Educational Practices and Strategies With Immersive Learning Environments: Mapping of Reviews for Using the Metaverse

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***Abstract*—The educational metaverse promises fulfilling ambitions of immersive learning, leveraging technology-based presence alongside narrative and/or challenge-based deep mental absorption. Most reviews of immersive learning research were outcomes-focused, few considered the educational practices and strategies. These are necessary to provide theoretical and pedagogical frameworks to situate outcomes within a context where technology is in concert with educational approaches. We sought a broader perspective of the practices and strategies used in immersive learning environments, and conducted a mapping survey of reviews, identifying 47 studies. Extracted accounts of educational practices and strategies under thematic analysis yielded 45 strategies and 21 practices, visualized as a network clustered by conceptual proximity. Resulting clusters "Active context", "Collaboration", "Engagement and Scaffolding", "Presence", and "Real and virtual multimedia learning" expose the richness of practices and strategies within the field. The visualization maps the field, supporting decision-making when combining practices and strategies for using the metaverse in education, highlights which practices and strategies are supported by the literature, and the presence and absence of diversity within clusters.**

***Index Terms*—Educational practices, educational strategies, immersive environments, immersive learning, learning environments, metaverse, virtual and augmented reality.**

I. Introduction

DUE to the recent and ongoing COVID-19 pandemic, interest in the use of technology that enables education to overcome location restrictions is at an all-time high. Instructors at all levels of education (early childhood, secondary, tertiary, adult) and in all academic fields have been forced to adopt remote technologies in their teaching. Common instructional practices and strategies are also being modified and new ones added, as the introduction of new technologies or novel applications of current technologies can sometimes lead to new ways of accomplishing the same objective, or new objectives altogether. Due to these unique circumstances, researchers might have the expectation of an initial flurry of studies on teachers' perceptions of the technology implementation, followed by limited case studies considering impacts that conflict due to differing contexts. This of course should lead to a moment of clarity wherein researchers realize the need to move beyond whether technologies as a whole "work" in a current context, and to ask what technologies work, in what specific administrative and technological contexts, with what specific populations. This is a common progression of research within the field of educational technology, which often tends to focus on outcomes-based research while neglecting the important details of how something was accomplished. Nieveen et al. [40] describe this as a trend which focuses on testing claims of causality, while others refer to it as technocentrism [1]. This dangerous tendency to focus on outcomes also is often confounded by what is commonly referred to as the "novelty effect", or the tendency for student performance to improve due to an increased interest in new technology and not because of any inherent learning affordances in the technology [9]. The important thing to note here is that if learning gains are due to novelty effects, they tend to decrease over time as student interest in the technology wanes [19]. Therefore, educational technology research needs to avoid the pitfalls of novelty effect and technocentrism and focus on the actual practices and strategies used by instructors.

This admonition of course applies to all educational technology research subfields, including that dealing with the educational metaverse, the most recent form of immersive learning environments [57]. Mystakadis [57] defined it as, "…an interconnected web of social, networked immersive environments in persistent multiuser platforms."

Research on immersive learning is the study of how learning occurs when a student is experiencing a technological, narrative, and challenge-based state of deep mental involvement that dims their awareness of the physical world [2], [41]. An extensive look at the current literature reviews in the field of immersive learning confirmed these more general facts: 1) There is a plethora of literature reviews that focus on the learning impacts of immersive learning technologies and environments, and 2) Very few literature reviews focus on the educational practices and strategies used in immersive learning environments [7]. Thus, the problem is that we are evaluating outcomes without a comparable way to

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describe the educational approaches that led to those outcomes. We are faced with an absence of synthesis of the educational practices and strategies used in immersive learning environments (e.g., [58]). Such a synthesis would consider important pedagogical details on the actual practices and strategies, the physical settings, and the broader contexts (organizational, normative, social, etc.) involved in immersive learning. However, there is a lack of studies providing a panorama of those details, with most cases being limited in time or scope, outside everyday instructional use, or not aligned to curricular goals [44].

Currently, there are only two, short literature surveys combining the metaverse and education [56], [58], which clearly identify this situation: mostly papers discuss opportunities and challenges or compare outcomes, rather than expose details on educational practices or strategies.

Thus, we focused on providing a pedagogic framework for the educational metaverse by expanding its ecological context, by identifying accounts of actual practices and strategies used in immersive learning environments in the various surveys conducted in the field. We identified many literature surveys that, although they did not focus on practices and strategies, at least mentioned accounts of them, which provided us with a diverse representation of the practices and strategies used in immersive learning environments. Following a rigorous survey selection process, we analyzed the resulting corpus through citation analysis [7], and thematic analysis.

We also considered Eacott's advice [17] as we sought to establish clear connections between the educational practices and strategies that we found in the survey accounts:

"There is a well-established school of thought arguing that there exists a considerable gap between espoused theory and practice. Redefining "strategy" and "strategic" in the educational context at the key features level by drawing on scholarly inquiry in the field and practitioner perspectives provides the opportunity to establish the construct within the field and set the parameters of inquiry." [17]

Thus, to acquire a better perspective on the outcoming result, we created a networked visualization of the immersive learning educational practices and strategies, based on their conceptual straightforward connections, utilizing inter-rater vetting. Because practices can be developed either from strategies or emerged from grassroots implementations, this visualization of connections between the strategy and practice themes exposed areas of inquiry for better research in both. We concluded by presenting the limitations of this study and providing future research recommendations.

II. Background

A. Immersion

Immersion is a concept that has been described and researched in diverse academic fields spanning from computer science to educational technology, from narrative studies to psychology. The advent and increase in availability of immersive technologies such as virtual reality, augmented reality, and some gaming systems has led to an overfocus on definitions and descriptions of immersion from a technocentric perspective. Namely, as either an objective feature of a technical system and its affordances [49], [59], or as a psychological state differentiated by the perceptions, interactions, and experiences of the user of these technical systems [55], [60]. Unfortunately, these two approaches to understanding immersion neglect aspects such as absorption with narrative [1], [4], [61], or the story within the experience, or with challenges – one's engagement to solve a problem or situation [20], [62]. Fortunately, recent literature reviews on the concept of immersion have addressed both of these aspects while attempting to integrate them with the technical and psychological aspects into a more holistic model [2], [41]. Thus in this survey of surveys we utilized Agrawal et al. [2] definition of 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", complemented by the multidimensional taxonomy of immersion dimensions provided by Nilsson et al. [41]: immersion as a phenomenon emerging from a combination of the technological system, the narrative, and the challenges.

B. Immersive Learning Environments

Immersion was presented in the previous section as a phenomenon experienced by an individual. Immersive learning thus refers to the emergence of that phenomenon of immersion in association with the phenomenon of learning: experiencing immersion while learning, promoting it, or leveraging it, for instance. And an immersive learning environment refers to the surroundings where that association develops. It is the locale where immersion's dimensions of narrative, system, and challenge occur in association with learning. "Within the immersive environment, the technical system acts and its properties emerge, the narrative content reaches, and the challenges are met." [7].

This means that immersive learning environments should be understood regarding learning processes and content, but also wider contexts, such as institutional and social concerns, teaching practice, integration of digital technologies, and more [15]. Thus, an immersive learning environment can be based on novel technologies, or on older ones, such as theatre accessories or paper-based materials; it can be entirely based on human interaction or indeed be an emergence of personal introspection or even meditation. The aspects of interest in an immersive learning environment include the physical settings and technology, but also the context, such as culture, organizations, and logistics. An immersive learning environment also involves participants' characteristics and means of interaction, all of which comprise the system dimension of immersion; the story, the visual features of the location and its participants, and the ongoing history of interaction among them, all of which comprise the dimension of narrative; and the tasks, goals, awareness of change, and engagement, which all comprise the dimension of challenge.

This understanding of immersive learning environments exposes the diversity of its aspects of concern for educators and researchers. A clear perspective on the actual pedagogic dynamics taking place when dealing with these environments is necessary to move beyond just considering whether they "work" in a context, to asking more detailed and informative research questions. For instance, what specific administrative, technological, and pedagogical aspects influence each other and in what ways, under which conditions, and in which contexts? It is important to look beyond mere statements of use and techno-centric reports of outcomes of such environments, towards more detailed descriptions and categorizations of the learning-relevant characteristics of such use. An informed description and specification of the educational strategies and practices that occur will help us to identify and analyze their potential outcomes, leading to research-based recommendations and knowledge. We thus put forward the need to identify the educational practices and strategies employed with immersive learning environments.

C. Educational Strategies and Practices

Strategy is generally understood as a plan or the multitude of ways in which plans are devised and employed. It stems from the military tradition, where it's been historically presented holistically as "the great work of the organization" [51]; and also as the pragmatic perspective, "the use of the engagement to attain the object of the war" [14]. These perspectives all consider strategy from a multiplicity of dimensions, depending on the authors (e.g., Sun Tzu uses Tao, Nature, Situation, Leadership, and Art). Such multidimensionality is also found in non-military fields, foremost Management Studies, which consider strategies as a combination of plan, ploy, pattern, position, and perspective [39], [63]. In Education, there has been a similarly fluid understanding of the concept of "strategy", without a consensus on the definition. This fluidness reveals itself through a diversity of perspectives about its dimensions and scope [17], [63], from holistic viewpoints that echo Sun Tzu's "great Work" perspective, like overarching goals and philosophy, to more pragmatic patterns like Clausewitz's, guiding decisions and practice towards goals. In this work, we have employed this broad understanding of educational strategies when analyzing our survey corpus, considering each potential element as representing a strategy regardless of whether they were holistic viewpoints or pragmatic patterns.

Holistic viewpoints of strategy can assume a variety of forms impacting practices. These include consideration for definitional issues, context-specific concerns, or theories [17], [63]. Definitional issues can be broad, overarching ideals (e.g., learning transfer), or scoping criteria, delimiting educational action (e.g., serious play), both of which are reflected under the category "encompassing concerns" in our outcomes. Context-specific concerns coalesce strategy around specific concepts of study (e.g., teacher professional development), which we reflect as the categories "technical context" and "educational context" in our outcomes. Theories also have a holistic strategic impact by driving learning design and pedagogical actions, e.g., influencing the choice of learning outcomes, the design of learning activities, the preparation of teaching actions, the configuration of the environment, and the assessment methods and criteria [10], [64], [36]. In this work, we employed this understanding of theories as holistic strategies when analyzing our survey corpus, considering whether or not to code an instance of theoretical aspects (we reflect this as the category "theory" in our outcomes).

Regarding strategies as pragmatic patterns, we sought to find accounts of pedagogical models or frameworks, as structured ways of interpreting and applying a combination of various theories toward goals of learning and instruction: They combine instructional guidelines with context-specific situations [46]. Each model or framework has implicit assumptions about what is important [8], which involve the alignment of underlying pedagogical theories with the aims of learning and teaching processes to achieve intended learning outcomes. This alignment produces specific patterns which guide decisions and practice toward goals (we reflect this as the category "Model or framework" in our outcomes).

We have also sought to identify accounts of pragmatic patterns developed independently of models or frameworks, since the novelty of the field of immersive learning would lead one to expect most educational strategies to emerge inductively, rather than from structured models. This led us to consider independent aspects such as the learning and teaching processes, assessment, and learning design.

Regarding learning and teaching processes, Merrill's first principles of instruction [38] categorized these emerging pragmatic patterns as instructional strategies consisting of combining modes of instructional interaction (e.g., tell, ask, show, and do) with specific academic subject area content, instructional sequencing, and learner guidance. The first principles of instruction state that learning is promoted when:

1) learners are engaged in solving real-world problems;
2) existing knowledge is activated as a foundation for new knowledge;
3) new knowledge is demonstrated to the learner;
4) new knowledge is applied by the learner; and
5) new knowledge is integrated into the learner's world.

However, Merril's perspective lacks contributions from research on learning via field-specific didactics, for which we considered the results of the Committee on How People Learn II: The Science and Practice of Learning (HPLII), created by the National Academies of Sciences, Engineering, and Medicine, with the goal of, "reviewing and synthesizing research that has emerged across the various disciplines that focus on the study of learning" [15]. The intent of this committee was to consider, "the research and research approaches with greatest potential to influence practice and policy" and "specify directions for strategic investments in research and development to promote the knowledge, training, and technologies that are needed to support learning in today's world". We thus reflected teaching-learning activities in light of Merrill's First Principles of Instruction and the work of the Committee on HPLII as "instructional strategies" in our outcomes.

