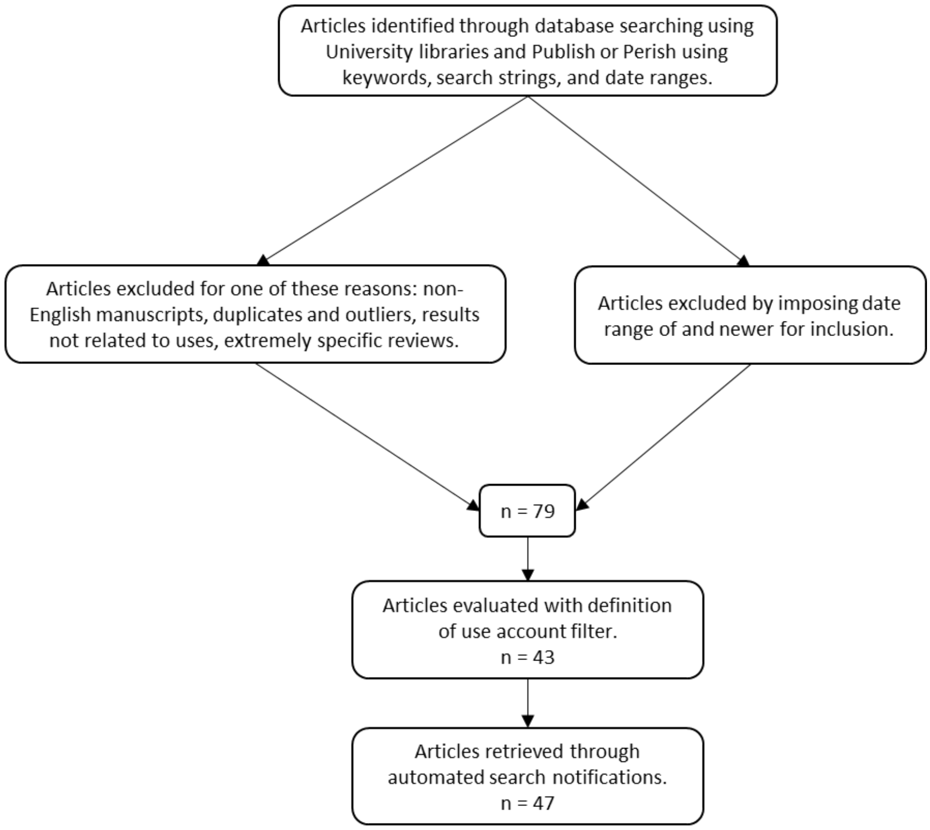

Figure 2: Systematic survey search process

Both search passes were performed on Google Scholar by paper title, using Harzing's Publish or Perish application [Harzing 2007] to retrieve results in a spreadsheet format. Actual papers were downloaded via our universities' library services and online public repositories. We then combined all search spreadsheets into one and deleted from the results duplicates and non-English manuscripts (two of the researchers only spoke English). We also eliminated outliers: results that, *from the title*, were clearly not related to immersive learning environments, and surveys that focused on a very narrow concept, such as training a specific surgical skill. Additionally, because most results were surveys from 2014 through the present, we excluded results before that period. This process resulted in n = 79 articles found.

The second step in the literature search involved application of our definition of "immersive learning environment" (see section 1). Using this definition as a filter, we read through the abstracts of all 79 articles, eliminating those that were not based on studies dealing with immersive learning environments (for instance, we excluded papers that did not focus on education). Some of these articles dealt with mobile augmented reality, which some might consider non-immersive. However, as we put forth above, immersion is not defined by the technology, rather the technology is but one aspect of it. Therefore, we did not exclude these articles because they could include accounts which, albeit with a lower level of technical immersion, still possessed relevant levels of narrative, and challenging aspects of immersion.

Search strings - First pass (2000-2020)
(survey OR review) AND immersive AND environment
(survey OR review) AND immersive AND learning
(survey OR review) AND "virtual reality" AND learning
(survey OR review) AND augmented AND learning
(survey OR review) AND augmented AND environment
(survey OR review) AND augmented AND environment
(survey OR review) AND "mixed reality" AND environment
(survey OR review) AND "mixed reality" AND learning
(survey OR review) AND reality AND education
(survey OR review) AND immersive AND education
Search strings - Second pass (2009-2020)
"Immersive learning" AND "scoping"
"Immersive learning" AND "systematic"
"Immersive learning" AND "review"
"Immersive learning" AND "literature review"

Table 1: Dataset of papers resulting from the search process

If we were not able to determine that from the abstract, we then checked the main body of the paper. This enabled us to eliminate, based on a sanity-check, papers which presented various issues: that listed only the bibliographies of authors in the field, without further contributions; that were not literature reviews in spite of the title and abstract; that were only abstracts or not peer-reviewed; and surveys which, albeit with an English-language indexed title, were written in another language. In parallel, while analysing the full body of the articles, we also filtered the 79 articles by the scope of this review, as stated in section 1: Surveys identifying accounts of actual uses on the ground rather than outcome measurements without enough clarification on how immersive learning environments were employed. This scope criterium also excluded papers focused on potential future directions for education, rather than actual uses.

This resulted in n = 43 articles remaining from our search. During the process of screening the abstracts, we received automated recommendations from academic-oriented sites such as Academia.edu, ResearchGate.com, and Google Scholar notifications, based on our browsing activity. These suggestions were similarly screened for inclusion or exclusion, using the same methods and criteria, which resulted in the addition of four more papers (n = 47).

4 Corpus

4.1 Outcome of search

Table 2 contains a complete list of the 47 survey papers discovered in the literature search process described in the previous section, including year, author, and title.

ID	Year	Authors	Title
P01	2019	Smutny et al.	A Review of the Virtual Reality Applications in Education and Training
P02	2019	Affendy et al.	A Review on Collaborative Learning Environment across Virtual and Augmented Reality Technology
P03	2019	Towers et al.	A scoping review of the use and application of virtual reality in pre-clinical dental education
P04	2019	Billingsley et al.	A Systematic Literature Review of Using Immersive Virtual Reality Technology in Teacher Education
P05	2019	Kamarudin et al.	Augmented Reality, Virtual Reality and Mixed Reality in Medical Education: A Comparative Web of Science Scoping Review
P06	2019	Pellas et al.	Augmenting the learning experience in primary and secondary school education: a systematic review of recent trends in augmented reality game-based learning
P07	2019	Petrovich Jr et al.	From Virtual to Real: An Expanded Systematic Review of Augmented Reality Learning
P08	2019	Concannon et al.	Head-Mounted Display Virtual Reality in Post-Secondary Education and Skill Training: A Systematic Review
P09	2019	Herpich et al.	How Mobile Augmented Reality Is Applied in Education? A Systematic Literature Review
P10	2019	Barrie et al.	Mixed Reality in Medical Education: A Narrative Literature Review
P11	2019	Wen et al.	Review of Augmented Reality in Education: Situated Learning with Digital and Non-digital Resources
P12	2019	Yu et al.	The applications of virtual reality technology in medical education: a review and mini-research
P13	2019	Fealy et al.	The integration of immersive virtual reality in tertiary nursing and midwifery education: A scoping review

