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Identifying Immersive Environments' most relevant Research Topics: An Instrument to query Researchers and Practitioners

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Abstract. This paper provides an instrument for ascertaining researchers' perspectives on the relative relevance of technological challenges facing immersive environments in view of their adoption in learning contexts, along three dimensions: access, content production, and deployment. It described its theoretical grounding and expert-review process, from a set of previously-identified challenges and expert feedback cycles. The paper details the motivation, setup, and methods employed, as well as the issues detected in the cycles and how they were addressed while developing the instrument. As a research instrument, it aims to be employed across diverse communities of research and practice, helping direct research efforts and hence contribute to wider use of immersive environments in learning, and possibly contribute towards the development of news and more adequate systems.

Keywords: immersive environments, research priorities, questionnaire.

1 Introduction

Even after over 30 years of educational research background, the use of immersive environments in education is not an everyday practice (Duncan, Miller, & Jiang, 2012). Although immersive technologies emerged in the 1960s, their educational use mostly started in the early 1980s, propelled by the popularity of text-based virtual words. Hew & Cheung (2010) contribute a valuable overview of knowledge in this regard.

One might hypothesize that perhaps immersive environments are not adequate platforms for learning contexts. However, research efforts addressed this concern and literature surveys have revealed a consensus: immersive technology, if applied within

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an adequate didactic/pedagogic framework is indeed effective for learning (Merchant et al., 2014).

So, if they are effective, what is causing low adoption? Lack of adoption of technological innovations in education is a widespread issue – it doesn't just affect immersive technology. As Dede (2000) already stated, "*Many research-based curriculum development projects foster a few isolated innovation sites, then disappear*." Technology adoption depends on a diversity of issues, schools being no exception. Current models, such as the revised UTAUT (Unified Theory of Acceptance and Use of Technology), deal with a combination of technical, social, and cultural aspects, such as performance and effort expectancy, facilitating conditions, attitudes, and more (Dwivedi et al., 2017). Thus, at the concrete level of immersive environments there could be issues such reliability (impacting performance expectations), the cost of providing and maintaining the educational experience (impacting effort expectancy), and many more. For instance, regarding attitudes a recent survey on one such kind of immersive environments – virtual worlds – concluded that organizations were not using them mostly because of pack mentality: looking over their shoulder they don't see other organizations using them or don't recognize the ones that do use them as being successful (Yoon & George, 2013). Many research efforts have investigated specific aspects of this issue of adopting or valuing immersive environments for learning and a relevant meta-review in this context was provided last year by Reisoğlu et al. (2017).

Our perspective is that studies that focus on such educational issues and practices have a typical shortcoming in that they envisage technology as something static. That is, educational technology as a constellation of products "as is", rather than something that has shortcomings and can change – and indeed changes. For instance, Duncan et al.'s taxonomy (2012) points out that the core research areas are learning theories, educational activity, learning environment, and population, with the supporting technology playing a minor focus – and the name itself, "supporting" technology, demonstrates this perspective of technology as something static, objectified, supporting material for activities, rather than a transformational or enabling factor. The aforementioned Yoon & George survey (2013) even reports that the technology itself does not have a significant impact in the level of organizational adoption – while at the same time failing to reflect whether the technology shortcomings couldn't be the reason for the overall lack of widespread adoption or clear success examples which are indeed identified as the main factors.

We put forward the argument that when studying educational technology from that static perspective, there will be plenty of data about outcomes and impacts of specific features of each product, but little towards potential outcomes of changing the technology itself. This argument stems from current perspectives of technology as mutable rather than static: technology artefacts as ever-changing embodiments of knowledge. Artefacts, by coming into existence, transform the overall context, thus generating new knowledge and new processes, while also changing the assumptions that originated their creation, thus originating new lines of action (Hevner, 2007).

Hence, our motivation is to assist the research community in looking at what needs to change in immersive environments, how they must evolve, to better support learn-

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ing – rather than just study their status. For this purpose, we present an instrument to identify research priorities amongst communities of researchers in immersive environments. This paper is structured as follows. First, we set the scope, by presenting the definition of immersive environments we employed. Then we summarize earlier work on the diversity of challenges for changing and adopting immersive environments in learning contexts. We proceed by explaining how we developed the instrument (a questionnaire) based on that overview; and finally, we present the final version of the research instrument.