Regarding assessment of teaching-learning activities, conclusion 7.5 of the aforementioned results of the Committee on How People Learn II: The Science and Practice of Learning affirm it as a critical tool in the context of learning in school, used for advancing students' learning and monitoring it. From learning models, assessment can identify the gap between current and desired students' learning and enable actions to narrow that gap. The committee presented research findings on assessment across two topics: providing feedback to learners and evidence-based assessment. Feedback, to be effective, requires balancing features such as learning targets (addressing the way learning activities developed), style (supporting the learner's progress), timing (delivered when there is the opportunity for the learner to benefit from it), and subject (the recipient has adequate self-efficacy to respond). Evidence-based assessment is presented by the committee under two topics: learning progressions and evidence-centered design. The former as models of "successively more sophisticated ways of thinking about a topic," establishing goals for summative assessment or guidelines for formative assessment. The latter as a recommendation that evidence-collection for assessment is connected to learning objectives and tasks, by considering what will be accepted as evidence of knowledge acquisition/construction and how that evidence will be analyzed and interpreted. In this work, we reflected this understanding as the category "evaluation and assessment" in our outcomes.

Finally, learning design is a combination of teaching activities (including assessment) with learning activities, mutually influencing and developing within a complex network of context factors, such as learning outcomes (planned and actually achieved), personal goals, prior skills, organizational context, and even logistics [32], [65]. Laurillard [65] proposed an approach to the design for learning which includes aligning goals, activities, and assessment; Monitoring alternative conceptions; Scaffolding theory-generated practice; Fostering conceptual change; and Encouraging metacognition. Aligning goals, activities, and assessment involves the process of accessing the experiences of the learner and using them to create aligned teacher-student goals, authentic assessments, and deep conceptual understanding. Monitoring alternative conceptions is the process of understanding a learner's preconceptions, how they think about a concept, and internal relationships within a concept, through the use of formative assessment that helps a learner to "think aloud." Scaffolding theory-generated practice involves task simplification, feedback and modeling, and design exercises that are focused on helping students to author a representation of their knowledge to share with others. Fostering conceptual change focuses on the use of exemplars that aid students in the skill of comparison and contrast as well as in developing conceptual structures. Encouraging metacognition involves motivating learners to practice and model metacognitive strategies such as peer assessment, group discussion, and comparison/contrast. In this work, we reflected this understanding as the category "learning design" in our outcomes.

Educational practices focus on a localized implementation of educational activities. They are linked to the context where they are being implemented, which can mean accounting for different aspects such as learner demographics, teacher credentials, and overarching government accountability, or indeed classrooms [37], [66]. It can also mean considering the rationale for actual actions of educators and other stakeholders. Specifically, "practices are organized nexuses of actions. (…) More specifically, the doings and sayings that compose a given practice are linked through (1) practical understandings, (2) rules, (3) a teleoaffective structure, and (4) general understandings" [48].

Educational philosopher Wilfred Carr summed up educational practice as "… a species of 'doing action' governed by complex and sometimes competing ethical ends which may themselves be modified in the light of practical circumstances and particular conditions." [13], [p. 173].

Thus, whereas educational strategies range from the abovementioned holistic viewpoints (overarching goals and philosophies) to pragmatic patterns guiding decisions and practice towards goals, day-to-day educational practices often rely on a more localized rationale for learning activities, but with a rationale nonetheless, beyond the mere statement of occurrence of an activity [7]. That rationale can arise from educators' judging how an overarching goal or philosophy might be pursued, or on how pragmatic patterns can be operationalized. But conversely, the practice rationale can emerge from the ground up, from tradition and beliefs of educators, from individual actions and choices occurring in the field of daily actions, with an intertwined or even conflicting relationship with strategies.

III. Method

A. Goal, Concepts, and Research Questions

We followed Kitchenham et al. [2] evidence-based process for systematic reviews (the systematic review template, p. 305). Our study falls under what she refers to as a "Mapping Study" as it is a survey of secondary studies. Thus, we detail the background, search process, primary study selection process, study quality assessment process, data extraction process, data synthesis process, study limitations, reporting and schedule.

As put forward in the introduction section, the gap we addressed was an absence of synthesis of the educational practices and strategies used in immersive learning environments. Thus, our goal was to provide a descriptive framework for pedagogical interventions in the educational metaverse by identifying accounts of actual practices and strategies used in immersive learning environments in the various surveys conducted in the field.

"Accounts of Strategies" were inductively defined from the data as when the literature reported broader, encompassing concerns, contexts, or theories (holistic perspective on strategy), which either inform the practice or emerge from it (pragmatic perspective on strategy). "Accounts of Practices" were also inductively defined from the data, when the literature reported a more localized rationale for learning activities, but with a rationale nonetheless, beyond the mere statement of occurrence of an activity. In previous work we have extracted plain statements of occurrence of an activity, considering them "Accounts of Use" [7].

To achieve the stated goal, we defined the following research questions for this survey of surveys.

RQ1. What educational practices are reported in surveys of immersive learning environments?
RQ2. What educational strategies are reported in surveys of immersive learning environments?

RQ3. What are the underlying connections between those educational practices and strategies?

B. Search Process

To find accounts of practices and strategies, we considered that in surveys, accounts of strategies and practices are brief, with minimal details about their source papers. One question is whether those accounts fall within our scope of immersive learning environments or not? Thus, we considered the global scope of each survey as an indicator of whether its accounts could be associated with immersive learning environments. To do so, we limited our harvesting of surveys to those focusing on environments where the educational interventions unequivocally intended to elicit immersion through explicit use of this term. However, as that might constrain the range of educational accounts, we complemented our corpus search with technology-oriented terms where immersion was typically introduced: augmented reality, virtual reality, or mixed reality.

This approach excluded surveys on generic educational technology, on videogames in education, and similar generic combinations of technology with learning. The rationale for this exclusion was that reported accounts in such wider surveys would conflate strategies originating from learning environments that were not immersive with strategies employed in immersive learning environments. Our approach of considering only surveys on environments that employed immersive technology sought to improve data quality of the harvesting of accounts of strategies with immersive learning environments from current surveys in the area. This approach included surveys focusing on narrative and challenge-based immersion, but only if those aspects occurred in environments with a relevant presence of immersive technology. The limitation of this approach is potentially under-representation of strategies more commonly found in low-tech immersive learning environments with or in environments that elicit immersion dimensions with non-immersive technology.

To find surveys focusing on environments where the educational interventions unequivocally intended to elicit immersion, we searched titles by combining two sets of keywords (Fig. 1 shows the process).

Set 1: Keywords use to find surveys *survey*, *review*
Set 2: Keywords used to find immersive learning environments *"immersive learning"*, *immersive*, *environment*, *"virtual reality"*, *"learning"*, *"augmented"*, *"mixed reality"*, *education*

These sets of keywords were used in combination to achieve a diversified but focused range of outcomes. E.g., if we were to combine just "survey" with "education", or just "review" and "environment", the outcomes would be diversified but unfocused on the topic. To increase focus, in the first search we included two keywords from set 2 alongside a keyword from set 1, but we have not used the keyword "immersive learning" in the search strings, since its outcome would duplicate those harvested when searching for keywords "immersive" AND "learning". The search strings we used were:

(survey OR review) AND immersive AND environment
(survey OR review) AND immersive AND learning

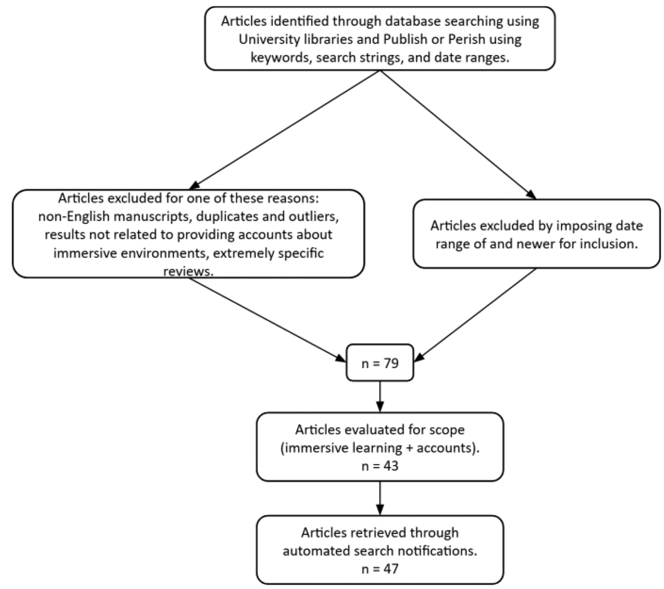

Fig. 1. Systematic search process.

(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 "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

These searches were conducted in the final months of 2019, with a date span of 20 years (2000 to 2020), to include potentially available preprints.

After this, we conducted a secondary search using the "immersive learning" keyword, combining it with keywords that would indicate a survey ("scoping" and "systematic"). The purpose was to include any possible papers that failed to match the first search due to lack of "survey" or "review" in the title. This secondary search, being complementary, was restricted to a shorter date span of 10 years (since 2009).

We performed the first and secondary search processes on paper titles using Google Scholar, via an automated search using Harzing's Publish or Perish application to get results into a spreadsheet format. Google Scholar was solely used due to its comprehensive coverage of academic publications [67]. PDFs of the papers were accessed through online public repositories and the library services of the researchers' home institutions.

C. Study Selection and Quality Assessment

The following step in the process (as shown in Fig. 1) involved identifying the inclusion and exclusion criteria as well as cleaning and quality control of the resulting corpus. We combined all search outcomes from the first and secondary search processes and removed all duplicate entries and non-English manuscripts (two members of the search team only spoke English). Titles were also individually examined to make sure that they were clearly related to immersive learning environments, and the resulting manuscripts removed. We also removed surveys that focused on an extremely focused topic, like training in an industry-specific technical skill. After this, we realized that a high percentage of results were more recent than 2013, so we omitted results before that year. This process resulted in n = 79 articles found.

The next step in the process shown in Fig. 1 was devoted to filtering out papers not matching: a) the scope of the definition of "immersive learning environment"; or b) the goal of identifying accounts of strategies or practices. We analyzed the paper abstracts and eliminated any articles with perspectives unrelated to education or learning. We hesitated when considering survey articles that focused on mobile augmented reality, which as a technology platform may be seen as non-immersive, but decided to keep these results because they may provide accounts of narrative or challenge-based immersive learning environments, as per the definition of this search (see Section I). That is, while mobile augmented reality's status as an immersive technology is debatable, it does not preclude its potentially immersive use in these other dimensions. We analyzed the entirety of the paper whenever an abstract did not suffice to determine inclusion in the corpus regarding being related to "immersive learning environments." This also enabled us to do quality control, leading to the elimination of papers with a variety of issues: mere listings of authors and papers, without further insights; some that were not actually literature reviews; papers without a body or published without peer-review; papers that were not written in English, even though they had been indexed with English-language title and abstract. We then analyzed the full text of the papers to complete the filtering according to the scope of "immersive learning environments" and according to the goal of identifying accounts of strategies and practices employed. This excluded reports of outcomes without details on the educational implementation of immersive learning environments and papers focused on potential future directions for education, not current ones.

This process yielded n = 43 articles. Additionally, our online activities during this search process resulted in automated recommendations from various web sites based on our browsing activity. We have followed these suggestions and similarly screened them for inclusion. This provided an additional four papers and a final corpus of n = 47.

D. Corpus

The corpus was analyzed both for the purpose of this work (accounts of practices and strategies with immersive learning environments) and in parallel for more mundane uses, which were published earlier, where it is listed [7]. In that earlier work, we also sought to comprehend the relationships and links between the surveys using a group/clustering analysis (Fig. 2). This involved inspecting each survey paper's reference section for evidence of who cited whom: 29 of the surveys were related through citation, and the other 18 did not cite another survey, nor were they cited by other surveys in the dataset.

Further, as shown in Fig. 2, we discovered that one particular survey was extremely influential: Bacca et al. [5]. It influenced almost all others, either directly or due to being the single survey within the corpus cross-referenced by Akçayır & Akçayır [3], which was the second most cross-referenced survey in the corpus. For the most part, other surveys updated these two and lacked awareness of each other. This singular influence of Bacca et al. [5] is potentially concerning, as it reveals possible bias toward one perspective over other, equally valid works. Alternatively, this could indicate that Bacca et al. is strong enough to be considered seminal work in the field.