P14	2019	Huttar et al.	Virtual Reality and Computer Simulation in Social Work Education: A Systematic Review
P15	2019	Ali et al.	A survey on Immersive learning approach towards current education system
P16	2019	Stavroulia et al.	Virtual Reality Environments (VREs) for Training and Learning
P17	2019	Fabris et al.	Virtual Reality in Higher Education
P18	2018	Wang et al.	A critical review of the use of virtual reality in construction engineering education and training
P19	2018	Gopalan et al.	A Review of Augmented Reality Elements in Science Learning
P20	2018	Hedberg et al.	A Systematic Review of Learning through Mobile Augmented Reality.
P21	2018	Goff et al.	Applications of Augmented Reality in Informal Science Learning Sites: a Review
P22	2018	Ibáñez et al.	Augmented reality for STEM learning: A systematic review
P23	2018	Sommerauer et al.	Augmented Reality for Teaching and Learning-a literature Review on Theoretical and Empirical Foundations.
P24	2018	Zhang	Augmented Reality in Foreign Language Education: A Review of Empirical Studies
P25	2018	Khoshnevisan et al.	Augmented Reality in Language Education: A Systematic Literature Review
P26	2017	Chen et al.	A review of using Augmented Reality in Education from 2011 to 2016
P27	2017	Fotaris et al.	A systematic review of Augmented Reality game-based applications in primary education
P28	2017	Kavanagh et al.	A systematic review of Virtual Reality in education
P29	2017	Akçayır et al.	Advantages and challenges associated with augmented reality for education: A systematic review of the literature
P30	2017	Tobar-Muñoz et al.	Augmented Reality Game-Based Learning: A Review of Applications and Design Approaches
P31	2017	Dalim et al.	Factors influencing the acceptance of augmented reality in education: A review of the literature
P32	2017	Saltan et al.	The use of augmented reality in formal education: A scoping review
P33	2017	Martirosov et al.	Virtual Reality and its influence on training and education–literature review

P34	2016	Hu et al.	Alternate Reality Game in Education: A Literature Review
P35	2016	Diegmann et al.	Benefits of Augmented Reality in Educational Environments - A Systematic Literature Review
P36	2016	Swensen	Potential of augmented reality in sciences education. A literature review.
P37	2015	Freina et al.	A literature review on immersive virtual reality in education: state of the art and perspectives
P38	2015	Saidin et al.	A review of research on augmented reality in education: advantages and applications
P39	2014	Zhu et al.	Augmented reality in healthcare education: an integrative review
P40	2014	Bacca et al.	Augmented reality trends in education: a systematic review of research and applications
P41	2014	Phon et al.	Collaborative augmented reality in education: A review
P42	2014	Nussli et al.	The components of effective teacher training in the use of three-dimensional immersive virtual worlds for learning and instruction purposes: A literature review
P43	2014	Saidin et al.	The potential of augmented reality technology in education: a review of previous research
P44	2019	Masmuzidin et al.	The current trends of augmented reality in early childhood education
P45	2018	Gandolfi	Virtual Reality and Augmented Reality
P46	2019	Pellas et al.	A systematic literature review of mixed reality environments in K-12 education
P47	2017	Fombona et al.	M-learning and Augmented Reality: A Review of the Scientific Literature on the WoS Repository

Table 2: Dataset of papers resulting from the search process

4.2 Analysis

A group/clustering analysis was performed to determine the relationships between the surveys in Table 2. This was an important first step because we wanted to have a better understanding of the connections between these surveys prior to doing thematic analysis on their contents. Figure 3 shows the results. We checked the references sections of all 47 survey papers, to determine which surveys referenced each other. Then we used VOS Viewer [van Eck and Waltman 2017] to group the articles using this referencing data and analyze the resulting groupings at an aggregate level. We discovered that only 29 of them were related by citations. The other 18 (38%) neither cited nor were cited by any other surveys in the dataset and have been eliminated from the visual.

Also, we reorganized the papers visual presentation to appear chronologically on the vertical axis, and subsequently scattered the papers on the horizontal access to minimize clutter and best view the connections between the individual papers.

Figure 3 shows how one of the surveys was particularly influential: Bacca et al. [Bacca, Baldiris, Fabregat, Graf and Kinshuk 2014] influenced most other surveys, either directly or by virtue of being cited by Akçayır & Akçayır [Akçayır and Akçayır 2017]. Most later survey efforts stem from this influence and are not entirely aware of each other. Freina & Ott [Freina and Ott 2015] and Chen et al. [Chen, Liu, Cheng and Huang 2017] emerge as a second-tier of influence, but not as widespread in subsequent citations as Akçayır & Akçayır [Akçayır and Akçayır 2017] and Bacca et al. [Bacca et al. 2014].

The preponderant influence of a single survey, discovered via the citation-based clustering of the publications harvested through the search process for this survey of surveys, revealed a parochial perspective: most survey authors did not consider the breadth and depth of results from others' work. Unfortunately, this points towards a fragmented, haphazard picture of the research done in immersive learning environments. This provides strong justification for a subsequent scoping study stemming from this survey of surveys, since scoping studies aim to expose the "extent, range, and nature of research activity (...) clarify a complex concept and refine subsequent research inquiries" [Levac, Colquhoun and O'Brien 2010].

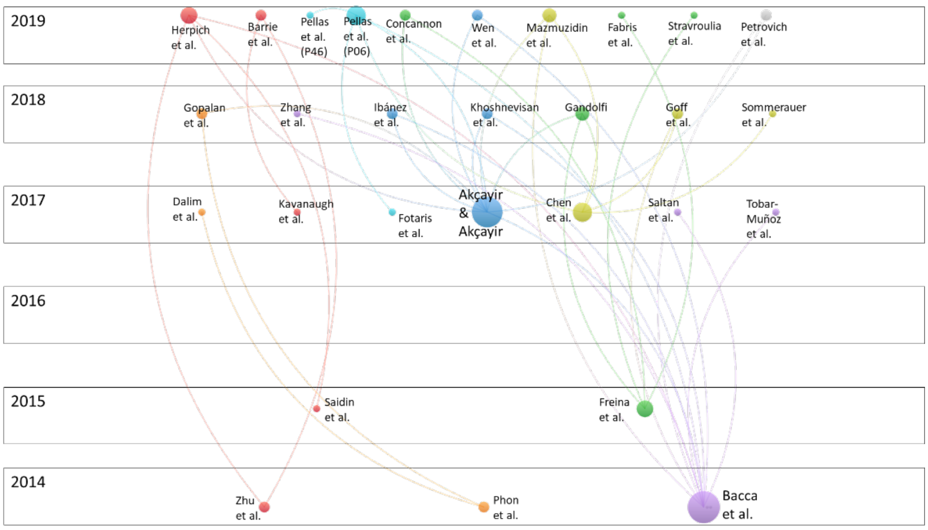

Figure 3: Diagram of citation relationships within the corpus

5 Data procedures

We followed the process prescribed by Vaismoradi et al. [Vaismoradi, Jones, Turunen and Snelgrove 2016], who recommended use of qualitative, thematic techniques to collect and analyze data to yield meaningful, credible, and practical results. To find accounts of use, we went through the full text of all 47 papers, collecting manuscript text excerpts with potential contributions on this topic. We have not considered reports of usage of a technology without a clear educational context.