2 What are immersive environments?

In the previous section, we associated the concept of "immersive environments" with virtual worlds, by mentioning their early text-based incarnations of the 1980s and more recent graphical environments studies by Yoon & George (2013). Many other technologies could have been mentioned – with simulators possibly springing to mind most readily, given the diversity and richness of this field of inquiry (Rosen, 2013). After all, simulators often resort to contexts where participants are immersed in the simulation. But the match isn't entirely adequate: for instance, physics simulators that provide schematic behavior representations are not immersive in the least; and conversely one simply needs to consider games where physical laws are an inspiration (at most) rather than directives, to find immersive environments which are not simulations. Videogames can also be immersive environments, and the research literature on such games can contribute to better understanding this field, but videogame research doesn't cover non-gaming immersive environments and includes non-immersive games, so again, the match isn't entirely adequate.

Rather, we find the concept of "virtual world" to be a useful proxy for "immersive environments", since "virtual world" as a concept has been subjected to many definition attempts and recently thoroughly analyzed ontologically (Nevelsteen, 2017). This stems from Dawley & Dede's (2014) perspective of virtual worlds as immersive environments "*in which a participant's avatar, a representation of the self in some form, interacts with digital agents, artifacts, and contexts*". That is, our perspective is that immersive environments are simply a superset of virtual worlds, by considering environments where a participant is not using an avatar to interact with the environment but still feels immersed, feels "present" in the environment – i.e., the participant is the avatar. If one considers immersive virtual reality, it is as if one is participating from within the avatar's body; if one considers augmented reality (or mixed reality, a term that is becoming commonplace), it is the participant's own body that is already immersed in the physical world. From the perspective of Presence research, this means we understand as immersive those environments which enable "*a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience*" (International Society for Presence Research, 2000).

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Thus, we establish our understanding of immersive environments as the superset of virtual worlds and similar technological platforms, with the common ability to generate a sense of presence. In this we encompass three-dimensional virtual worlds such as Second Life, multiuser videogames such as World of Warcraft, and text-only virtual worlds such as Multi-User Dungeons, but also three-dimensional simulators and non-physical environments such as three-dimensional first-person data visualizations scenarios. In fact, since an avatar is not required, we can consider physically-expanded environments such as augmented reality or mixed reality scenarios, since we all are naturally immersed on our physical environment, which is overlaid with extra virtual content in such scenarios.

3 Technology challenges of immersive environments in learning contexts

In previous papers (Morgado, 2013; Morgado, Manjón, Gütl, 2015) arguments have been raised regarding three categories of challenges that virtual worlds face, preventing their widespread adoption: challenges of making the technology available to educational actors; challenges regarding content production techniques; and challenges related to large-scale deployment. In view of our perspective of immersive worlds as a superset of virtual worlds, as argued in the previous section, we employed those challenges as a baseline for our work. In this section we summarize these challenges.

Challenge Category 1: making the technology available to educational actors. Educational actors must be able to employ the technology that provides the immersive environments. Assuming as trivial the cases were the entire immersive content is provided via physical media, the non-trivial cases are those provided via computer networking, including augmented reality situations where the digital content is being provided over the network. The previous papers point out three sub-challenges:

a. Network architectures and features
b. Software employed by users
c. Isolation vs. interconnection

Challenge 1a) refers to the impact on educational activities (including at the organizational level) of different aspects of computer networking. One example of such an aspect is topology. For instance, client-server networking implies having to manage a central server and provide the bandwidth for each participant to reach it, which can be taxing for some scenarios such as small primary schools and non-formal educational groups; on the other hand, peer-to-peer networking does away with these issues but renders the entire experience dependent on individual participants' machines, which can be harder to manage and organize. Research is needed to identify in detail the actual impact in educational scenarios, both at the individual and organizational levels, of the various technical aspects of computer networking.