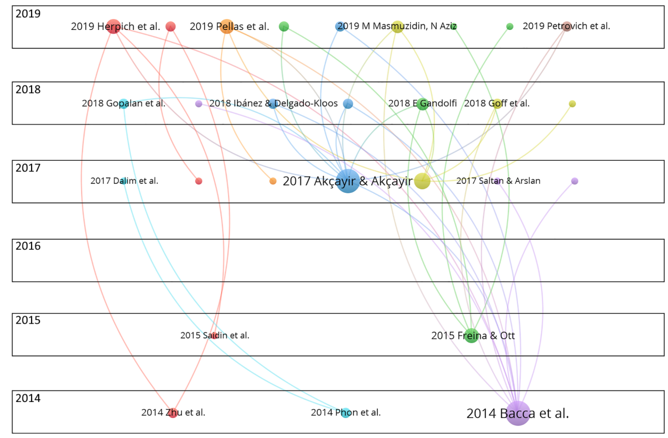

Fig. 2. Diagram of citation relationships within the corpus [7].

E. Data Extraction and Synthesis Procedures

We followed the process prescribed by Vaismoradi et al. [52], who recommended use of qualitative, thematic techniques to collect and analyze data to yield meaningful, credible, and practical results. We chose Vaismoradi et al. over other valid approaches to qualitative, thematic analysis for two reasons. First, it provided an analytical and detailed approach to theme construction and development. Second, it was cited by other scoping reviews in the related fields of computer science and education, which allows us to build on the past methods used [24], [31], and [47].

To find accounts of strategies and practices, we analyzed the full text of the 47 surveys in the corpus, extracting text excerpts with potential valid accounts. These excerpts were generalized as patterns, as a preliminary procedure in support of subsequent categorization. For example, the excerpt:

> (…) case management using role-plays conducted in Second Life. [27]

was generalized as:

> (…) case management using role-plays conducted in [virtual world]

The resulting set of excerpts was coded into a table, each associated with an ID of its source survey. This process resulted in 650 items with potential accounts of strategies or practices. We processed them to identify which would qualify as a practice or a strategy account, under our definitions presented in Section II-C: an account of practice "when the literature reported more localized rationale for learning activities, but with a rationale nonetheless, beyond the mere statement of occurrence of an activity", and an account of strategy "when the literature reported broader, encompassing concerns, contexts or theories (holistic perspective on strategy), which either inform the practice or emerge from it."

We first sought to ensure inter-rater vetting between the two researchers [52]. This involved confirming that each researcher acknowledged the aforementioned definitions of "account of practice" and "account of strategy". Next, after approving those definitions, we reached agreement on how each definition could be applied to a text excerpt. This application process involved our working individually to classify 100 text excerpts as either a "practice" or "strategy" or something else. Third, we met to discuss our methods and reached a consensus on our approach. Fourth, we categorized the rest of the text excerpts (n = 650). We realized as we performed this analysis that several text excerpts represented both an account of practice and an account of strategy. As a result, we split these entries into two, resulting in a total of 691 text excerpts. We asked a third researcher in immersive learning to examine all disagreements in categorization and to decide on how he would categorize the item, which happened in 139 of the 691 cases. He also provided the reasons for his categorization. If the third researcher chose one of the categorizations that one of us had made, that then became the categorization for that text excerpt. For the cases when that researcher disagreed with both of our categorizations, we met as a panel to discuss arguments and selected the resulting category per consensus.

The outcome was the classification of 342 excerpts as accounts of practice and 195 as accounts of strategy, with the rest deemed as reflecting more mundane reports (educational uses without a rationale). These two sets of data (practice accounts and strategy accounts) were subjected to thematic analysis [52]. We started theme development by coding each excerpt for concepts associated with educational practices and strategies, respectively. Examples of practice codes are "practice and assessment using real life objects and navigating real life places" and "role playing alongside other human operated avatars". Examples of strategies codes are "opening learning contexts to inaccessible or unfeasible situations"; "practice for mastery".

As part of the coding process, we consolidated duplicate labels and resolved any contradictory codes (e.g., codes which did not reflect the accounts they were coding). We also considered ambiguous codes, e.g., which albeit reflecting their coded accounts, might mislead us into a different interpretation of their meaning for subsequent analysis. One example of this is when we discovered that we were coding accounts of computational aspects, instead of accounts of learning aspects. This occurred for account ID 20, "the use "Abstract (…) shapes [instead of realistic shapes]". This was first coded by both researchers as "use abstract shapes", but upon discussion we realized it reflected a computational interface definition rather than an educational account. The pedagogical rationale in the cited paper was to avoid the problems of a detailed representation of a shape through the provision of an abstract shape that only had the relevant details, thus simplifying the procedure for the student. As a result, we corrected that code to "procedure simplification".

The next step in our analysis involved the creation of themes through the process of classifying, comparing, and labelling. We first examined codes for similarities and classified them under similar generalizations. Then we reflexively examined the original text excerpts and compared them with the codes, looking for cases where the scope of each code didn't reflect the original text, purging coded instances that didn't match the classifications, and connecting codes to form themes. We then brainstormed labels that best fit each of these emerging themes, which helped us to "think aloud" and externalize our thoughts about each theme. As a final part of this step, we clarified our themes by adhering to the different phases of immersion and distancing, substitution of proper terminology from the literature in place of some of the words that were inductively derived, and then finally settling into established definitions.

For the themes related to accounts of practice, we finished this part of our analysis with 111 codes that were allocated among 21 major themes. These were further grouped together by similar characteristics under categories of concern: Assessment, Deployment, Institutional, Learning Design, and Preparation (see Fig. 3).

For the themes related to accounts of strategy, we finished this part of our analysis with 345 codes that were allocated among 45 major themes. These were further grouped together by similar characteristics under categories of concern (eight in total): Educational Context, Encompassing Concern, Evaluation and Assessment, Instructional Strategy, Learning Design Strategy, Model or Framework, Technical Context, and Theory (see Fig. 4).

IV. Results

The results of our analysis are presented in the following tables. Table I presents the themes from the review of practices. Table II presents the themes from the review of strategies. Each theme is defined by providing a category, a title, and a description, alongside examples of its representation in the documents that were surveyed. This approach was taken to show the results of the coding and theming process that occurred during the thematic analysis phase.

V. Discussion

The results from the previous sections enable us to answer research questions RQ1 (Table I) and RQ2 (Table II). Regarding RQ3, we chose to interpret practices and strategies in light of their mutual connections, in order to cultivate an understanding of clusters of affinity. These clusters might then expose potential for synergies or opportunities for innovation. This method of interpretation exposed areas where there is potential to leverage currently published research to achieve closer ties between strategies and practices. It also revealed opportunities to guide future research inquiry.

The methodology we used to analyze the connections between practices and strategies was as follows: we created a matrix of practice themes and strategy themes, and two of the researchers discussed the relationship between each theme definition in practices and each theme definition in strategies, until consensus was reached on the existence of a straightforward relationship. We then asked the third researcher to act independently to

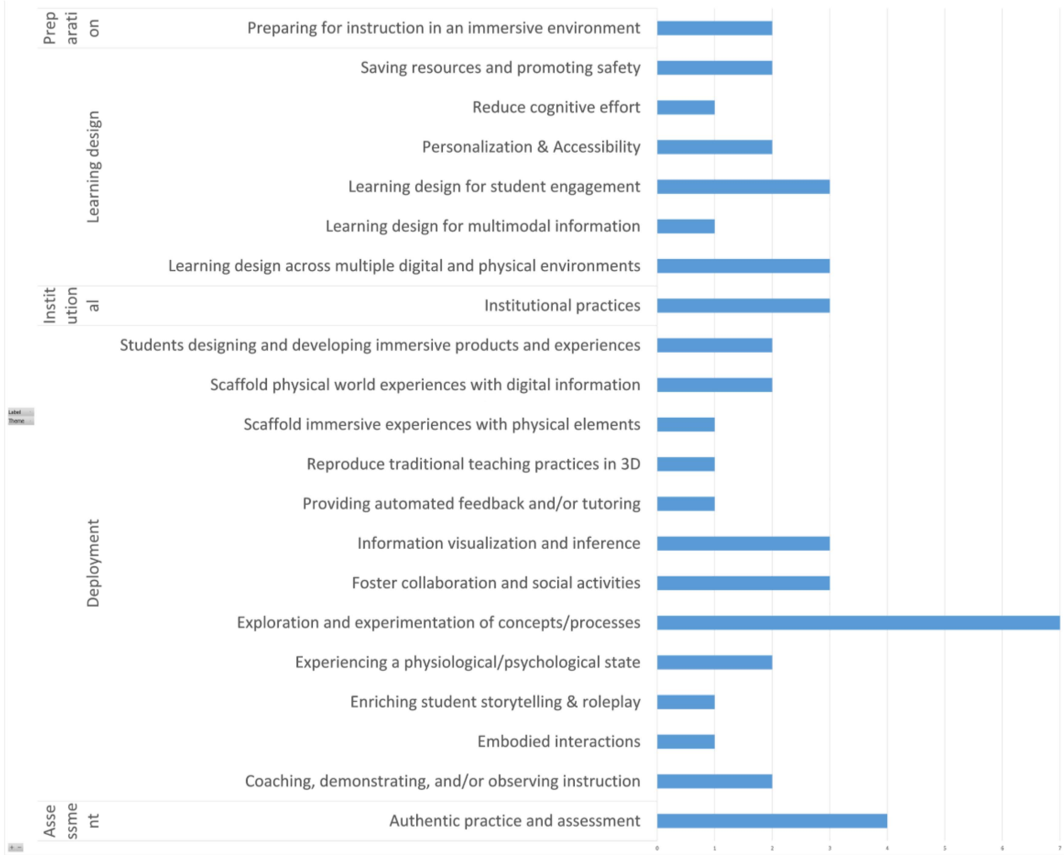

Fig. 3. Themes of practices from the mapping of reviews, relative prevalence.

perform this coding process, meeting afterwards for discussion of coding discrepancies until agreement. For example, the strategies' theme "Access unfeasible situations" was defined from the accounts of strategy as "(…) enabling situations which are inconvenient or impractical, due to resource constraints, ethical implementation issues, or hazardous situations." This had a straightforward relationship with the practice theme: "Exploration and experimentation of concepts/processes", because it "involved exploring, experimenting and interacting with the characters and features within immersive learning environments". As a counter-example we did not find any straightforward relationship between the instructional strategy theme "metacognition", which was defined from the accounts of strategy as having the "the goal of helping learners to develop awareness and control of their cognition" and the practice theme of "Coaching, demonstrating, and/or observing instruction" because awareness and control of one's own cognition does not have a clear relationship to "(…) coaching students either in person, at a distance, or by automated means." It should be noted that although we grouped the models and frameworks by themes in our coding of the strategy accounts, we did not utilize those themed groupings in our mapping of the connections between strategies and practices. While mapping these connections we realized that the discrete models or frameworks provided more interesting interpretations of the relationships between these models and frameworks and their corresponding practices.

The final matrix was then visualized as a network using VOSviewer software [53]. In this network visualization (Fig. 5), each circular node represents a practice or strategy theme extracted from the literature. We prefixed node labels with "P" for practice themes, and "S" for strategy themes. The relationships between themes are represented as links between their respective nodes.

The number of links associated with each node was used to define its visual size, hence helping identify themes with more connections. For instance, "Providing automated feedback and/or tutoring" is a practice theme and thus is prefixed "(P)"; it has 12 links to other themes and therefore its diameter is much larger than the strategy theme "Customization theories", which has only 3 links to other themes.