In this process, we generalized the actual pattern for each account of use. For instance:

> "Highlighting - Google Glass to guide surgeons by providing AR images of portal and hepatic vessels in patients' surgical sites." [Concannon, Esmail and Roduta Roberts 2019]

was generalized as:

> "Highlighting - Google Glass to guide (...) by providing AR images of (...) in (...) [specific context] sites."

We converted the extracted data into a table and cleaned it by identifying line breaks which had been wrongly converted into separate entries. For each entry, we kept the ID of the manuscript where it was collected. After this process, we obtained 650 items reporting potential accounts of use. These were then processed to establish which items qualified as accounts of use following our definition laid out earlier in section 2.1, "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."

The process began by ensuring that two researchers had the same understanding of what an "account of use" was, from the above definition, and how it could be applied to text excerpts. Vaismoradi et al. [2016] refer to this process as inter-rater vetting and involved the two individuals working side-by-side. First, each researcher individually categorized 100 items as "use" or otherwise. They discussed their rationale and consolidated their approach. Then they individually categorized the remainder of the 650 items. In this process, they identified entries which clustered several different cases and split them into their various individual cases, subjecting each to the same categorization process. The total number of items was 691. When their opinions diverged, a third researcher was asked to provide a tie-breaking judgment using the same definitions. This occurred in 139 of the 691 cases, and comments were provided by the third researchers as to his rationale for the tiebreaking judgment. The final tally yielded 156 use accounts.

We then used thematic analysis to focus on the explicit description of the content of communication with a limited reflection on its implicit meaning [Vaismoradi et al. 2016]. Theme development was initiated by coding entries with conceptual (key aspects, disciplines, and facets of the study phenomenon) and relationship codes (connections between aspects, disciplines, and facets). While coding, we interactively cross-checked this approach, to identify misleading situations or contradictory approaches. For instance, we detected situations where we were coding computational uses instead of learning uses. One such situation was account ID 20, the use "Abstract (...) shapes [instead of realistic shapes]". Originally, we had coded it as "use abstract shapes". However, the use of abstract shapes is the computational interface approach, but the educational use of that approach as reported in the original paper was simplifying the procedure for the student, avoiding the complications of detailed shapes when training dental surgery skills. Hence, we corrected that code into "procedure simplification".

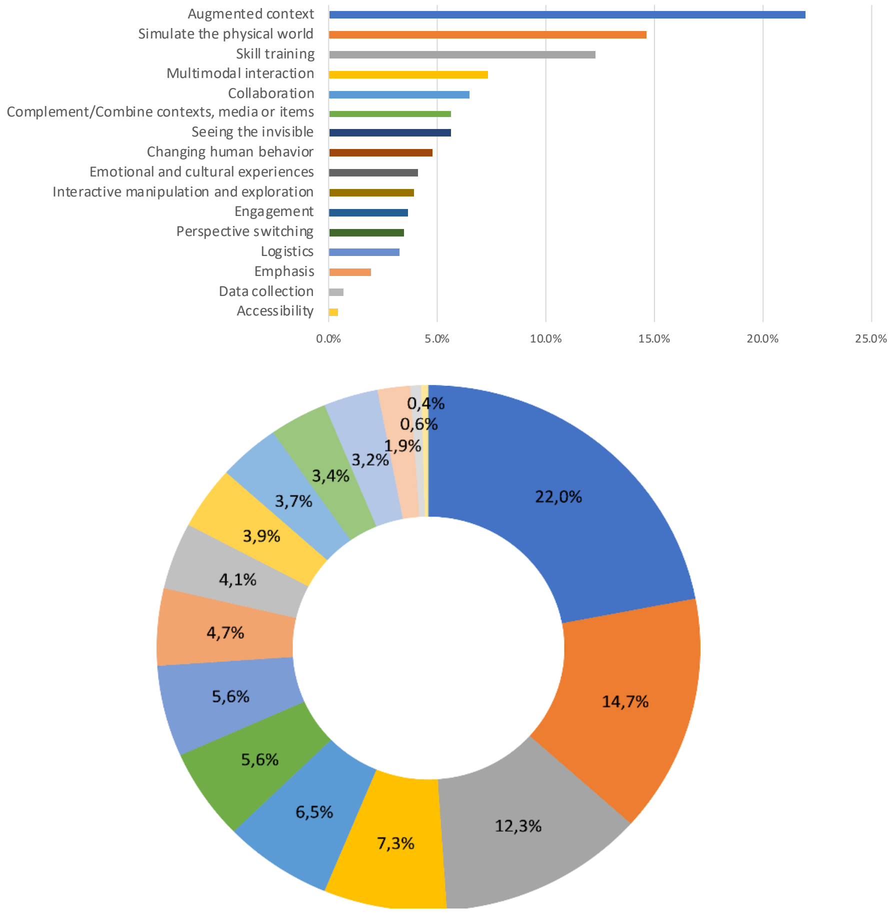

Figure 4: Themes from the survey of surveys, by percentage of the total

Our next step was theme construction, which involved classifying, comparing, and labelling. Classifying involved clustering codes that had a variety of details and subtleties under a similar generalization. Comparing involved a process of revising codes when we found that their scope would not be adequate for the original text excerpts they were meant to represent, eliminating negative cases that didn't match the code classification, and linking codes together to begin to form themes. Labeling involved coming up with a phrase or sentence that captured the overall meaning of the theme, to help externalize tentative concepts among the research team. The theme definitions and descriptions are provided in Section 5.1 below. Finally, themes were rectified, following stages of immersion and distancing, considering established knowledge from the literature regarding terminology, and stabilizing into settled definitions. This process yielded 16 major themes, among which were distributed 464 total codes, resulting in the final panorama shown in Table 3 and Figure 4. The prevalence column in Table 3 was calculated by dividing the number of codes for each theme by the total number of codes.