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Challenge 1b) refers to the impact of using different kinds of software to provide the immersive environment. For instance, having specialized software that needs to be installed locally raises several concerns which may or not be relevant for different educational scenarios. One such concern is whether installing the software on a participant's computer requires administrative access to it. This is trivial in bring-your-own-device scenarios but complex when an organization manages the computers. Conversely, in bring-your-own device scenarios there is a plethora of hardware configurations and software ecosystems, with associated risks of shortcomings (e.g., performance, screen sizes) and conflicts (mismatching graphic drivers, firewalling or virus detection conflicts, etc.). And from an organizational perspective, the use of specific pieces of software for immersive environments introduces an unknown element of network security and stability: what is the network behavior of that software? how can a network administrator recognize legitimate traffic? does this software opens new pathways for intruders to attack or leverage the organization's network? The previous papers pointed out two alternatives to using specialized software: using Web browsers to access immersive environments and video streaming them while uploading user interaction actions. Immersive web browsing is trending towards the use of WebGL, but its support is far from being widespread, and no research on how immersive environments behave on the Web in actual educational scenarios, regarding the issues mentioned above. As for the video streaming alternative, although a few companies started providing such services in the early 2010s (e.g., OnLive, OTOY, Gaikai, MEO Jogos), the majority has folded. Sony does provide such a service, called PlayStation Now. The scarcity of alternatives has contributed to an almost absolute absence of research results on the educational impact of this approach.
Finally, challenge 1c) deals with the isolation or connection to the world of immersed users (e.g., a class, a training session), and the impact of this isolation/connection on the educational activities. For instance, if each immersive experience is provided by different organizations/entities/software, this may require educational activities to deal with multiple login credentials, multiple sets of user settings, multiple interfaces to learn. These aspects bring with them time and support issues which impact educational activities and need to be researched: for instance, OpenSimulator+Hypergrid is a technology that enables users across different organizations to have a single login and interface for accessing the immersive environment but has been shown to have scaling and security risks (Clark-Casey, 2010), albeit these could be acceptable in some educational scenarios but not in others. In some multiuser environments, such as most massive multiuser games, the environment is "sharded". That is, multiple copies of the same environment are provided on different online servers, and users accessing one such copy (a "shard") cannot interact within the immersive environment with users accessing a different copy (a different "shard"). This is a technical solution for a technical problem (online workload of dealing with many users) but may constrain the planning and feasibility of specific educational activities.

Challenge Category 2: content production techniques. These set of challenges are related to the source of the content found in immersive environments, and whether it can be changed/provided during the educational process or not. The previous papers

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pointed out two distinct sets of challenges, depending on the level of involvement of technical experts:

a. When content is produced by technical experts
b. When content is produced by the participants in the educational process

Here, "technical experts" are not only computer programmers but also graphic designers, modelers, and all other skilled creators which can be involved in the creation of an immersive environment, possibly in concert with learning designers and subject-matter experts such as historians, physicists, or others. If the involvement of experts is high, this leads to better-crafted environments. On the other hand, it diminishes the flexibility and scope of immersive educational activities, since participants are typically focusing on experiencing whatever interactions and content was provided for them beforehand, not on creating or contributing their own.

Regarding challenge 2a), content production by experts implies its own kind of problems. Combining technologists with artists and subject-matter experts implies greater costs in human resources and management complexities, such as different methods of communicating, different goals, different expectations. For instance, Neves et al. (2010) point out that the uncertainty of carrying out communication goals is a recurring condition in videogame development. Overall, there is little research on the impact of decisions that must be made for development, such as which tools to use, what will be the actual workload, what risk may arise during content development and how they can be mitigated, or what methods can enable a project to be more easily changed during development or updated later (Anderson, 2011).

As for challenge 2b), the focus is on different issues, since content production is not done prior to the educational activities but as part of them. There are indeed tools and systems for such "user-created content", and research is needed regarding the experience of users while creating (difficulties, time, frustration or success, simplicity or complexity, etc.). And, on how different participants (teachers, trainers, students, trainees) can learn how to use the tools. Not least, research is needed on how to improve tools beyond their current state, since – as pointed out in the introductions – we must also avoid seeing tools as static technology.

One aspect of content production is considering not only traditional user-created content (3D objects, imagens, videos, single-character animations) but also more complex, interactive content that can be realized in immersive environments, such as multi-character choreographies. Further, user-created content can be interactive, not just passive, but more research is needed on interaction-development tools and processes geared towards non-experts. Instead of simply considering non-experts as unskilled creators in need of limited, simple tools, research needs to consider that expert creators are typically generalists in the application of their creations (e.g., a model can be used for a movie, a game, or an educational activity), whereas for educational actors it may feasible to use specialized tools, that acknowledge the educational context. In this regard, existing research on programming by demonstration (Lieberman, 2001) and computer-supported cooperative work (Cruz et al., 2012) may be tapped, towards new insights and solutions for complex, interactive content production by educational activity participants.