We analyzed the topology of this matrix of connections to identify clusters of connectivity, identified by different colors and described below. A cluster is a grouping of nodes (e.g., a grouping of strategies and practices) that are connected through the coding process described above. Hence, each strategy or practice theme is only assigned to one cluster. An argument can be made that some themes might be assigned simultaneously to more than one cluster, i.e., making non-exclusive grouping, but this also introduces major technical challenges [54] and is not supported by VOSviewer, thus we elected to assign each theme to one cluster only. The clustering technique employed by VOSviewer groups nodes by maximizing what is known as

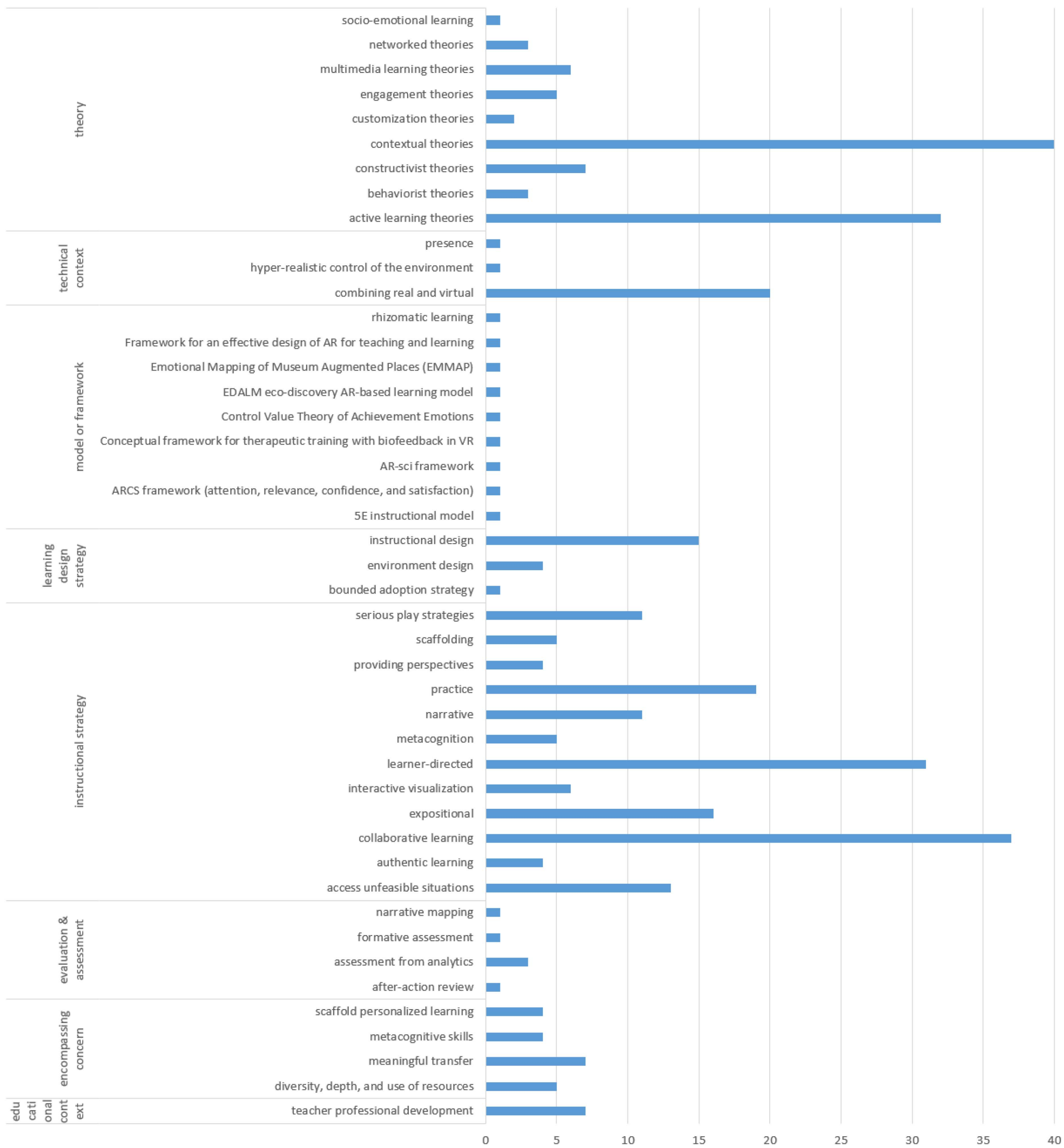

Fig. 4. Themes of strategies from the mapping of reviews, relative prevalence.

a Quality Function (1) [54]:

$$Q\ (x_1, \ldots, x_n) = \sum_{i=1}^{n} \sum_{j=1}^{n} \delta\,(x_i, x_j) \left(a_{ij} - \frac{\gamma}{2n}\right) \quad (1)$$

In this function, n is the number of themes and a_{ij} the relatedness of theme i with theme j (explained below). γ is a resolution parameter (explained further ahead), and x_i represents the cluster to which theme i is assigned. Function $\delta(x_i, x_j)$ is 1 when $x_i = x_j$ and 0 otherwise. The above parameter a_{ij} denoting the relatedness of a theme i with a theme j is provide by this formula (2):

$$a_{ij} = \frac{c_{ij}}{\sum_{k=1}^{n} c_{ik}} \quad (2)$$

In this formula, c_{ij} is 1 if there is a relationship between theme i and theme j and 0 otherwise. Consequently, the relatedness of themes i and j is inversely proportional to the total number of themes related to i. For instance, if theme i is connected to 4 other themes, including j, their relatedness is ¼, but if i is only connected to 2 other themes, including j, then their relatedness is greater, ½. That is, the number of relationships of a theme dilutes the relatedness of each individual one of those relationships.

The resolution parameter γ enables researchers to determine how fine-grained the clustering is. Lower resolutions lead to a smaller number of clusters (to the point of considering that all themes belong to the same cluster); higher resolutions lead to a larger number of clusters (to the point where each theme is alone in its own cluster). No value of γ is considered optimal [54]: researchers clustering the themes must "try out different values

TABLE I
THEMES AND CATEGORIES DERIVED FROM REVIEW OF PRACTICES

Category	Theme	Definition	Example
Assessment	Authentic practice and assessment	Practices which aimed to make connections between real-world problems, tasks, and outcomes, as well as assessments based on those practices	"to provide direct services through virtual reality or simulation technology (i.e., client interviews, case management skills, identification of discrimination and oppression)" (cf. Paper 14).
Deployment	Exploration and experimentation of concepts/processes	Practices which involved exploring, experimenting and interacting with the characters and features within immersive learning environments	"Engagement - HMD VR (Google Cardboard) (...) users experience stages of the water cycle from the perspective of a water droplet." (cf. Paper 8).
	Foster collaboration and social activities	Practices which involved fostering collaboration, teamwork, and social interactions	"community presence (sense of belonging)" (cf. Paper 42).
	Information visualization and inference	Practices which involved visual interpretation, analysis, and inference	"comparison of different designs at the same time:" (cf. Paper 18)
	Coaching, demonstrating, and/or observing instruction	Practices which involved coaching students either in person, at a distance, or by automated means	"tutors (...) to compensate for shortcomings of the simulation" (cf. Paper 3)
	Experiencing a physiological/psychological state	Practices which involved experiencing a specific physiological or psychological state within the immersive environment	"raise teacher's awareness and maximize their skills in identifying similar vision problems by placing them to the position of a visually impaired student" (cf. Paper 16)
	Scaffold physical world experiences with digital information	Combined inquiry-based educational practices involving the use of location and visual cues as triggers, with augmented reality applications which complemented physical world locations and features with digital information overlays	"used a camera to recognize printed markers in (...) a physical library that triggered the game's various learning missions" (cf. Paper 27)
	Students designing and developing immersive products and experiences	Practices involving students in the design and development of comprehensive immersive experiences or products	"students can create their own virtual realities and then ask for feedback" (cf. Paper 45)
	Embodied interactions	Practices involving interactions with the digital content via actions performed with the physical body of participants, including hand movements and walking around	"Students wave their hands in an AR motion-sensing environment set in a lab that uses Microsoft Kinect and magnets to trigger the virtual magnet model and the simulated magnetic field." (cf. Paper 27)
	Enriching student storytelling & roleplay	Practices involving immersion to enrich student activities in storytelling and character roleplaying	"a robot and a handheld projector for supporting students' storytelling activities" (cf. Paper 11)
	Providing automated feedback and/or tutoring	Practices where students were provided with automated feedback or automated tutoring	"It was also capable of providing quantitative feedback to users, based on their performance on specific tasks within the virtual world." (cf. Paper 8)
	Reproduce traditional teaching practices in 3D	Practice based on reproducing traditional teaching within an immersive environment	"delivering IVR [Immersive Virtual Reality] lectures" (cf. Paper 45)
	Scaffold immersive experiences with physical elements	Practices where students' immersive experiences are impacted or enriched by the status of physical elements	"the narrative structure of a board game, the physical floor materials, a student's first-person embodied experiences, the third-person live camera feed, and the augmented-reality symbols become integrated in an inquiry learning activity" (cf. Paper 22)
Institutional	Institutional practices	Practices at the institutional level, namely enabling teacher collaboration and best practices	"Enable collaboration between faculty members to share ideas for enhancing the [VR course] system" (cf. Paper 8)
Learning Design	Learning design across multiple digital and physical environments	Practices which combined traditional digital media with immersive media, with an emphasis on the merging of immersive and non-immersive systems	"real collaborative learning was introduced, the communication between the learners and their activities (...) [occurs via] interface and communication module to migrate objects and users between multiple virtual environments (and the real world)" (cf. Paper 23)
	Learning design for student engagement	Practices aimed at driving student engagement by means of various tactics, such as customization, gamification of assessment, eliminating distractions, or novelty effect	"utilized (...) digital badges to track student progress and achievement through an AR curriculum. " (cf. Paper 7)
	Personalization & Accessibility	Practices which customized the learning environment based on the learner's profile, including their prior knowledge of the subject area	"VR (...) to create lessons that change according to other needs held by the student (...) [e.g.] lessons provided by this software would change according to the personal requirements (in terms of exercises required) of the user" (cf. Paper 28)

(continues)

of γ and to choose the value that seems to give the most useful results" [54]. We explored the outcomes of various resolution levels to find clustering that minimized spatial entwining of nodes in the layout, and thus visually more interpretable, but not to the point of being trivial, ending with $\gamma = 1.02$.

The layout can be done by applying several algorithms, again with no optimal method to select among them, since they are meant to support visual interpretation and hence depend on their outcomes for different sets of clustered nodes. Typically, these algorithms use relatedness to define attraction or repulsion

TABLE I
(CONTINUED)

(continued)			
	Saving resources and promoting safety	Practices with an objective of reducing the mistakes which occur in real life skill practice opportunities through the use of immersive environments	"allow for damage to occur within the virtual world, allowing users to safely learn from mistakes that would normally cause real-world machinery to collapse or cause personal injury" (cf. Paper 8)
	Learning design for multimodal information	Practices focused on the development of information-diverse immersive experiences	"more information should be provided so that students could access a wide variety of information, selected from the same topic" (cf. Paper 24)
	Reduce cognitive effort	Practices intended to reduce the cognitive effort of the student	"AR may be used (...) to reduce students' cognitive effort to achieve understanding of a phenomenon" (cf. Paper 36)
Preparation	Preparing for instruction in an immersive environment	Practices related to preparation of instruction in immersive environments, by creating instructional content, such as as objects, environment, or characters	"improve the realistic nature of the simulation by extending authentic learning tasks inside a vertical screen" (cf. Paper 46)