Theme	# codes	Prevalence	Description
Accessibility	2	0.4%	The theme "Accessibility" represents accounts of use of immersive environments for learning activities with the intent to improve accessibility of physical/other settings for people with disabilities.
Augmented context	102	22%	The theme "Augmented context" represents accounts of use of immersive environments for 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	22	4.7%	The theme "Changing human behavior" represents accounts of use of immersive environments for learning activities designed to alter individuals' physical or attitudinal patterns toward themselves, others, or in response to a specific stimulus.
Collaboration	30	6.5%	The theme "Collaboration" represents accounts of use of immersive environments 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	26	5.6%	The theme "Complement/Combine contexts, media or items" represents accounts of use of immersive environments 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	3	0.6%	The theme "Data collection" represents accounts of use of immersive environments for learning activities 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	19	4.1%	The theme "Emotional and cultural experiences" represents accounts of use of immersive environments for 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	9	1.9%	The theme "Emphasis" represents accounts of use of immersive environments for learning activities to draw the attention of the participants by various means, which may or may not include extra information.
Engagement	17	3.7%	The theme "engagement" represents accounts of use of immersive environments for learning activities to support focused attention. This includes enjoyable, motivating experiences.
Interactive manipulation and exploration	18	3.9%	The theme "Interactive manipulation and exploration" represents accounts of use of immersive environments for 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.
Logistics	15	3.2%	The theme "Logistics" represents accounts of use of immersive environments for learning activities to coordinate situations involving multiple types of resources or their scarcity (time, equipment, personnel, funding).
Multimodal interaction	34	7.3%	The theme "multimodal interaction" represents accounts of use of immersive environments 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.).
Perspective switching	16	3.4%	The theme "perspective switching" represents accounts of use of immersive environments for learning activities to experience different roles, perspectives and viewpoints. This includes embodiment and spatial change.
Seeing the invisible	26	5.6%	The theme "Seeing the invisible" represents accounts of use of immersive environments for 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	68	14.7%	The theme "Simulate the physical world" represents accounts of use of immersive environments 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	57	12.3%	The theme "Skill training" represents accounts of use of immersive environments for 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.

Table 3: Resulting themes on accounts of use of immersive learning environments

6 Results

6.1 Theme 1: Augmented context

As is strikingly visible from Figure 4, Augmented Context was the predominant account of use. Most research studies cited in these surveys used immersive environments for learning activities that provided complementary, setting-aware information to the users. This included information based on positioning and nearby items, via overlays or other means. Information overlay often included the used of augmented reality to provide information on a specific object or location using visual markers, but it was also used in more sophisticated ways, such as (cf. paper 5): "AR where a virtual trajectory was overlaid on a screen for trainees to trace using [hand tools]". It also involved collection of context-aware information, not just consumption of it (cf. paper 15): "Camera phones and smartphones allow users to gather information in a variety of locations." Finally, augmented perception was also a part of the augmented context, as a text excerpt from paper 4 stated, "augmented perception [by opacity of virtual students, for] teachers [to] (...) more uniformly spread their gaze [to engage students] than teachers with normal perception".

6.2 Theme 2: Simulate the physical world

This theme involves accounts of use of immersive environments for learning activities that imitated or mirrored aspects of the physical world. Simulation codes dominated this theme. For example:

> "Participants navigated (...) [microscopic scale] and had to create (...) [local process] during an activity (...) experience (...) [local process] from a vantage point inside a [microscopic structure]" (cf. paper 4)
>
> "Users pilot (...) within a simulated environment that resembles a real-world location" (cf. paper 8)
>
> "simulation [technical-specific procedures]" (cf. paper 13)

Visualization of the real world was also a large emphasis in this theme:

> (cf. paper 17): "to better visualise the [geometric, location and specific topic aspects of elements]"
>
> (cf. paper 25): "The applications created by AR enable the usage of three-dimensional models (i.e., 3D objects, images, videos and animations) both separately and simultaneously"

With that said, this theme also included spaces and processes:

> (cf. paper 16): "an HMD is combined with the body tracking of the user, or at least hand or foot tracking, it could be utilized to train athletes or normal people to play sports or even just for exercising without having the need to go to an actual gym:
>
> (cf. paper 31): "virtual reconstruction of heritage"

Finally, the theme encapsulated specific concerns about the fidelity of the environment or process being simulated:

> (cf. paper 8): "Users pilot (...) within a simulated environment that resembles a real-world location"
>
> (cf. paper 17): "VR recreations of a patient's [organ and its features]"

6.3 Theme 3: Skill training

The third major theme was skill training which was defined as accounts of use of immersive environments for learning activities that provided users with the targeted training needed to gain the knowledge and expertise necessary to fulfil the requirements of a specific task. Codes related to specific expertise being trained dominated this theme, covering medical (and other) procedural skills, soft skills, and skills learned to respond to events. For example, (cf. paper 14): "simulation [technical-specific procedures] procedures". Interestingly, usage of immersive environments for learning procedures tended to focus on the simplification of these procedures. For example, paper 8 cited the example of performing a virtual interview on a virtual client, as well as simplified tasks being done on virtual patients, while paper 11 mentioned asking and providing guidance in a context-reliant workplace. Other skills being trained were soft skills such as communication (cf. paper 8), and self-regulation (cf. paper 5). Response to events skills focused on responses to dangerous situations and safety risks (cf. paper 8, 42), as well as classroom management skills for teachers: (cf. paper 16): "help teachers deal with today's multicultural classrooms and cultivate their empathy and reflection skills"

Other codes in this theme related to the specific concept of practice. For example, (cf. paper 5) discussed hand tool practice, "AR where a virtual trajectory was overlaid on a screen for trainees to trace using [hand tools]"; and (cf. paper 17), "learning of the correct positioning of [technical aspects]". A significant aspect of this practice was the rich context that immersive environments can provide, such as the human body system performing a virtual interview on a virtual client (cf. paper 47), and (cf. paper 8), "performing a virtual interview on a virtual client".

A significant number of codes were also related to assessment of the skills being trained. These assessments usually required performance of a specific procedure under specific conditions (cf. papers 1, 2, 4) as well as both individual and collaborative task performance (cf. paper 2). For example, (cf. paper 4), "Participants navigated (...) [microscopic scale] and had to create (...) [local process] during an activity (...) experience (...) [local process] from a vantage point inside a [microscopic structure]." A few other codes emphasized learning content knowledge in immersive environments, but those were in the minority (cf. paper 6, 35), "using AR technology (...) helping visitors keep their memories of the artwork vivid".