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Challenge Category 3: large-scale deployment. This third set of challenges deals with the integration and interoperability of immersive environments with the ecosystem of educational computing. For widespread use of immersive environments, one must envision them as being enmeshed in the overall computational activities of education – including educational management. For instance, can assignment progress by students be tracked in immersive environments? Can teachers readily realize where in the immersive environments students are requiring support? Can providing that support be streamlined? Can managers of entire schools, districts, or business training companies have a clear perspective of the ongoing activities? Can support staff readily identify issues and solve them? Can the specific content of immersive environments be managed alongside the content of other non-immersive educational computing systems?

These aspects have been the subject of some efforts, such as the SLOODLE project (Kemp & Livingstone, 2006), which enables access to the Moodle learning management system (LMS) from within Second Life or OpenSimulator, or the MULTIS architecture (Morgado et al., 2017), which puts forward a method for LMS interoperability with serious games and virtual worlds. Silva et al. (2014) propose defining multi-character choreographies in a platform-independent way so that can be reused in different environments and Maderer et al. (2013) propose adjusting immersive tasks automatically according to a learner's knowledge or skill level, but these are still early contributions. Considering field reports of requirements from corporate training (Morgado et al., 2016), a significant amount of research is needed to identify and define actual requirements for education contexts, prototype and test new systems, and ultimately provide educational scenarios with immersive environment solutions which are feasible for widespread deployment.

4 Developing a questionnaire for researchers and practitioners

4.1 Motivation

From the above overview of the situation, we believe that an interdisciplinary set of research perspectives is required. The close interaction between the development of technology, its organizational impacts and constraints, the way it empowers changes in educational practice but is also delimited by educational contexts and goals, all point towards a combination of research on Information Systems, Software Engineering, Educational Technology, and Educational Sciences. Other aspects still, such as network security aspects, point towards Computer Science or even Computer Engineering approaches. Improving tools for educators that are not computer-savvy may require adequate contributions from research in didactics of specific fields, from Sports Science to Biology, from Arts to Mechanical Engineering. Others fields still may contribute with significant insights into these areas, such as Communication Sciences, Anthropology and more. In view of this diversity, we aim to establish a research agenda for the community, by analyzing its viewpoint on the challenges,

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which the community may then tackle using each individual researcher's epistemological tools.

4.2 Research focus

Following our stated motivation, we seek to find out what are the perspectives of researchers and practitioners in the field of immersive learning environments regarding the relevance of the various identified challenges towards their dissemination and adoption. Further, we seek to find out whether there are challenges that we neglected to include.

4.3 Setup

When developing a new research instrument, one may resort to empirical data or on theoretical knowledge (Hyrkäs et al., 2003). To pursue the stated focus, given the lack of empirical data, we set forth from the theoretical arguments summarized in the previous section. We arranged those arguments into a tentative form of the instrument, a questionnaire where each topic is queried on relevance. We organized the topics into three sections, matching the three categories of challenges, and in each section included an open question asking for any missing research challenges.
The second phase of developing the research instrument is expert review (*ibid.*). We thus subjected the tentative questionnaire to several rounds of expert feedback. After each round, we updated it following the changes recommended by the experts, resolving reported inconsistencies and ambiguities, and clarifying any items that led to expert misinterpretation, as described ahead in the "Method" section.

4.4 Method

For conducting the expert review, we pursued iterations with researchers working in the field of immersive learning environments. Two researchers were involved (in parallel) in each iteration, whose profiles are summarized below. We have also considered the feedback from a reviewer of the initial submission of this paper to the iLRN 2018 conference as a third phase of expert review, since that reviewer reported having read the entire questionnaire and provided specific feedback on it.

Iteration 1

Expert 1. Reader at a British university, focusing on distributed systems and networking, including the behavior of immersive environments, but also on technology-enhanced learning using these systems. Google Scholar statistics: more than 150 papers, h-index 19, most cited paper with 60 cites. Male.

Expert 2. Associate Professor of Educational Technology at a North-American university, focusing on educational inclusion aspects of immersive environments, on life

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skills training for special needs populations, and art curation. Google Scholar statistics: more than 50 papers, h-index 8, most cited paper with 140 cites. Male.