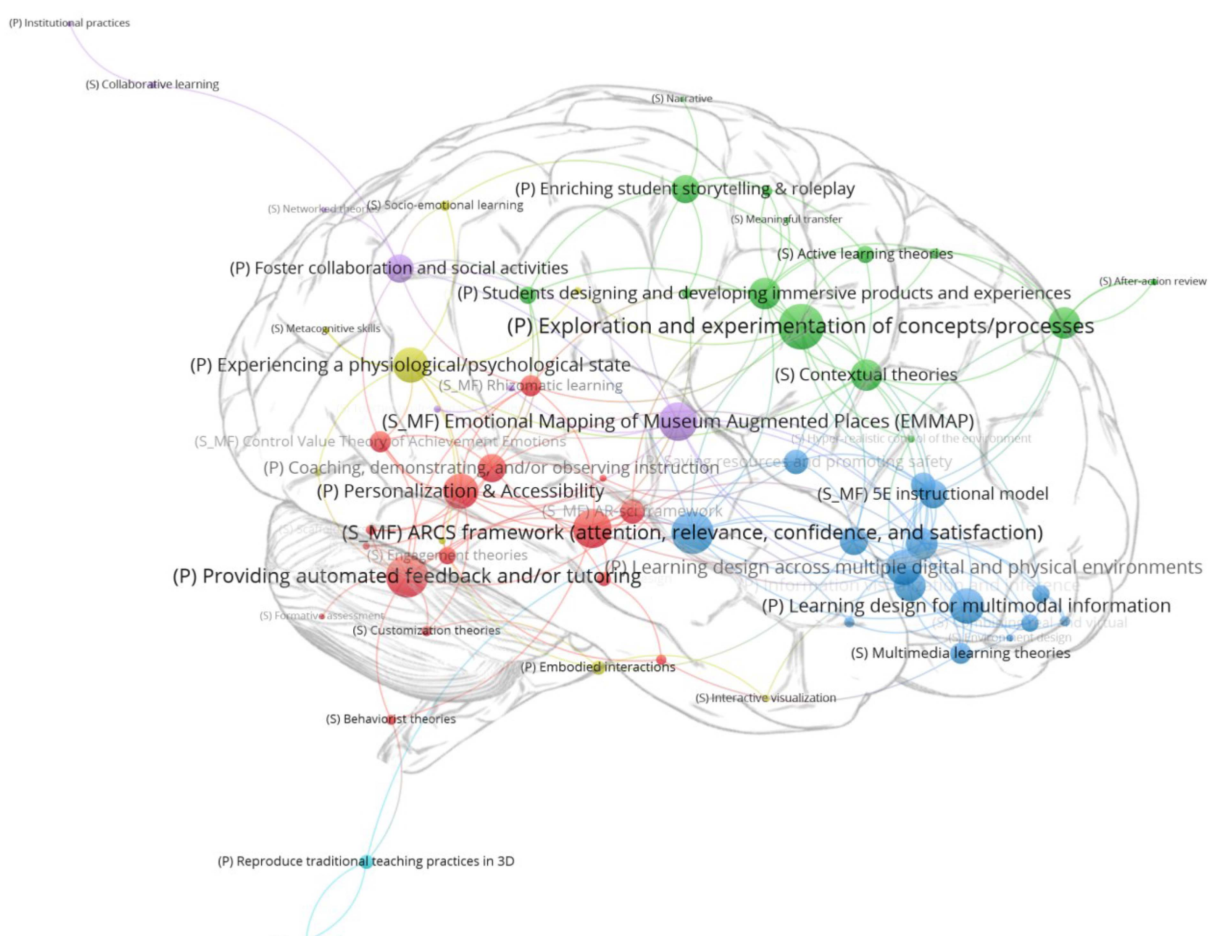

Fig. 5. The immersive learning brain network.

between nodes, and an overall energy calculation of those attractions and repulsions is minimized to find the optimal layout. Some of these algorithms highlight the most peripheral nodes vs. the most well-connected (central) ones, others minimize that peripheral distance to enable better view of the connections between central nodes (e.g., minimize the distance ratios). We selected one such later layout technique, LinLog Modularity, which enables interpreting distance between nodes (themes) and clusters according to: "the distance of two dense, sparsely connected clusters approximates their inverse node-normalized cut in layouts with minimal node-repulsion LinLog energy, and approximates their inverse edge-normalized cut in layouts with minimal edge repulsion LinLog energy" [42]. This layout enables us to interpret theme and cluster relatedness visually, without blending visually the most central themes to highlight the peripheral nature of the others.

TABLE II
THEMES AND CATEGORIES DERIVED FROM REVIEW OF STRATEGIES

Category	Theme	Definition	Example
Educational Context	Teacher professional development	Strategies focused on guiding the practice and implementation of specific pedagogical skills. and knowledge	"Immersive VR allows teachers to practice these skills in a controlled environment away from actual students." (cf. Paper 4)
Encompassing Concerns	Diversity, depth, and use of resources	Strategies whose holistic viewpoint was concerned with empowering students with diverse and in-depth resources	"VR technology could expose [learners] (...) to a larger variety of (...) environments and experiences than what would be possible during a class lecture or practicum experience" (cf. Paper 4)
	Meaningful transfer	Strategies whose holistic viewpoint was concerned with transfer of learning across domains by developing authentic learning experiences	"AR technology can also be combined with global positioning system (GPS)-enabled smart devices or quick response (QR) codes to create a unique, compelling and meaningful learning experiences" (cf. Paper 25)
	Metacognitive skills	Strategies whose holistic viewpoint was concerned with the development of metacognitive skills, such as creativity and time-management (i.e., self-regulation)	"Using VREs is an innovative approach that can promote creativity skills allowing users to develop their own VRE, which results in idea generation, while offering new educational opportunities" (cf. Paper 16)
	Scaffold personalized learning	Strategies whose holistic viewpoint was concerned with supporting individualized development, including parental involvement and personalized learning	"[Learning Approach] Groupwork/Parent-child interactive learning" (cf. Paper 25)
Instructional Strategies	Access unfeasible situations	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of enabling situations which are inconvenient or impractical, due to resource constraints, ethical implementation issues, or hazardous situations	"immersive VR being incorporated into post-secondary education and skill training (...) overcoming problems concerning time and space (...)" (cf. Paper 8)
	Authentic learning	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of situating "learning tasks in the context of future use (...) to develop robust knowledge that transfers to real-world practice." [25]	"structuring virtual learning according to psychological factors along with fidelity to real equipment" (cf. Paper 33)
	Collaborative learning	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of developing "joint intellectual effort" [33] involving students, teachers, or other participants	"storytelling as a first instruction, followed by observations in real-world environments (e.g., botanical garden, museum, in nature), either in single or group-based tasks to later share their findings with their colleagues in class and gain further experiences in a reflection and discussion session, to finally experiment with their own and other's findings." (cf. Paper 23)
	Expositional	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of providing traditional direct instruction or non-participant observation	"provide students with general ideas about a subject; then, these ideas are progressively differentiated in terms of details and specificity following a presentation instructional strategy" (cf. Paper 22)
	Interactive visualization	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of leveraging the immersive context for visualization of learning content, including embodied/vision-haptic interaction	"Contextual visualization: to display virtual content according to a specific context." (cf. Paper 30)
	Learner-directed	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of providing learners with "control regarding the specific issues they address and the ways they address those issues" [43, p. 300]	"Scientific discovery instructional strategy (...) AR application follows Bruner's (...) guidelines for providing effective instruction by allowing students to infer knowledge through their interaction with 3D digital objects representing [topic content], presenting relevant content in a structured way, and giving immediate feedback" (cf. Paper 22)
	Metacognition	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of helping learners to develop awareness and control of their cognition [21]	"[In their AR Design Framework for learning] Inside a learning sequence, elements of coaching, collaboration, and reflection should be included, as well as the application of multiple practices, learning skills, and technology." (cf. Paper 23)
	Narrative	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of communicating the cultural significance of knowledge and actions through narrative organization [12]	"design is that "this is not a game" (...), which allows the players to shift between the real world and the fictional realm by themselves." (cf. Paper 34)
	Practice	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of enabling "regular, skillful performance" [45] of physical motions, social interactions, or intellectual activities	"[students] can practice specific, planned skills to mastery in a fully controlled environment" (cf. Paper 4)

(continues)

TABLE II
(CONTINUED)

(continued)			
	Providing perspectives	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of experiencing alternatives, i.e., “permitting multiple perspectives” (cf. Paper 33)	“VR environments (...) provide (...) experts an ideal space to replicate situations similar to those that they face, providing them the opportunity to be trained as many times as necessary and experiment on the proper course of action but within a safe three-dimensional environment” (cf. Paper 16)
	Scaffolding	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of providing scaffolding to learners	“the design of effective teacher training (...) based on the following pillars: (a) how to help traditional teachers transform into virtual teachers through careful scaffolding by more experienced virtual teachers (...)” (cf. Paper 42)
	Serious play strategies	Strategies within a pragmatic pattern that guided instructional decision-making and practice towards the goal of leveraging playfulness by relating it to a learning purpose [26]	“Digital game-based learning using an educational AR system based on situated learning theory to enhance library instruction.” (cf. Paper 6)
Evaluation and Assessment	After-action review	An evaluation and assessment strategy, representing the pragmatic pattern of after-action review, the process of “reviewing practices applied to complete tasks, to reflect, learn and enhance these practices” [23]	“debriefings during and/or after a training session, where individuals reflect on the training, to foster transfer of such complex team tasks” (cf. Paper 33)
	Assessment from analytics	The pragmatic pattern of basing the evaluation and assessment strategy of immersive learning on the collection of analytics about the process or performance	“design elements like storytelling, accomplishing missions, or implementing variation using mini-games between learning steps used a database for game story and learning process data to analyze learner’s performance and their gaming skills.” (cf. Paper 23)
	Formative assessment	An evaluation and assessment strategy, representing the pragmatic pattern of providing students with informational feedback on their performance, learning process, and status, which they can use to reflect, and act, such as for self-regulation, or to plan or reorganize their processes	“debriefings during and/or after a training session, where individuals reflect on the training, to foster transfer of such complex team tasks” (cf. Paper 33)
	Narrative mapping	An evaluation and assessment strategy, representing the pragmatic pattern of narrative mapping, the process of “synthesizing and conceptualizing the rich variety of interactions that typically takes place within a lived space” [30]	“a podium surrounded by styrofoam painted to resemble a cave. A curvilinear projection screen, mounted to the underside of the podium, served as a window into a microworld. Interaction with the user, Narrative mapping with the aid of two virtual personas - Problem-solving learning tasks in natural science through narrative mapping” (cf. Paper 46)
Learning Design Strategies	Bounded adoption strategy	A singular account (cf. Paper 135) which reported on the “bounded adoption” strategy for the design of immersive learning experiences	“the most of limited human and financial resources should be put into the design of [the] experiment itself, especially the interaction process, which does not so heavily rely on hardware.” [50]
	Environment design	Accounts that guided the learning design practice by focusing on aspects of the immersive environment, such as rendering them visually stimulating or organizing them as combinations of transient spaces	“identify and use creative and visually stimulating (...) virtual spaces rather than sending students to virtual spaces that attempt to replicate the brick and mortar classroom” (cf. Paper 42)
	Instructional design	Accounts that guided the learning design practice by focusing on aspects of the instructional design	“examine a curriculum and then decide on the most effective rather than the most appealing method to use technology to improve his or her pedagogy” (cf. Paper 42)
Models or Frameworks	Situated learning frameworks	Combined two frameworks that guided decision-making and practice, using situated learning theories	Conceptual framework for therapeutic training with biofeedback in VR - this framework aims to support the development of virtual reality applications for therapeutic training purposes, employing low-cost solutions with biofeedback. Its concept is matching to therapy goals the virtual reality mechanisms used for simulating pain coping and therapeutic procedures [22]. Its account in the data simply reported its existence, classifying it as an educational use of virtual reality for the purpose of convenience: lowering costs and/or enabling portability (cf. Paper 8).
	Motivational frameworks	Combined two frameworks that guided decision-making and practice, using emotional and motivational theories	The ARCS framework (attention, relevance, confidence, and satisfaction) - this framework was developed for improvement of the motivational aspects of curricula. It is made up of conceptual categories that surround human motivation, a group of motivational implementation strategies, and a motivational systematic design process [29]. The account of its use focused on four of the conceptual motivational categories: attention, relevance, confidence, and satisfaction, and on how they are used by teachers and students when designing augmented reality in high school teaching/learning (cf. Paper 45).
(continues)			

TABLE II
(CONTINUED)