6.4 Theme 4: Multimodal interaction

Some of the research studies cited in these surveys used immersive environments for learning activities that combined various types of user inputs/outputs. Types of inputs mentioned included facial expressions, eye gaze tracking, touchscreen, accelerometer, wireless pen, interactive panels, and sketch-based interaction. These were used in many ways, for example:

> (cf. paper 2): "incorporate other input modalities such as facial expression and eye gaze tracking to (...) *social engagement and support collaboration awareness among users in collaborative environment*"
> (cf. paper 8): "a platform that can *subject users to intangible stimuli such as fear, addiction, and violence*"
> (cf. paper 45): "HMD, a wireless pen, and an interactive panel *were used to teach Physics*"
> (cf. paper 6): "stimulates interaction through learners' body movements *to increase physical exercise*"
> (cf. paper 46): "sketch-based interaction (...) *for recognition of hand-drawn sketches*"

Types of outputs mentioned involved the notion of, "[...]feel(ing) and interact(ing) with exhibits." (cf. paper 21); including the sense of touch, recognition of surface features: "allow the operator to feel like they are making contact with [...] and, as they run the virtual tool across its surface would be able to feel the surface features." (cf. paper 3). These aspects of haptic feedback were often used to allow users to "feel" physical forces (cf. paper 37) Finally, more traditional outputs such as audio, text, images, and video were used to present information ((cf. paper 19).

One specific type of output was real-time feedback to a user's actions or status. This involved creation of a "repeatable system that produces objective measures of performance while providing real-time feedback to users" (cf. paper 8). For example:

> (cf. paper 3): "the use of abstract modes of interaction to elicit real operative events in the simulation environment (...) for example (...) the user would apply (...) the haptic arm, and then click a button in order for [an event to occur] within the simulated environment".

Sometimes this involved feedback to biological parameters gathered from the user, "A virtual environment of a [locale] (...) relaxation scenario will change from calm to stormy, depending on the user's [variable physical parameter] (...)." (cf. paper 8). Or in the case of paper 11, "asking and providing guidance in a context-reliant workplace".

6.5 Theme 5: Collaboration

Some of the research studies cited in these surveys used immersive environments for learning activities which involved the social phenomena that characterize group work. This included the diversity of domains of collaboration, such as live vs. remote, synchronous vs. asynchronous, and situation/contextual factors, etc. For example, uses for live collaboration often emphasized the concept of social presence: "incorporate other input modalities such as facial expression and eye gaze tracking to (...) social engagement and support collaboration awareness among users in collaborative environment" (cf. paper 2), and the simultaneous nature of the collaborations: "[...] both separately and simultaneously" (cf. paper 25), and the idea of a shared space (cf. paper 2). Juxtaposing the usage of live collaboration codes were ones that focused on remote collaboration, which emphasized such things as immersive environments' utility for collaborating in an online course (cf. paper 42), sharing data to a remote collaborator in a virtual reality environment (cf. paper 2), and the use of avatars to collaborate (cf. paper 2).

6.6 Theme 6: Complement/Combine contexts, media, or items

Some of the research studies cited in these surveys used immersive environments for learning activities which intended to leverage the combination of physical and traditional digital media with immersive elements as a catalyst for learning. A generalized example from paper 31 illustrates this: "students to examine an augmented 3D model (...) in conjunction with a set of real (...) components [associated with it]". These elements may be in juxtaposition, alternation or mutually impacting each other. Several of the citations in these surveys were in connection with the use of immersive learning technologies to complement traditional contexts/media such as lectures and textbooks (cf. paper 17), as well as picture and graphic books (cf. paper 11, 25, 27) for learning a wide range of academic subjects. For example: "primary students experience learning English with the aid of (...) [AR pop-up] books during recess time in the school library" (cf. paper 25). However, other, more innovative uses include mirroring and interacting with physical and virtual 3D models (cf. papers 31, 46), using a physical interface metaphor to manipulate virtual objects (cf. paper 38), and to synthesize physical game and game objects with virtual content. For example:

> "used markers to control characters in the game (...) used markers in a game board to perform interactions (cf. paper 30)

> "AR offers the opportunity to participate in games using real-world learning objects (e.g., maps, books, and tools) (cf. paper 6)

6.7 Theme 7: Seeing the invisible

Some of the research studies cited in these surveys used immersive environments for 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. Seeing the invisible codes included the visualization of forces (cf. paper 8, 27, 38, 46), microscopic organisms or features (cf. paper 9, 47), object trajectories (cf. paper 5), 3D representations of difficult to access organs (cf. paper 38, 39), and historical replicas of long dead civilizations (cf. paper 45). For example:

> "overlay graphics on top of the physical props to visualize these forces [...] invisible to the human eye" (cf. paper 38)
>
> "represent physical and chemical phenomena in micro and macromolecular scale, through simulated 3D virtual representations" (cf. paper 38)
>
> "Clinical care is also interested in AR because it provides [professionals] with an internal view of [the target], without the need for invasive procedures" (cf. paper 39)
>
> "allowed visitors to see from a fixed position a restored version of [ancient city]" (cf. paper 45)

However, seeing the invisible also included visualizing abstract concepts, often through the insertion of notes as an overlay onto a view of the real world (cf. paper 9), but also as a way to address common misconceptions (cf. paper 1):

> "(...) offers the ability to bring to life invisible, abstract, and complex concepts (...) AR can augment the physical world by computer-generated perceptual information and integrate immersive sensations that are perceived as natural parts of the real-world environment" (cf. paper 6).

6.8 Theme 8: Changing human behaviors

Some of the research studies cited in these surveys used immersive environments for learning activities that were designed to alter individuals' physical or attitudinal patterns toward themselves, others, or in response to a specific stimulus. Codes grouped under this sub theme clustered around changing participants' physical actions, such as in paper 6, "shifting human mobility patterns (...) explore this media within educational contexts", in paper 15, "QR codes and GPS coordinates can be used to track and guide movement of the students." and to focus (cf. paper 6) as well as spread user's gaze uniformly: "[for] teachers [to] (...) more uniformly spread their gaze [to engage students] than teachers with normal perception" (cf. paper 37).

Codes also surrounded the concept of altering participant's attitudes and thoughts, such as in paper 8, "the use of immersive VR to improve a user's attitude toward a community, cultural movement or service", to cultivate reflection (cf. paper 16),
"help teachers deal with today's multicultural classrooms and cultivate their empathy and reflection skills", and to practice social responses:

> AR provides opportunities for the learner to use the language in a spontaneous and unplanned way (...) exposed to situations like these (...) to prepare them to use the target language in real life (cf. paper 24).

6.9 Theme 9: Emotional and cultural experiences

Some of the research studies cited in these surveys used immersive environments for 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. Simulated experiences cited included cultural diversity and movements (cf. paper 8, 16), reconstructing historical experiences (cf. paper 31) and experiences that involve exposure to unexpected situations: "AR provides opportunities for the learner to use the language in a spontaneous and unplanned way (...) exposed to situations like these (...) to prepare them to use the target language in real life" (cf. paper 24). Many experiences focused on simulations of dangerous situations or events (cf. papers 8, 13, 16, 42, 47). For example:

> "The ability to interact with virtual objects that would be deemed too dangerous in the real world" (cf. paper 8).
> "preparing (...) students for infrequent emergency situations" (cf. paper 13).
> "help teachers identify bullying issues and distinguish them from simple teasing between the students" (cf. paper 16).
> "used to prepare students (...) such as in the virtual training of safe street-crossing" (cf. paper 42).