Iteration 2

Expert 3. Assistant Professor at a Continental Europe university, focusing on motivational and engagement aspects of game design and development, with prior experience in the video game industry. Google Scholar statistics: more than 50 papers, h-index 8, most cited paper with 39 cites. Female.

Expert 4. Professor at a North American university, lecturing on learning design and technology and with a research focus on sociocultural aspects of online learning and entrepreneurship education. Google Scholar statistics: more than 350 papers, h-index 37, most cited paper with 346 cites. Female.

Iteration 3

Expert 5. A reviewer of the original submission of this paper to the iLRN 2018 conference. Profile not disclosed to us due to blind review. Self-reported reviewer confidence as "3 (medium)".

4.5 Outcomes

Through the expert-validation iterations, were collected several kinds of feedback:

1. Structural - related to the visual organization of the questionnaire.
2. Context clarification - aspects which could be misunderstood by researchers from fields other than computer science;
3. Ambiguity - aspects which could lead to differences of interpretation and subsequent impact on meaningfulness of answers.
4. Missing aspects - new questions which would be relevant to ask

In the following Tables 1, 2, 3, and 4, we provide some examples of these kinds of feedback and questionnaire changes implemented due to it.

Table 1. Changes from feedback of expert feedback – Structural

Initial form and feedback	After feedback
Each question had the relevance options listed below: *This is a sample question text.* - *Not relevant* - *A curiosity* - *Somewhat* - *Very*	We organized the various questions in a table, in each section. E.g.:

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- *Extremely relevant* *This is another question text.* - *Not relevant* - *A curiosity* - *Somewhat* - *Very* - *Extremely relevant* **Feedback:** «*list these in a table format with 1-5 options across the top. This would help users to better read all of the questions in the context of the main statement*» - Expert 2	
Feedback: «The "other aspects" comment area at the bottom of each page and the "Final comments" area on page 7 should be optional, not required» - Expert 2	We made the items "Other aspects" and "Final comments" optional.

Table 2. Changes from feedback of expert feedback - Context clarification

Initial form and feedback	After feedback
Some questions had technical computing terms within. E.g.: *Multiuser interaction in immersive environments and virtual worlds is typically achieved via computer networking, either entirely as a virtual medium or to overlay virtual content on the physical medium in augmented reality.* *Network architecture and features* *The peer-to-peer (P2P) model of networking means that no main computing server (local or online) needs to be available, and that no single server needs to have the horsepower (and network bandwidth) to host the clients. It also means that the operation of the networking depends on the individual operation of peers.* **Feedback:** «*You may want to link to quick descriptions of all technical terms. I knew all of them of course, but I know some educational technology researchers who do immersive learn-*	We have rephrased the text to avoid the dense computational lingo and provided a background information section to clarify the most technical terms. E.g. *Assuming as trivial cases were immersive content is provided via physical media, non-trivial cases are those provided via computer networking, including augmented reality situations where the digital content is being provided over the network.* *Hence, we'd like to find out about the relevance of researching the impact of different aspects of computer networking on educational activities (both at the individual and organizational levels).* *Background information:* *"Client/Server" networking means that an online computer system provides the immersive content. This can be on the Internet or within a private network of a school or business. This computer system needs to*

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ing research but might struggle with some of the more technical terms. For example, client-server, peer-to-peer (...) *educational management methods, network configurations, network impact, network behavior* (...) *attack vectors* (...) *local rendering* (...).» - Expert 2 «*I am not a computer scientist, but am a practitioner and researcher in the design of immersive environments for learning (coming from a content and instructional design perspective) and the questions they are asking seem esoteric*.» – Expert 5	*have the horsepower and network bandwidth to host the devices being used by teachers/students, and enables content management at a single location.* *"Peer-to-peer" networking means that there is no main system, the immersive content is jointly shared by a community of users' devices; there is no need for network access outside those devices (i.e., it can work for users in a room, without Internet access); it also means that the operation of the network is relying on the individual operation of each peer device (its performance, its connectivity, etc.).*
Some concepts were not immediately understood, even for experts with a computing background. E.g.: *Which educational and training uses of immersive environments and virtual worlds can be enabled by accessing them via video streaming instead of local rendering.* **Feedback:** *«We're mostly familiar with SL style of VR interaction but the streaming video model really requires an example*» - Expert 1 «*Questions are too long, need streamlining*» - Expert 4	We have rephrased and simplified the questions to make them clearer, e.g.: *Identifying learning contexts where using video streaming can render immersive environments feasible.*