(continued)			
	Inquiry-based models and frameworks	Combined three models and frameworks that guided decision-making and practice, using inquiry-based learning strategies for science education	5E instructional model - this is a guided inquiry-based model, comprising a cycle with five phases: engagement, exploration, explanation, elaboration, and evaluation. It is an “hands-on, minds-on, inquiry-based scientific pedagogy (...) one of the widely-adopted pedagogies as an indoor activity in the natural-science teaching” [34]. The account of its use focused on educational approaches for the use of mobile augmented reality (cf. Paper 9).
	Social constructivism models	Combined two models that guided decision-making and practice, using social constructivist theories	The Emotional Mapping of Museum Augmented Places (EMMAP) model combines the use of AR technology, based on QR codes, with the co-construction of a map for each learner, with each location being “tagged” with items such as stories, myths, poetry, memories, natural environment geography, messages to be read in the future, etc. The account (cf. Paper 9) reports an aim to use it to develop innovative pedagogies.
Technical Contexts	Combining real and virtual	Strategies within a pragmatic pattern that guided instructional decision-making and practice by leveraging the technological affordance of being able to combine virtual elements with the real world	“require learners to solve complex problems by combining collected evidence from the real world and virtual information in real time” (cf. Paper 27)
	Hyper-realistic control of the environment	Strategy that guided instructional decision-making and practice by leveraging the technological affordance of being able to control more aspects than one would in the physical world	“support environments that allow for more control than what would be available in real life, especially when dealing with intangible concepts.” (cf. Paper 8)
	Presence	Strategy that guided instructional decision-making and practice by leveraging the technological affordance of being present in a technology-based environment	“AR/IVR in online and blended learning can support an immersive “liveness” (...) – i.e., a mediated experience that aims to highlight the “here and now” rather than stage post-produced content” (cf. Paper 45)
Theories	Active learning theories	Learning or educational theories related to active learning. This included active learning theory proper	“[virtual worlds] interactive and active teaching as learning activities can take place in dispersed and diversified virtual spaces, defined as transient spaces” (cf. Paper 42)
	Behaviorist theories	Learning or educational theories related to behaviorism, either by stating the control of stimuli to impact behavior or by specifying the behaviorism-related mastery learning theory [16]	“stimuli found in virtual environments [to] affect both a user’s cognitive and affective states, which in turn leads to behavioral changes (technology adoption behavior)” (cf. Paper 8)
	Constructivist theories	Learning or educational theories related to constructivism, either by stating it directly, or describing the underlying processes of assimilation and accommodation	“VR approaches can be used to support constructivist learning theory, offering users engaging learning activities allowing them to conquer knowledge on their own and connect it to their previous knowledge” (cf. Paper 16)
	Contextual theories	Learning or educational theories related to contextual approaches which focus on the relationship between content and its context [28]: experiential learning, situated learning, and simulation theory	“Jefferies (sic) Simulation Theory - The development process of simulations includes context, background and design characteristics, resulting in dynamic interactions between the facilitator and learner through the use of appropriate educational strategies.” (cf. Paper 8)
	Customization theories	Learning or educational theories that focused on personalizing, i.e. customizing the educational approach to the individual: learning styles theory and perceptual centering	“The theory of implementing a virtual event that makes the user feel central to the environment, resulting in an authentic illusion” (cf. Paper 8)
	Engagement theories	Learning or educational theories that were related to engagement as the driver of learning	“Flow Theory - A positive experience associated with immersive VR (...) induced by intrinsic motivation, well-defined goals, appropriate levels of challenge and feedback.” (cf. Paper 8)
	Multimedia learning theories	Cognitive theory of multimedia learning [35] either directly or by enunciating similar principles	“AR technique served as a valuable learning scaffold by enabling learners to visualize details, and to recognize and make sense of hidden information” (cf. Paper 11)
	Networked theories	Learning theories which focused on connections in a network of actors or its transformation	“application of mobile VR in education: (...) Connectivism— ‘Community Hub (e.g., Google Plus, Facebook, and Twitter).’ ” (cf. Paper 8)
	Socio-emotional learning	Related to social and emotional learning theory [18] through the application of similar principles	

This approach resulted in the following clusters, which we are calling the Immersive Learning Brain Network (Fig. 5) due to a coincidental spatial layout that resembles a human brain. We emphasized this poetical imagery by overlaying a brain illustration underneath the clustering. This is not meant to represent analogies to specific processes that occur in the brain.

Although we coded Models/Frameworks as Strategies, their position in the network revealed that they had a different purpose compared to other strategies. Models/Frameworks always served as nodes bridging between different clusters, whereas other categories of strategies would often be limited to connections within a cluster. This makes sense because as we explained above, models and frameworks interpret and apply

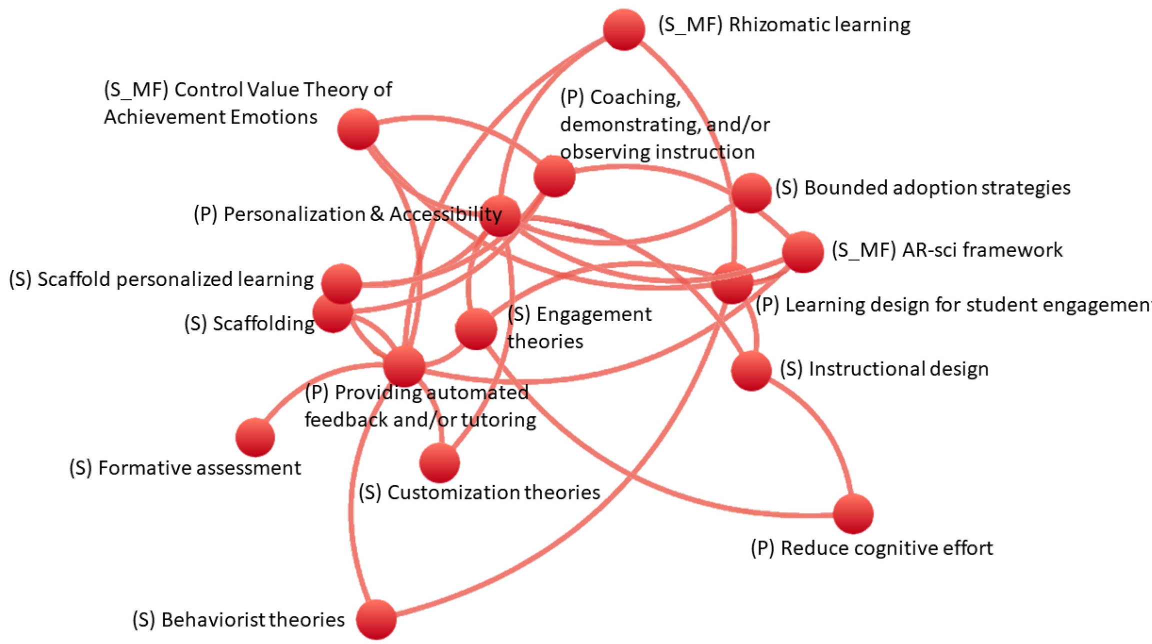

Fig. 6. Engagement and scaffolding cluster.

TABLE III
CODED PRACTICES AND STRATEGIES FOR CLUSTER 1

Practices	Strategies (Models/Frameworks)	Strategies (other categories)
Coaching, demonstrating, and/or observing instruction (8 connections) Learning design for student engagement (11 connections) Personalization & Accessibility (10 connections) Providing automated feedback and/or tutoring (12 connections) Reduce cognitive effort (3 connections)	AR-sci framework (7 connections) Control Value Theory of Achievement Emotions (6 connections) Rhizomatic learning (6 connections)	Behaviorist theories (3 connections) Bounded adoption strategies (2 connections) Customization theories (3 connections) Engagement theories (5 connections) Formative assessment (1 connection) Instructional design (4 connections) Scaffold personalized learning (3 connections) Scaffolding (2 connections)

a combination of various theories toward goals of learning and instruction, meaning that they must deal with the complexities and complications of actual implementation in actual learning environments. Thus, we prefixed them with (S_MF) in the diagram, instead of just (S), and in our cluster descriptions below, we are presenting models/frameworks as a separate column alongside other strategies.

Within the elements of the cluster shown in Fig. 6 and Table III, the most-connected and central nodes are four practices: Providing automated feedback and/or tutoring; Learning design for student engagement; Personalization & Accessibility; and Coaching, demonstrating, and/or observing instruction.

Therefore, we looked at how other nodes connected with these four practices. Three of those practices are connected by the strategy of Engagement theories: Providing automated feedback and/or tutoring, Personalization & Accessibility, Learning design for student engagement. This same strategy also connects the remaining practice in the cluster, Reduce cognitive effort. The other practice theme, Coaching, demonstrating, and/or observing instruction, is connected to two of the other high-connectivity practices by the "Scaffold personalized learning" strategy. We thus chose to label this cluster the "Engagement and Scaffolding" cluster.

Within the context of this cluster, this indicates that strategies based on engagement theories or scaffolding of personalized learning offer the most immediate opportunities to inform these immersive learning practices, based on the accounts identified in the literature surveys. It also indicates that there is research potential in connecting the remaining major practices' theme, Coaching, demonstrating, and/or observing instruction, with engagement strategies, and the practice of learning design for students' engagement with scaffolding of personalized learning. Further research potential lies in connecting these engagement and scaffolding practices with other strategies. For example, in this cluster the strategies' theme "Rhizomatic learning" is only connected to the practice theme "Coaching, demonstrating, and/or observing instruction", pointing to potential in connecting rhizomatic learning strategies with "Personalization and accessibility", "Learning design for student engagement", and other practices. Also, there is potential for connecting or distant strategies in other clusters with the main practice themes in this cluster.

Within the elements of the cluster shown in Fig. 7 and Table IV, the most-connected and central nodes are four practices: Exploration and experimentation of concepts/processes;

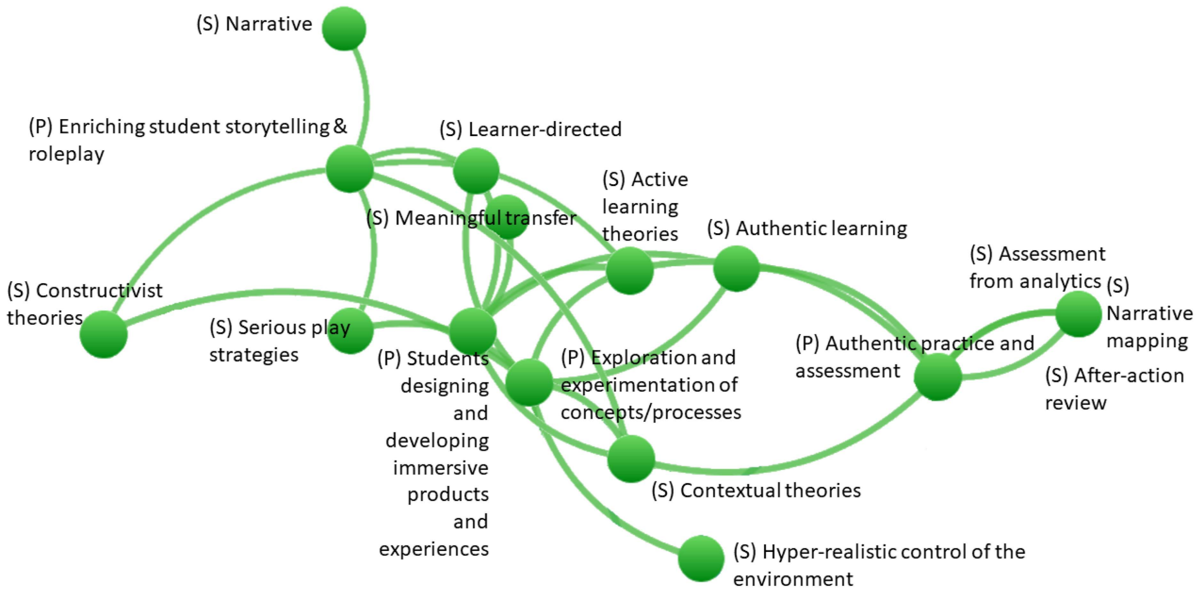

Fig. 7. Active context cluster.

TABLE IV
CODED PRACTICES AND STRATEGIES FOR CLUSTER 2

Practices	Strategies (Models/Frameworks)	Strategies (other categories)
Authentic practice and assessment (9 connections) Enriching student storytelling & roleplay (8 connections) Exploration and experimentation of concepts/processes (13 connections) Students designing and developing immersive products and experiences (9 connections)		Active learning theories (5 connections) After-action review (1 connection) Assessment from analytics (1 connection) Authentic learning (9 connections) Constructivist theories (5 connections) Contextual theories (9 connections) Hyper-realistic control of the environment (2 connections) Learner-directed (3 connections) Meaningful transfer (1 connection) Narrative (1 connection) Narrative mapping (1 connection) Serious play strategies (3 connections)

TABLE V
CODED PRACTICES AND STRATEGIES FOR CLUSTER 3

Practices	Strategies (Models/Frameworks)	Strategies (other categories)
Information visualization and inference (9 connections) Learning design across multiple digital and physical environments (10 connections) Learning design for multimodal information (10 connections) Saving resources and promoting safety (7 connections) Scaffold physical world experiences with digital information (9 connections) Scaffold immersive experiences with physical elements (5 connections)	5E instructional model (8 connections) ARCS framework (attention, relevance, confidence, and satisfaction) (12 connections) Conceptual framework for therapeutic training with biofeedback in VR (8 connections) EDALM eco-discovery AR-based learning model (7 connections) Framework for an effective design of AR for teaching and learning (3 connections)	Diversity, depth, and use of resources (3 connections) Combining real and virtual (5 connections) Environment design (2 connections) Multimedia learning theories (6 connections)

Authentic practice and assessment; Students designing and developing immersive products and experiences; and Enriching student storytelling & roleplay.