Additionally, some uses of immersive technologies for learning focused on helping the user to experience emotions in a safe space, such as fear, addiction, and violence (cf. paper 8), empathy (cf. paper 16), and even to experience what it feels like to swap bodies with a member of the opposite sex: "VRE (..) for genders to swap bodies, so a woman could feel as being inside of the body of a man and vice versa" (cf. paper 16).

6.10 Theme 10: Interactive manipulation and exploration

Some of the research studies cited in these surveys used immersive environments for 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.
Codes associated with this overall theme include 3D interactions representation (cf. paper 3), assembly/disassembly of a product (cf. paper 8), kinaesthetic interactions, such as body movements (cf. paper 6), and learner-content interactions (cf. paper 2, 8) - for example, "Dynamic topographic data was digitally rendered onto a virtual 'sandbox,' showing different types of terrain within the virtual environment. Users were able to interact with the terrain. (cf. paper 8). There were multiple forms of interactions, such as touchscreen, accelerometer, global positioning system (GPS) sensors, solid state compasses (cf. paper 6). Interactions also occurred in context, such as an ecological system (cf. paper 47), and had a distinct purpose, such as to provoke the occurrence of a specific reaction or event (cf. paper 3) or, "[...] to sort through a collection (...) along with a timeline (cf. paper 41).

6.11 Theme 11: Engagement

Some of the research studies cited in these surveys used immersive environments for learning activities that support focused attention. These uses involved raising engagement (cf. paper 29), increasing motivation (cf. papers 40, 42), for example, "stimulating, visual appeal and content (...) [to] invigorate students by creating a divergence from front-taught lessons" (cf. paper 42). There was some focus also on the use of immersive environments to engage specific types of students (e.g. ADD, unmotivated, cf. paper 15) and for specific purposes, such as social engagement (cf. paper 2) and to increase enjoyment (cf. paper 29).

6.12 Theme 12: Perspective switching

Some of the research studies cited in these surveys used immersive environments for learning activities to experience different roles, perspectives, and viewpoints. This includes embodiment and spatial change. Viewpoint changes were summed up best by paper 42, "learner can move freely through the environment and view it from any position and model the full physical behavior of objects", and included navigation of geographic or organic materials that were normally microscopic (cf. paper 4, 9, 11), as well as viewing the world or universe from above (cf. paper 8, 17). This theme also included codes involving the experience of others' perspectives, such as groups of people that are stigmatized by society (cf. paper 16), other genders (cf. paper 16), characters in a game (cf. paper 30), and bullied students in a classroom (cf. paper 16).

6.13 Theme 13: Logistics

Some of the research studies cited in these surveys used immersive environments for learning activities that coordinate situations involving multiple types of resources or their scarcity (time, equipment, personnel, funding). Codes under this theme clustered under the concept of operating a remote tool or robot (cf. paper 2, 8. 28). For example, "students (...) operate real tools located on university grounds through a virtual environment (cf. paper 28). Other code clusters in this theme focused on using immersive technologies for learning to provide a substitute experience due to its lack of availability and access in the real world, including outdoor experiences (cf. paper 47), teacher field placements and training (cf. paper 4), and athlete training:

> an HMD is combined with the body tracking of the user, or at least hand or foot tracking, it could be utilized to train athletes or normal people to play sports or even just for exercising without having the need to go to an actual gym (cf. paper 16)

6.14 Theme 14: Emphasis

Some of the research studies cited in these surveys used immersive environments for learning activities to draw the attention of the participants by various means, which may or may not include extra information. Codes grouped under the theme emphasis involved supplementing the user with additional information and graphical overlays (cf. paper 8. 35).

6.15 Theme 15: Data collection

Some of the research studies cited in these surveys used immersive environments for learning activities that collect data from the users. This includes data that users actively harvest from their location and data about the users themselves. QR codes, GPS coordinates were gathered from immersive technologies for learning (e.g. smartphones) for the purpose of tracking and guiding student movements (cf. paper 15). Moreover, the data collected was used to create objective performance measures that provided real-time feedback to users (cf. paper 8).

6.16 Theme 16: Accessibility

Some of the research studies cited in these surveys used immersive environments for learning activities with the intent to improve accessibility of physical/other settings for people with disabilities. This survey cited research that discussed the use of immersive environments to increase accessibility for people with disabilities (cf. paper 47).

7 Discussion: themes per immersion dimension

To comprehend a panorama of the various use themes, we set to classify them according to the immersion dimensions of Nilsson et al. (see section 2.1). There is no established or recommended process to evaluate these dimensions, due to their novelty. Thus, we again followed the inter-rater vetting process [Vaismoradi et al. 2016], comparing and contrasting two researchers' classification to minimize bias. Two researchers independently considered how each theme focused on system immersion, narrative immersion, and challenge immersion and classified them using a 0 to 1 rating for each theme, at 0.25 intervals, based on the descriptions in Table 3, emerging from the 47 surveys studied, and on the definitions of the immersion dimensions in section 2.1. The two researchers then jointly discussed their classifications until consensus was reached. The resulting classifications are shown in Table 4, which represent their positioning on the Nilsson et al. conceptual space.

For example, the theme "Accessibility" represents accounts of use of immersive environments for learning activities with the intent to improve accessibility of physical/other settings for people with disabilities (see Table 3). The researchers' bilateral judgement from this description was that it was highly focused on systems immersion (rating 1), since technical approaches are at the core of accessibility research, but also significantly focused on narrative immersion (rating 0.75), since accessibility approaches are often about providing alternative descriptions. It was rated as having little or no focus on challenge immersion (rating 0) due to its inherent purpose of providing increased access to all people to the actual tasks and engagement aspects, rather than changing them. As another example, the theme "Emotional and cultural experiences" represents accounts of use of immersive environments for 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 (see Table 3). The researchers' bilateral judgment from this description was that it was not focused on technological aspects (rating 0), due to being about non-physical concepts, but highly focused on narrative immersion (rating 1), since narratives are the core element bringing alive those non-physical concepts, and somewhat related to challenge immersion (rating 0.25), given that there is mention of "responses" and "situations", implying some user agency.