Table 3. Changes from feedback of expert feedback – Ambiguity

Initial form and feedback	After feedback
The relevance options were: - *Not relevant* - *A curiosity* - *Somewhat* - *Very* - *Extremely relevant* **Feedback:** «*A curiosity might be less understandable than something like, "A little relevant"* » - Expert 1	We added the term "relevant" to each option: - *Not relevant* - *A little relevant* - *Somewhat relevant* - *Very relevant* - *Extremely relevant*
We were using the expression "Education and Training" with the intent to imply that	We replaced "education and training" with "learning contexts" throughout the question-

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the questions could apply to diverse learning situations, not just formal education, but also professional training. However, this could be misinterpreted. **Feedback:** «*I would be inclined to be careful about referring to training and education as the same thing, and where appropriate phrase the questions in such a way as to distinguish between the two. For example, Medical students spend a lot of time being "trained" whereas Biology students spend time being "educated". »* - Expert 1 «*Clarify the difference between training and education (used together on several pages). Is this an age group difference (adults vs. primary and secondary)?* » - Expert 2	naire.
The main question before each set of items was ambiguous. **Feedback:** «*The main question posed by the questionnaire "how relevant are the following aspects for setting research priorities in this area?" was difficult for me to interpret. Are they asking whether each aspect is a challenge or barrier to being able to conduct research? Or whether each aspect is a relevant area to be studied?"* » – Expert 5	We rephrased the main question, to avoid this ambiguity. It now reads: *Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?*

Table 4. Changes from feedback of expert feedback - Missing aspects

Initial form and feedback	After feedback
We were explaining about how users might use browsers or specialist applications, and asking about the relevance of research topics such as "Context of administrative access to users' machines", "The risk of software conflicts or hardware shortcomings", etc. **Feedback:** «*if the VR is accessed via a standard browser then there is no need to install special client software. Chrome and Firefox have forced Unity to improved the WebGL versions of their outputs by not supporting the Unity (or any other) NPAPI plug-in. So,one useful*	We added the following opening item to this section: *Identifying the value of being able to use standard browsers for accessing the immersive environment rather than installing specific applications.*

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question might be the value of being able to use standard browsers for accessing the VR world rather than installing specialist applications. Once that is out of the way you can certainly ask about admin access to students personal computers at home» - Expert 1	
Lack of relevant context data in the personal information section. **Feedback:** «*"Personal Information" this is very general and doesn't seek to elicit a respondent's self-perceived IT competences, in particular, familiarity with multi-user virtual environments.* » - Expert 1	We've added a topic to the section, asking "*Years of experience with immersive environments*"

5 The final questionnaire

The result of the process is a questionnaire which can be used as an instrument to query communities of researchers and practitioners on immersive environments regarding their views of the relevance of the various research topics presented, as well as collect missing topics, within the provided topics structure.
The final questionnaire is provided in full as an appendix to this paper. It will also be submitted for archival as a research instrument to the open repository of Universidade Aberta, at https://repositorioaberto.uab.pt/ under our authorship.

6 Final thoughts

Immersive environments for education are diversified and rich. The early text-only systems of the 1980s have now been replaced with graphics-intensive environments, and via augmented reality they are blending with everyday environments, hence the novel term "mixed reality". Educational adoption is however lacking, particularly if one looks beyond occasional usage and seeks to find cases of widespread, long-term use. Enthusiasts are leading the way, but widespread use requires technology to become adequate also for non-enthusiasts. Research needs to look at the technological issues from an educational use perspective, from the wide perspective of learning contexts, all the way from the individual to the organization.
With this paper, we are providing an instrument to query the research community involved in immersive learning and ascertain the relevance and priority of an encompassing set of challenges facing immersive learning environments. Hopefully this will lead to a diversity of results across varying communities and contribute to focusing research efforts. Ultimately, our hope is that the research will generate newer and more adequate technologies, rendering the use of immersive environments widespread in education, training, and other learning scenarios.