Therefore, we looked at how other nodes connected with these four practices. All those practices are connected by the strategies of Contextual theories and Active Learning theories. The practice themes, Enriching student storytelling & roleplay and Exploration and experimentation of concepts/processes are connected to by the "Constructivist theory" strategy. We thus chose to label this cluster the "Active Context" cluster.

Within the context of this cluster, this indicates that strategies based on contextual and active learning theories offer the most immediate opportunities to inform these immersive learning practices, based on the accounts identified in the literature surveys: they already connect to all practices in the cluster. Further research potential lies in connecting other strategies with these

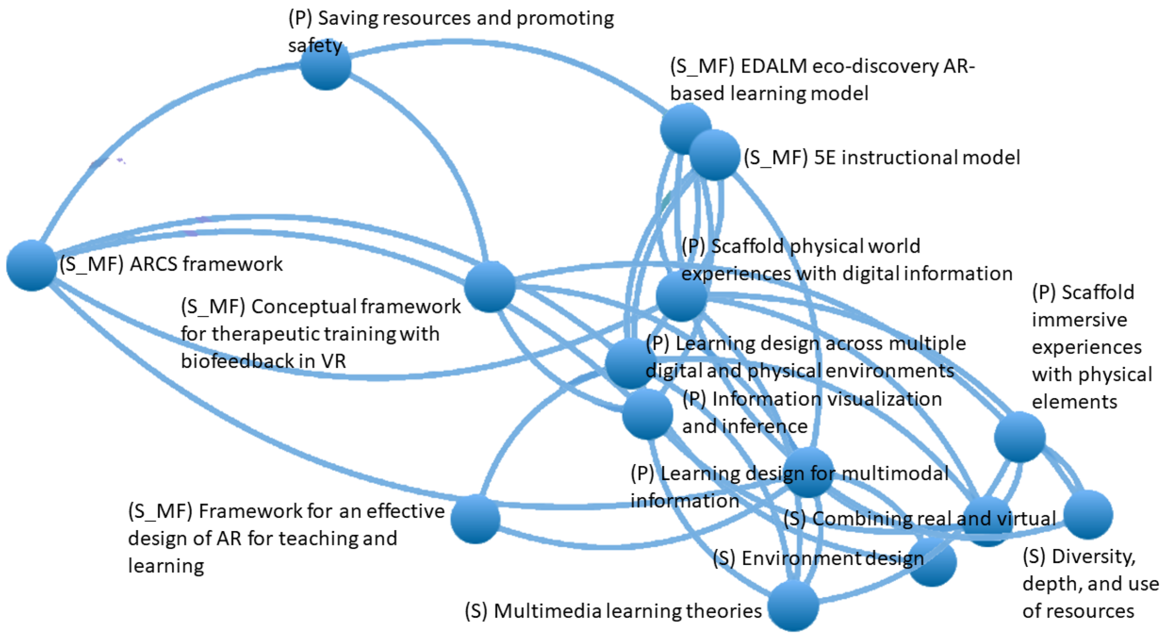

Fig. 8. Real and virtual multimedia learning cluster.

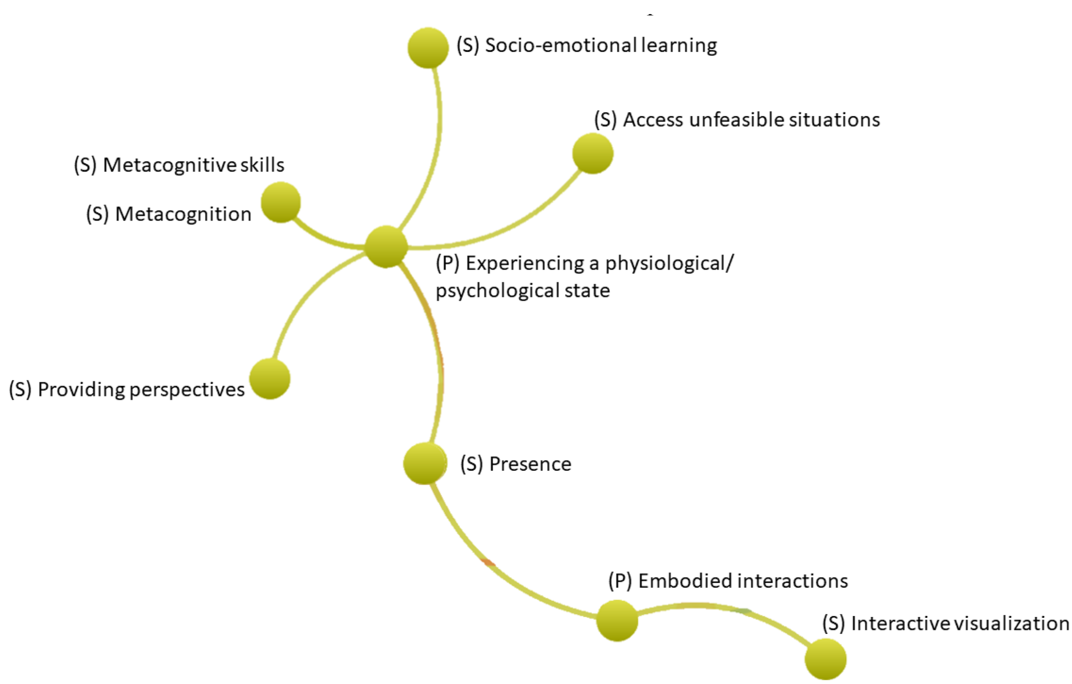

Fig. 9. Presence cluster.

major practices' themes. For example, in this cluster the strategy theme "serious play" is only connected to two practice themes "Exploration and experimentation of concepts/processes" and "Enriching student storytelling & roleplay", pointing to potential in connecting it to other practices. Also, there is potential for connecting distant strategies in other clusters (e.g., customization theories), with the main practice themes in this cluster.

Within the elements of the cluster shown in Fig. 8 and Table V, the most-connected and central nodes are four practices: Scaffold physical world experiences with digital information; Learning design across multiple digital and physical environments; Learning design for multimodal information; and Information visualization and inference. Therefore, we looked at how other nodes connected with these four practices. All those practices are connected by three models/frameworks: "ARCS framework

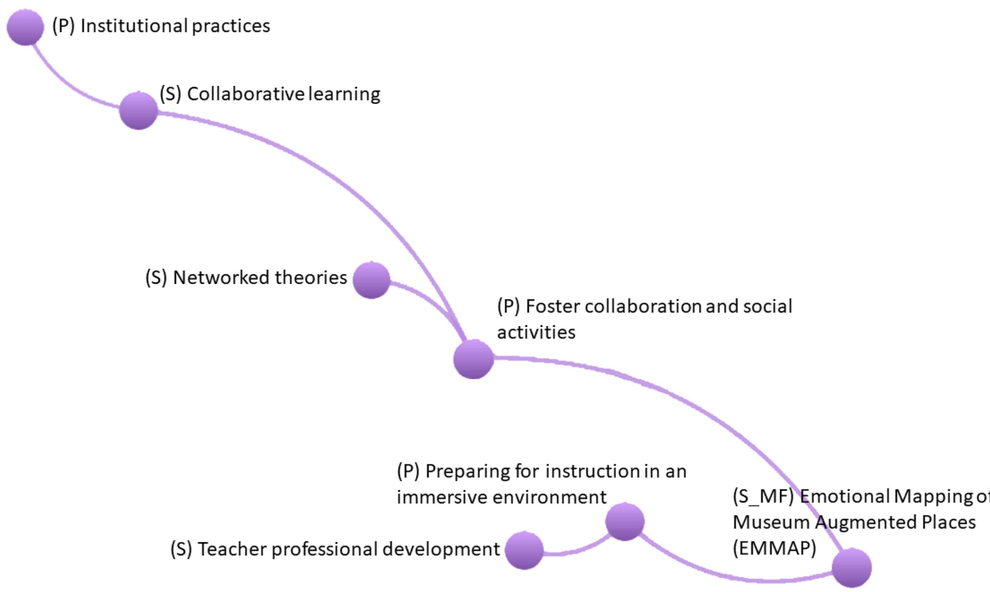

Fig. 10. Collaboration cluster.

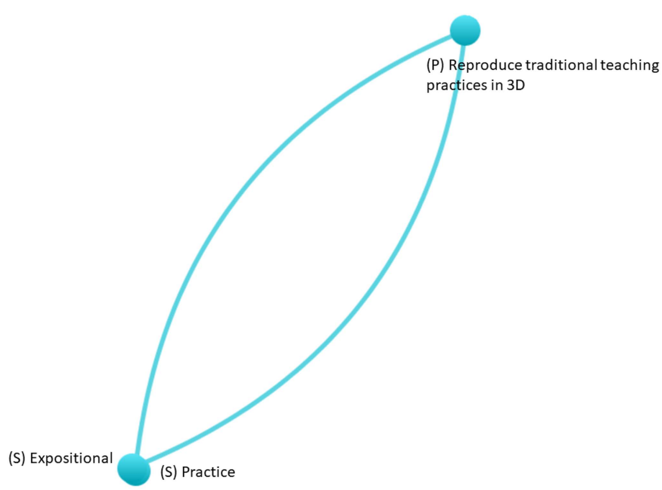

Fig. 11. Traditional practices cluster.

TABLE VI
CODED PRACTICES AND STRATEGIES FOR CLUSTER 4

Practices	Strategies (Models/Frameworks)	Strategies (other categories)
Embodied interactions (4 connections) Experiencing a physiological/psychol ogical state (10 connections)		Access unfeasible situations (2 connections) Interactive visualization (2 connections) Metacognition (1 connection) Metacognitive skills (1 connection) Presence (2 connections) Providing perspectives (2 connections) Socio-emotional learning (3 connections)

(attention, relevance, confidence, and satisfaction)", "EDALM eco-discovery AR-based learning model"; "5E instructional model". However, two strategies, "multimedia learning theories" and "combining real and virtual" connected not just these four practices but one more, "Scaffold immersive experiences with physical elements", meaning they connected all except one of the practices in this cluster. We thus chose to label this cluster the "Real and virtual multimedia learning" cluster.

Within the context of this cluster, these internal cluster connections indicate that strategies based on multimedia theories and the combination of real and virtual offer the most immediate opportunities to inform these immersive learning practices, based on the accounts identified in the literature surveys: they already connect to almost all practices in the cluster. Further research potential lies in connecting these strategies to the single remaining practice in the cluster, "Saving resources and promoting safety". Also, there is potential for connecting distant strategies in other clusters with the main practice themes in this cluster.

Within the elements of the cluster shown in Fig. 9 and Table VI, the most-connected node is a practice, "Experiencing a physiological/psychological state". This practice is connected to all nodes in the cluster except for three nodes sprouting from it: "Presence" and "Interactive visualization" strategies, and the "Embodied interactions" practice. The "Presence" strategy connects the main practice of "Experiencing a physiological/psychological state" and the sprout mentioned in the previous sentence. We thus chose to label this cluster the "Presence" cluster.

Within the context of this cluster, this indicates that strategies based on Presence offer the most immediate opportunities to inform these immersive learning practices, based on the accounts

TABLE VII
CODED PRACTICES AND STRATEGIES FOR CLUSTER 5

Practices	Strategies (Models/Frameworks)	Strategies (other categories)
Foster collaboration and social activities (8 connections) Institutional practices (1 connection) Preparing for instruction in an immersive environment (2 connections)	Emotional Mapping of Museum Augmented Places (EMMAP) (11 connections)	Collaborative learning (2 connections) Networked theories (1 connection) Teacher professional development (2 connections)

TABLE VIII
CODED PRACTICES AND STRATEGIES FOR CLUSTER 6

Practices	Strategies (Models/Frameworks)	Strategies (other categories)
Reproduce traditional teaching practices in 3D (4 connections)		Expositional (1 connection) Practice (1 connection)

identified in the literature surveys: they already connect to all practices in the cluster. Further research potential lies in connecting other strategies with these major practices' themes. For example, in this cluster the strategies' theme "interactive visualization" is only connected to the practice theme "Embodied interactions", pointing to potential in connecting it to the other practice. Also, there is potential for connecting distant strategies in other clusters with the main practice themes in this cluster.