Theme	System immersion	Narrative immersion	Challenge immersion
Accessibility	1	0.75	0
Augmented context	0.25	0.75	0.5
Changing human behavior	0	0.5	0.5
Collaboration	0	0.25	1
Complement/Combine contexts, media or items	0.75	0.25	0
Data collection	0.5	0	0.5
Emotional and cultural experiences	0	1	0.25
Emphasis	1	0.25	0
Engagement	0	0	1
Interactive manipulation and exploration	1	0	1
Logistics	1	0.75	0.75
Multimodal interaction	1	0	0
Perspective switching	1	1	0
Seeing the invisible	0.5	0.75	0
Simulate the physical world	1	0.5	0.5
Skill training	0	0.5	1

Table 4: Classification of use themes per immersion dimension

Figure 5 presents the themes in Nilsson et al.'s three-dimensional immersion conceptual space in a 3D scatterplot, where several clusters emerged. We started with a tentative visual clustering and calculated the central points of each cluster. Then we checked if any point was closer or equidistant to the central point of a different cluster, and if so, reassigned it and recalculated. This process was iterated until all points were closer to their cluster's central point than to the central point of any other cluster. Finally, we attributed human-meaningful labels to each resulting cluster.

- Cluster 1: High System, Low Challenge, Low Narrative
  "Complementing"
  (Combined prevalence: 14.8%)
    - Emphasis
    - Multimodal interaction
    - Complement/Combine contexts, media or items

- Cluster 2: High System, Mid-High Challenge, Mid-High Narrative
  "Simulating"
  (Combined prevalence: 17.9%)
    - Simulate the physical world
    - Logistics

- Cluster 3: High System, Mid-High Challenge, Low Narrative
  "Exploring"
  (Combined prevalence: 4.5%)
  - Data collection
  - Interactive manipulation and exploration

- Cluster 4: Low System, High Challenge, Mid-Low Narrative
  "Engaging"
  (Combined prevalence: 22.5%)
  - Skill training
  - Engagement
  - Collaboration

- Cluster 5: Low System, Mid Challenge, Mid-High Narrative
  "Experiencing"
  (Combined prevalence: 30.8%)
  - Augmented context
  - Emotional and cultural experiences
  - Changing human behavior

- Cluster 6: Mid-High System, Low challenge, High Narrative
  "Accessing"
  (Combined prevalence: 9.4%)
  - Perspective switching
  - Accessibility
  - Seeing the invisible
  -

The data clusters highlight the main research paths and trends on uses of immersive learning environments today. The least-explored clusters point to promising future research directions, where more empirical data has the potential to make a significant contribution. Even more pressing is the absolute lack of empirical data on areas which emerge as entirely void, using the Nilsson et al. conceptual framework (Figure 6). This lack of data may be due to actual lack of research or simply to lack of acknowledgement of current research in those areas by authors surveying immersive learning environments:

- Void 0: Low System, Low Narrative, and Low Challenge
  (i.e., almost non-immersive in all regards)

- Void 1: Mid-Low Narrative, the entire central span of System and the full span of Challenge immersion
  (i.e., immersion via challenges and some technology, rather than narrative

- Void 2: Low System, High Narrative, High Challenge
  (i.e., low-tech immersive environments)

- Void 3: High System, High Narrative, High Challenge
  (i.e., combining high-tech with strong interdisciplinary aspects)

Unsurprisingly, there is a void (Void 0) at the Low System, Low Narrative, and Low Challenge location, which can be interpreted as simply the consequence of the surveys having scoping out non-immersive systems. However, that void expands beyond this location, becoming the largest void (Void 1), by encompassing the combination of Mid-Low Narrative, and the entire central span System immersion and the full span of Challenge immersion. Only the theme Data Collection falls in this range, and at a mere 0.6% prevalence. This low representation among the themes may indicate a need to increase research on the use of immersive environments to collect data about users, as well as for users to collect data. It may also point out the need to develop other uses in this space or understand why they may not be desired. For instance, low system immersion environments, such as technology-rich Internet-of-Things environments would likely occupy this space, with varying degrees of narrative and challenge immersion. Similarly, another part of this void, high challenge immersion environments with medium systems immersion, points towards a lack of representation of environments such as interactive escape rooms, mixed reality arcades, and smart toys, smart board games or smart card games.

Another void (Void 2), with no themes at all, is at Low System, High Narrative, High Challenge. This was surprising, since it can be envisioned as the location of traditional gamebooks (e.g. the "Choose Your Own Adventure" series) or indeed traditional role-playing games. This void may point towards current research failing to consider learning uses of these older formats of immersive environments, and a promising future research direction. It may also point to a need to research immersive environments that emphasize generalizability of its uses in low-tech learning environments and strong social validity.

The final void (Void 3), at High System, High Narrative, High Challenge, is perhaps a consequence of the demanding nature of creating immersive learning environments that target the highest levels on all three dimensions combined. The closest theme, Logistics, deals with the coordination of situations involving multiple types of resources or their scarcity (time, equipment, personnel, funding), aiming to provide alternatives to physical world activities or feel present at the distance while operating remote laboratory equipment. This void thus may be pointing towards a technical shortcoming gap: the elusive absolute immersion in a virtual world or absolute ability to interact remotely with other people and equipment at a different location as if one was there.