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Appendix

Questionnaire: Technological Hurdles of Adopting Immersive Environments in Learning Contexts

This survey, for which we thank you for your cooperation, aims to achieve a vision of the needs and perspectives of practitioners and researchers regarding the challenges arising from the use of immersive environments in learning contexts. Your answers will be kept strictly anonymous and will only be used for statistical and category analysis, ensuring the confidentiality of the data.
Please take a moment to complete this survey to let us know your opinion.
The estimated completion time is approximately 20 minutes.

Your contribution is fundamental for this research. Your opinion counts.

For each of the following questions, please answer according your current situation.

1 Accessing Immersive Environments

Assuming as trivial cases where immersive content is provided via physical media, non-trivial cases are those provided via computer networking, including augmented reality situations where the digital content is being provided over the network.

Hence, we'd like to find out about the relevance of researching the impact of different distribution models of computer networking on educational activities (both at the individual and organizational levels).

Background information:

"Client/Server" networking means that an online computer system provides the immersive content. This can be on the Internet or within a private network of a school or business. This computer system needs to have the horsepower and network bandwidth to host the devices being used by teachers/students and enables content management at a single location.
"Peer-to-peer" networking means that there is no main system, the immersive content is jointly shared by a community of users' devices; there is no need for network access outside those devices (i.e., it can work for users in a room, without Internet access); it also means that the operation of the network relies on the individual operation of each peer device (its performance, its connectivity, etc.).

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Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Studying the consequences for the learning context of adopting immersive environments based on client-server vs. peer-to-peer networking.					
Analysing which immersive learning environments would benefit from the decentralized storage and computational workload provided by peer-to-peer, and which would be harmed by it.					
Analysing which educational management methods for teachers, trainers, and educational organizations using immersive environments would these alternative network models imply.					
Researching aspects impacting the daily work of network administrators, such as network behaviour of immersive environments (configurations, performance impact, security, costs).					
Researching the relationship between network behaviour of immersive environments (configurations, performance impact, security, costs) and specific educational activities.					

Other aspects: _____

Still regarding access to immersive environments, we would now like to ask you about issues related to the software that is used.

Regardless of networking, users see immersive environments in software running on their devices. This software may be a commonplace Web browser or a specific application. Both alternatives have implications for home use vs. organizational use.

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Background information:

"Video streaming": some online services carry out the heavy computational task of generating 3D immersive graphics for each user and send the results as a live video, as if watching YouTube, so that even low-end devices can display high-quality graphics. User interactions are sent over the Internet to the servers, which show the outcome on the screen, possibly with a small delay.

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Identifying the value of being able to use standard browsers for accessing the immersive environment rather than installing specific applications.					
Analysing the feasibility of requiring the use of applications that need be installed in users' or school's machines.					
Studying the risk of software conflicts or hardware shortcomings of immersive environment software.					
Identifying security vulnerabilities and tactics used for malicious exploit of these network-aware applications.					
Identifying methods to streamline installation and updating of immersive environment software.					
Identifying methods to manage, monitor, track, and debug immersive environment software.					
Studying the operational behaviour of immersive environments on Web browsers (e.g., usability, interfaces, vulnerabilities).					
Identifying learning contexts where using video streaming can render immersive environments feasible.					
Identifying learning contexts where using video streaming is not feasible for using immersive environments.					

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Other aspects: _____

Regarding access to immersive environments, we would like to ask about the level of connection between participants and resources.

The most common situation is for participants and resources of immersive environments to be restricted to a specific computer system online, managed by a single organization. However, there are also some cases where people and resources can move across immersive environments managed by different organizations.

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Analysing learning implications of immersive environments that perform "sharding": users access different copies of the same environment, rather than being all together online, to avoid the computational complexity of managing many users in the same space or on different time zones (this is a typical situation in online multiplayer games).					
Creating/Identifying technological solutions to enable resources to be shared across different immersive environments.					
Creating/Identifying technological solutions to enable users to access different immersive environments without requiring new login procedures.					
Creating/Identifying technological solutions to enable users' virtual personas (i.e. avatars) to access different immersive environments.					
Studying scaling and security issues, at the technological level, of sharing users and resources across different immersive environments.					
Studying the relevance, for					

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learning contexts, of learning content and activities in immersive environments being tied (locked-in) to a specific kind of technology, i.e., of not being able to move them to newer technologies.					