This cluster explored in Fig. 10 and Table VII is almost entirely a string of practices and strategies with little connections among them. The most-connected central nodes are a practice, "Foster collaboration and social activities" and a model/framework, "Emotional Mapping of Museum Augmented Places (EMMAP)". These nodes are connected to each other and bridge the two ends of the cluster. Since EMMAP is a specific model/framework for use with augmented reality in a museum context, we deemed collaboration to be a more apt, generic descriptor. Thus, we chose to label this cluster the "Collaboration" cluster.

Within the context of this cluster, this indicates that collaboration practices and strategies, including networked theories, are based on accounts identified in the literature surveys that offer immediate opportunities to inform each other, but are poorly linked to other strategies and/or practices. Thus, research potential lies in connecting those other practices and strategies with collaboration. For example, in this cluster the strategies' theme "teacher professional development" is only connected to the practices theme "Preparing for instruction", pointing to potential in connecting it to "fostering collaboration and social activities" and "institutional practices". Also, there is potential for connecting distant strategies in other clusters with the main practice themes in this cluster.

This cluster shown in Fig. 11 and Table VIII is formed by two strategies coalescing around the "Reproduce traditional teaching practices in 3D" practice: Expositional, and Practice. We thus chose to label this cluster the "Traditional practices" cluster.

Within the context of this cluster, this indicates that practices based on reproducing traditional ones in 3D offer the most immediate opportunities to inform these immersive learning strategies, based on the accounts identified in the literature surveys: they already connect to all strategies in the cluster. Further research potential lies in connecting strategies in other clusters with this major practice theme or connecting these strategies to practices in other clusters.

VI. Global Outlook

We consolidated all connections between nodes in different clusters to get a global outlook of how clusters are related, shown in Fig. 12. In it, each node is one of the clusters listed above, and its size represents the number of internal nodes (practices and strategies). The width of the lines represents the number of connections between them. For example, the line between "Engagement and Scaffolding" (16 internal nodes) and "Real and virtual multimedia learning" (15 internal nodes) is quite thick because it represents 24 different connections. The same quality and relatedness functions were applied, and the same LinLog modularity layout algorithm.

This global outlook reveals a backbone of strong connections from "Engagement and Scaffolding", through "Real and virtual multimedia learning" and up to "Active context". Connections with the "Presence" and "Collaboration" clusters, or among these, are much weaker. Connections with the "Traditional practices" clusters are extremely weak and only between it and two other clusters (2 connections with each).

VII. Conclusion

As stated in the introduction, the gap we addressed was an absence of synthesis of the educational practices and strategies used in immersive learning environments, to which we have now contributed both a synthesis (Research questions 1 and 2) and a descriptive framework for pedagogical interventions in the educational metaverse (Research question 3). We based these results on an extensive analysis of 47 literature surveys that reviewed research on the educational practices and strategies used in immersive learning environments.

We discovered a wealth of accounts on educational practices and strategies with immersive learning environments, which we clustered around their straightforward connections from a conceptual perspective. This provides a map of the field, supporting decision-making for educational use of the metaverse or future research, including on the design of new systems for the educational metaverse. Instead of just being a list, the descriptive framework for pedagogical interventions has been organized by clusters of conceptual proximity and relatedness. This does not prevent practitioners and researchers from electing to combine practices and strategies from distinct clusters: our descriptive framework is meant to bring clarity to the results and provide guidance, not prescribe actions.

For example, an instructor attempting to teach their students how to solve scientific problems might seek out help from the

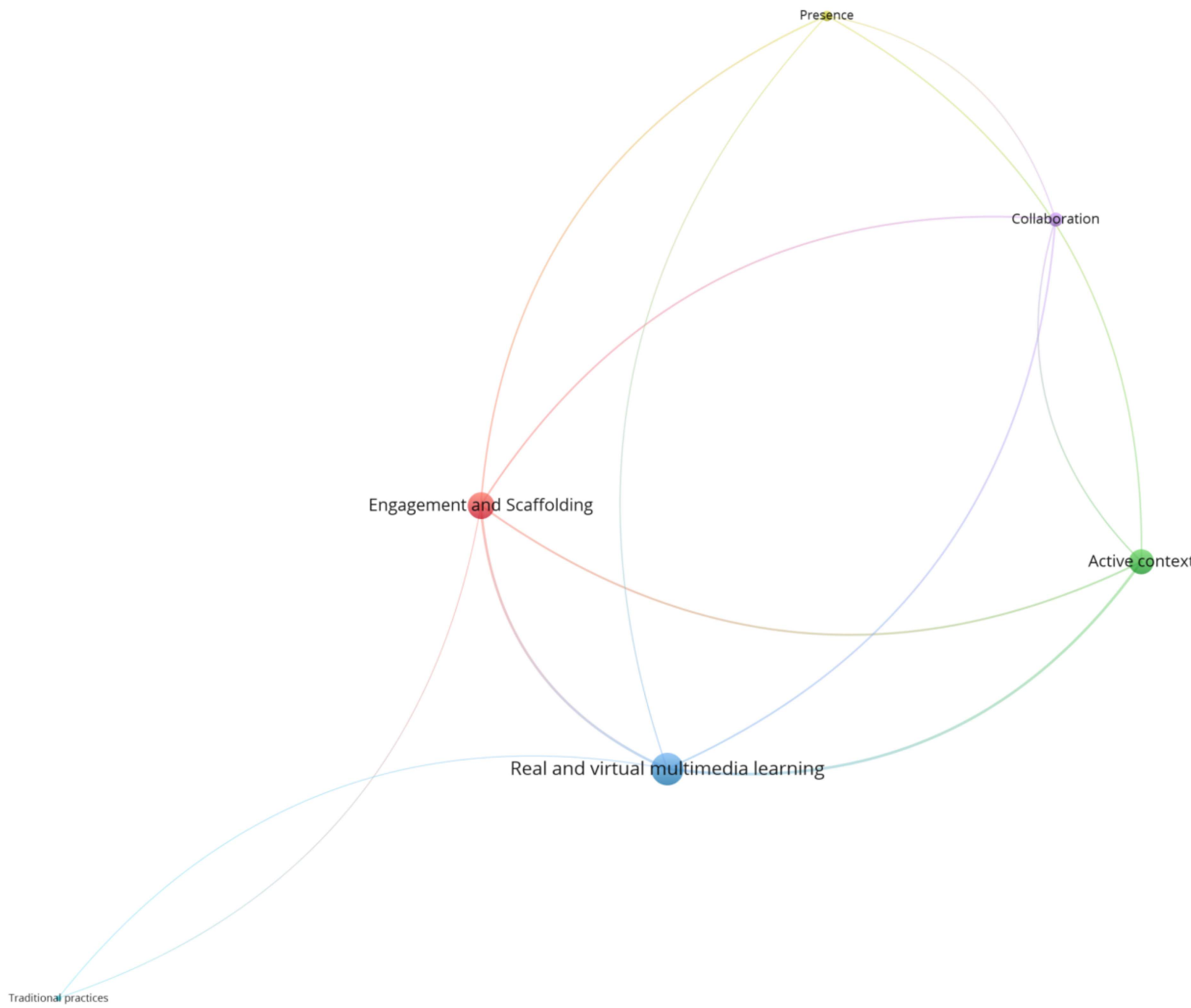

Fig. 12. Global outlook cluster.

"Real and virtual multimedia learning" cluster. In doing so, the professor could network among the most-connected and central practices: Scaffold physical world experiences with digital information; Learning design across multiple digital and physical environments; Learning design for multimodal information; and Information visualization and inference. While exploring each of these practices, one would see that all of them are connected by three models/frameworks: "ARCS framework (attention, relevance, confidence, and satisfaction)", "EDALM eco-discovery AR-based learning model"; "5E instructional model". Additionally, the instructor could consider the various strategies in the cluster ("Diversity, depth, and use of resources", "Combining real and virtual", "Environment design", "Multimedia learning theories") as further guidance. This cluster thus provides a tool for the educator - a map to help them explore when deciding on the combination of practices and strategies to use in their classroom.

A researcher interested in exploring the relationship between presence and learning activities may consider exploring the "Presence" cluster. In doing so one would find a close relationship between the practices "Experiencing a physiological/psychological state" and "Embodied interactions", which may spur one towards research exploring that relationship using strategies in the same cluster: "Access unfeasible situations", "Interactive visualization", "Metacognition", "Metacognitive skills", "Presence", "Providing perspectives", and "Socio-emotional learning". Additionally, the educational technology researcher may decide to explore less straightforward relationships, by combining nodes in this cluster and a distant cluster's unconnected practices and strategies, e.g., between "Experiencing a physiological/psychological state" and "Embodied interactions" (cluster 4, "Presence") and "Multimedia theory" (cluster 3) or "Authentic learning" (cluster 2). Thus, this descriptive framework for pedagogical interventions can support researchers to be more specific when describing the practices that they are implementing or researching, through linking them to or extending our framework.

Another conclusion stems from considering the overall outlook of clusters and their connections (Fig. 12). We recall that the existence of a node within a cluster reveals the existence of that area of concern in actual literature accounts, and the number of nodes within a cluster - reflected in its size in the overall outlook - thus reveals the diversity or richness of practices and strategies within it. The links between nodes or clusters do not stem from the underlying accounts but from the researchers' judgments on their conceptual straightforward connection. Hence weak links between clusters point towards lack of practices and/or strategies that readily map to each other across those clusters. This may indicate a need for more diversity in strategies and practices within clusters, to expose more straightforward links between them. E.g., three nodes only in the "Traditional practices" cluster limits the straightforward connections with other clusters. Should a more diverse range of traditional practices and strategies exist, i.e., documented as accounts in the literature employing immersive learning environments, this would then enable more connections to be established with other clusters. Our visualizations can thus serve as maps exposing the presence and absence of diversity in some clusters of practice and strategy accounts in the literature.

VIII. Limitations and Future Work

The corpus was based on studies mentioning immersion, complemented with studies mentioning technological platforms closely related to it: augmented, virtual, and mixed reality. This approach may underrepresent studies on low-technology immersive learning environments that do not explicitly use the terms "immersion" or "immersive". This opens an avenue for future work to explore studies on immersive learning using low or no technology, enriching the overall perspective on educational practices and strategies used in this field.

The methods used to establish straightforward connections between strategies and practices, from which the clusters emerged, involved qualitative agreement between three researchers. Although this provided an in-depth insight from our backgrounds and experiences, it did not provide a generalizable account that can be easily transferable to other researchers and practitioners who are from very different academic fields. The connections were established between the theme definitions that emerged, not between actual field accounts. Thus, they provide an indication of affinity between the concepts, but no indication on whether the practices and strategies are occurring in isolation or together in the actual field. Interesting future work would be to map these themes to the original literature reference behind each account, to ascertain which practices and strategies co-occur in the field.

The qualitative agreement between three researchers to establish straightforward conceptual connections between practices and strategies was based upon the themes found in the current literature. The introduction of new literature accounts, of different theme development processes, or considering the perspectives of other researchers may result in different connections. This would recast the topology of the network and the constitution of its clusters. Hence, future work should include both the need to update this literature survey regularly and vetting the theme development and theme connections with a wider community of researchers.

Also, the concept of straightforward conceptual connection is dependent on individual researchers' background, experiences, and perspectives on education and technology. This mapping approach method may display different perspectives among research communities. One possible outcome may be a solution to overcoming the current conceptual and methodological fragmentation in the field of immersive learning [6]. This could occur through an evolution of the connections' quality from "straightforwardness" to other dimensions or methods of relating themes, exposing multiple viewpoints on this field of inquiry and practice. Hence, it may enable immersive learning researchers from diverse academic fields to freshly consider unfamiliar and interdisciplinary viewpoints.

The mapping of these connections also reveals a need for further models and frameworks that could clarify relationships between strategies and practices that do not have straightforward conceptual connections. For instance, the "Contextual theories" strategy is currently not connected to the "Embodied interactions" practice. However, a model/framework could provide that connection, proposing pedagogical, technology use, or administrative relationships between that strategy and that practice. Models and frameworks may also provide interpretive lenses to scaffold existing connections. Such models should consider mapping our descriptive framework to the underlying educational contexts and disciplines (e.g., primary, secondary, higher education, industry, etc.). They should also consider whether the various practices and strategies relate to specific disciplines, and hence provide grounded contributions to their didactics. We can envision developing immersive learning environments integration models to help practitioners to implement immersive environments, strategies, and practices in an integrated manner.

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