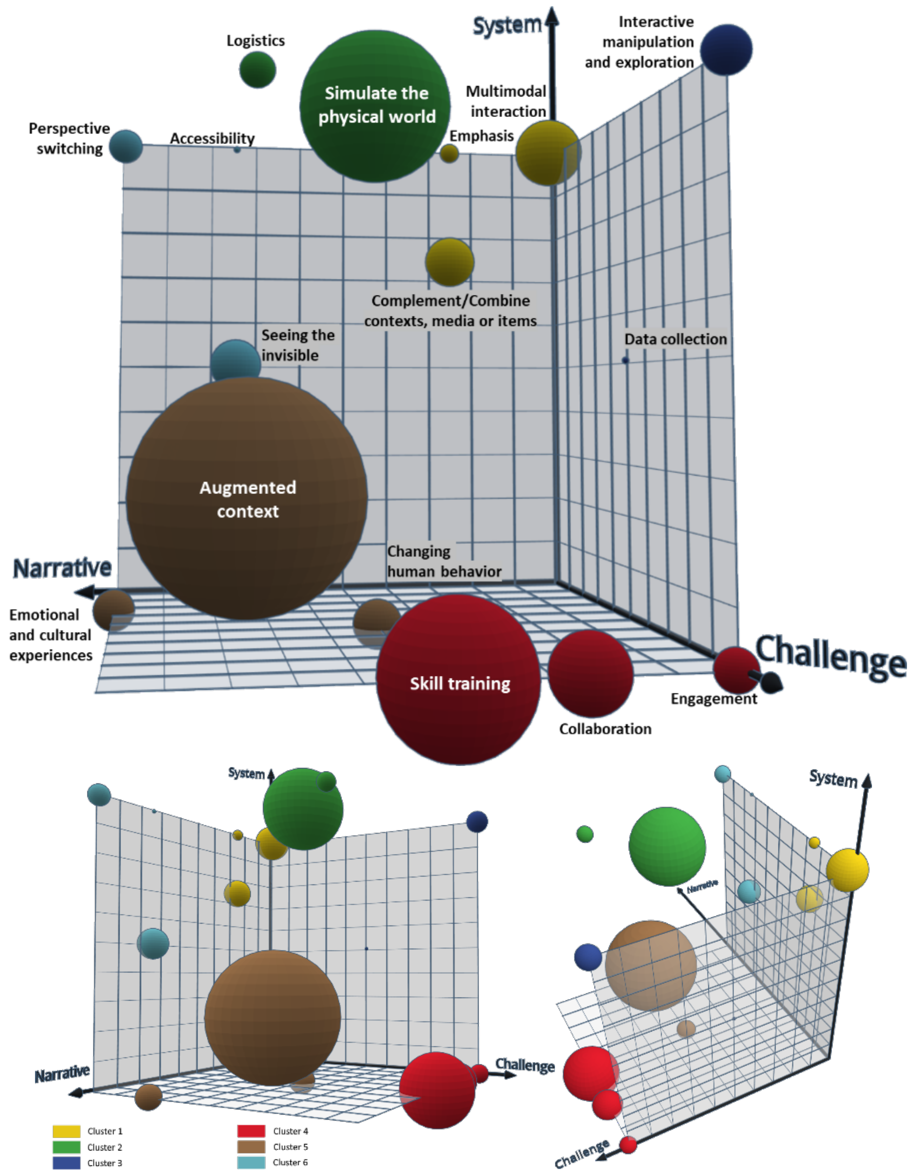

Figure 5: Dispersion of use themes per immersion dimension (top: labelled; bottom: alternative perspectives)

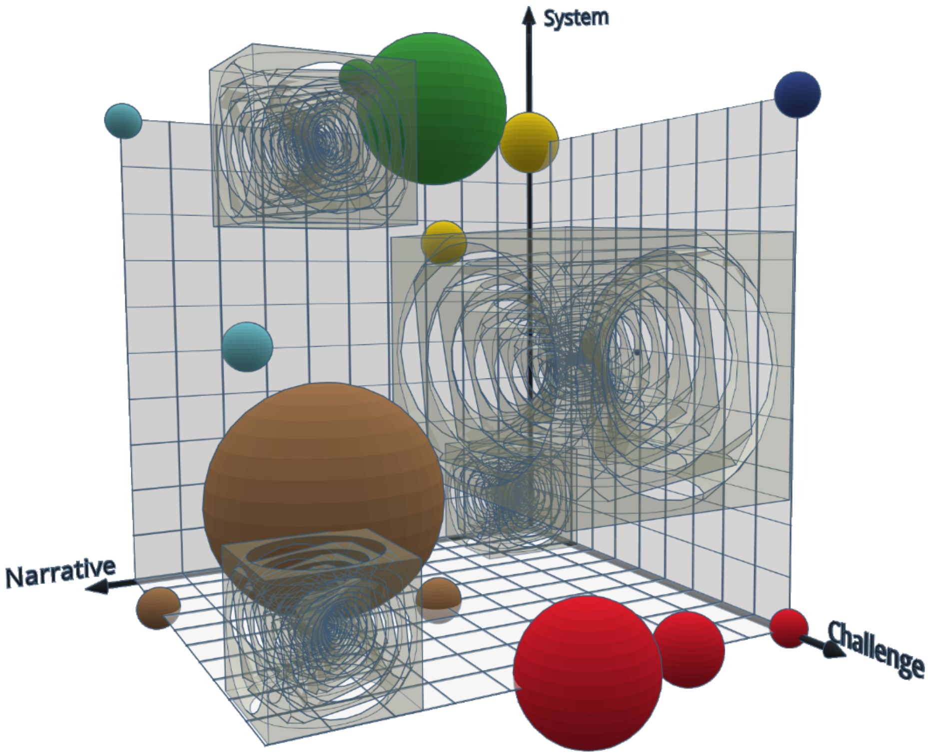

Figure 6: Voids denoting lack of research-provided accounts of uses of immersive learning environments.

The clusters, i.e., the non-gaps, are also informative regarding their relative prevalence. While Clusters 1, 2 and 4 have similar prevalence, and Cluster 5 somewhat higher prevalence, clusters 3 and 6 have minimal prevalence, pointing towards areas most in need of research to highlight, describe, and analyse these kinds of uses. Cluster 3, High System, Mid-High Challenge, Low Narrative, comprises Data collection & Interactive manipulation and exploration. Cluster 6, Mid System, Low challenge, Mid-High Narrative, has the single theme Seeing the Invisible. These are areas which have some accounts of use but much need for research.

8 Conclusions

We sought to inform future research efforts on immersive learning environments by surveying out how current research is grounded in actual empirical facts about their use, rather than collecting stated outcomes or prospective reflections. The resulting panorama revealed relevant gaps in the empirical grounding of current knowledge, thus contributing to the establishment of future goals for the research community. We have also used visuals to convey the disparity between the prevalence of different accounts of use and the voids in their coverage.

The gaps were identified by analysing accounts of actual uses of immersive learning environments in the various surveys conducted in the field. There have been dozens of surveys in the last few years, as shown in the previous sections, and our rationale is that this creates a corpus of knowledge likely suitable to ascertain an overall panorama. The survey selection process identified relevant surveys and accounts of use, which were then subjected to citation analysis, thematic analysis, and finally scrutinized to identify gaps and draw future research recommendations.

The resulting voids point towards the need for more immersive learning environments research on physical spaces with system immersion, such as Internet of Things, Interactive Escape Rooms, Mixed Reality Arcades, smart board games and similar (Void 1); the need for revisiting the use of traditional immersive environments like game books and traditional role-playing games (Void 2); the need to push for ambitious high-narrative, high-challenge, high-system environments, such as encompassing embodied participation in metaverses and highly-present remote operation of physical equipment (Void 3). The areas of low prevalence highlight the need for more research on leveraging data collection, both by users and from users, and on interactive exploration, both for the visible and the invisible.

9 Future Work

The research needs provided in the results and conclusions are only from a perspective of accounts of use of immersive learning environments. As stated in the introduction, research on immersive learning environments needs to tackle both the dimensions of evaluation research and design & development research: look into what works, how it works, and the contextual aspects, but also understand how to design and develop the experiences, including deployment, monitoring, assessment, outreach, etc. Thus, we plan to follow up this work with an analysis of other levels of accounts found in the literature: pedagogic practices and pedagogic strategies.

A survey of surveys only provides metalevel information and not the granular level data available in a scoping literature review or the even finer, quality-balanced results provided by a systematic literature review. As a result, a scoping literature review should be done to identify where the specific elements of current knowledge can be found, clarify concepts, confirm the relevance of inclusion criteria and dimensions, and focus on potential questions for subsequent systematic literature reviews, which can then yield even stronger evidence-based panoramas of current knowledge on immersive learning environments.

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