Other aspects: _____

2 Producing Content in/for Immersive Environments

In an immersive environment, the user experiences a virtual shared space, with its own features and content, such as topography, objects, and agents (controlled by other users or by computer systems). This content provides context and features for the educational process. Its production may be done by experts in dealing with the several technologies or by the actors of the educational process themselves.

If the involvement of experts is high, this leads to better-crafted environments. On the other hand, it diminishes the flexibility and scope of immersive educational activities, since users are typically focusing on experiencing whatever interactions and content was provided for them beforehand, not on creating or contributing their own.

Firstly, we would like your viewpoints on the relevance of researching aspects related to content production by technical experts.

Background information:

"Technical experts": people with advanced skills related to content production, such as programmers, animators, artists, sound editors, etc.

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Identifying the impact on technical workload and project risk of adopting some production tools over others (for content production by experts).					
Identifying the impact on technical development flexibility (e.g., changes, updates) of adopting some production tools over others (for content production by experts).					

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Also on content production, we would like your viewpoint on the relevance of researching aspects related to the participation of educational actors (educators, students, trainers, trainees, etc.).

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Studying the development processes of immersive environment content by non-technical users.					
Studying the adequacy of current development tools for immersive environment content geared towards non-technical users.					
Designing training methods for development tools of immersive environment content geared towards non-technical users.					
Creating/Identifying development tools that enable non-technical users to create interactive behaviours for objects in immersive environments.					
Creating/Identifying development tools that enable non-technical users to create interactive virtual characters for immersive environments.					
Creating/Identifying development tools that enable non-technical users to define virtual characters' behaviours by demonstrating what is intended and generalizing from that demonstration.					
Creating/Identifying development tools that enable non-technical users to create choreographies of groups of virtual characters for immersive environments.					
Creating/Identifying development tools that enable non-technical users to create interactive stories with multiple virtual characters for immersive environments.					
Creating/Identifying development					

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tools that enable non-technical users to express higher-level semantics, such as "from home to work", instead of raw data such as x-y-z coordinates.					
Creating/Identifying development tools that enable non-technical users to produce content collaboratively.					

Other aspects: _____

3 Deploying Immersive Environments

Typical education and learning contexts employ software known as learning management systems, which account for organizational structures such as courses, administrative support such as attendance records, and store educational resources and data.

We would like your viewpoints on the relevance of researching the integration of immersive environments with learning management systems.

Based on your experience and research background, how relevant do you think the following aspects are as areas of interest for the global research community to pursue in the future?

	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant
Creating/Identifying solutions for tracking student progress while doing assignments in immersive environments.					
Creating/Identifying solutions for teachers/trainers to be able to identify learning support needs and provide extra resources directly within immersive environments.					
Creating/Identifying solutions for learning management systems collect student assessment data from immersive environments.					
Creating/Identifying solutions for learning management systems to provide feedback and guidance to learners directly within immersive environments.					
Creating/Identifying solutions enabling learning management					

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systems to manipulate the content of the immersive environment.					
Creating/Identifying solutions enabling learning management systems to adjust tasks within an immersive environment according to the learner's knowledge or skill levels.					
Ascertaining the sets of requirements for improving the integration of immersive environments with learning management systems.					
Creating/Identifying solutions for recording what happens within an immersive environment from the users' perspective.					
Creating/Identifying solutions for recording what happens within an immersive environment from a user-independent perspective.					
Identifying technical support staff training needs to support the deployment of immersive environments at organizations.					
Ensuring that all users within an immersive environment witness the same occurrences at the same time.					

Other aspects: _____

4 Personal information

Gender: □ Male □ Female

Age:
□ Up to 24 □ Between 25–35 □ Between 36–45 □ Between 45–54 □ Older than 55

Academic qualifications:
□ Graduate (BSc/BEd/BA/BEng, etc.)
□ Master's
□ PhD
□ Other
If "Other", which? _____

Field of expertise: _____

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Years of experience with immersive environments and/or virtual worlds:

□ Up to 5
□ Between 5 - 10
□ More than 10

Research area (write none if not involved in research): _____

Number of research papers on immersive environments and/or virtual worlds published in the past 3 years:

□ None
□ Up to 3
□ Between 4 - 6
□ Between 7-9
□ 10 or more

Final comments (any suggestions, clarifications regarding doubts interpreting questions, etc.): _____