Research priorities in immersive learning technology: the perspectives of the iLRN community

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Abstract. This paper presents the perspectives of the Immersive Learning Research Network community on the relevance of various challenges to the adoption of immersive learning technology, along three dimensions: access, content production, and deployment. Using a previously-validated questionnaire, we surveyed this community of 622 researchers and practitioners during the Summer of 2018, attaining 54 responses. By ranking the challenges individually and within each dimension, the results point towards higher relevance being placed on aspects that link immersive environments with learning management systems and pedagogical tasks, alongside aspects that empower non-technical users (educational actors) to produce interactive stories, objects, and characters.

Keywords: immersive learning, immersive technology, immersive environments, research priorities, iLRN, Immersive Learning Research Network

1 Introduction

Star Trek's holodeck has not yet materialized in our physical world. But in the Second Life virtual world, an open-source version has been around since at least August of 2007[1], and its marketplace lists hundreds of offerings by the "holodeck" keyword[2]. The Minority Report gesture-based interface (Molen et al., 2002) now seems something a graduate student could program as a dissertation project and there are even commercial offerings inspired by it (e.g. Oblong Mezzanine[3]). The first

[1] http://wiki.secondlife.com/w/index.php?title=Holodeck&oldid=28527
[2] https://marketplace.secondlife.com/products/search?search[keywords]=holodeck
[3] https://www.oblong.com/mezzanine

issue of the Virtual Reality journal, almost 24 years ago, already included a paper with an overview of uses of virtual reality in education (Schroeder, 1995). And yet, despite more than 30 years of educational research and technology development, immersive environments are not found to be part of everyday practice in educational and training institutions (Duncan, Miller, & Jiang, 2012).

This is particularly flummoxing given that the emerging consensus from literature reviews indicates that immersive technology is effective for learning, if applied alongside an adequate didactic-pedagogic approach (Merchant et al., 2014). The volume of knowledge on this subject might lead one to expect to find widespread adoption, not the opposite, so what may be causing low adoption?

The pattern of adoption of technology in education – or the lack thereof, despite its potential or effectiveness, is far from an issue restricted to immersive environments. “*Many research-based curriculum development projects foster a few isolated innovation sites, then disappear*” (Dede, 2000). In education and training contexts, as in organizational and individual contexts in general, the adoption of technology is a process rather than an event or a single decision. A process that is dependent on a diversity of interrelated issues. Several theoretical models address this process, relating technical, social, individual, and cultural factors, i.e., combining the complex interaction of technological dimensions, human dimensions, and organizational dimensions. Some notable models are the revised UTAUT (Unified Theory of Acceptance and Use of Technology) that includes constructs like attitudes, facilitating conditions, and expectations of performance and effort, among others (Dwivedi et al., 2017); the Concerns-Based Adoption Model (CBAM), which proposes diagnostic dimensions of innovation configuration, levels of use, and stages of concern, the latter targeting individuals’ diverse concerns: informational, personal, management, consequence, collaboration, and refocusing (Hall & Hord, 2011); the Diffusion of Innovations model, whose perspective entails seeing new ideas (such as the use of immersive technology) spread over time within a social system (Rogers, 2004); and many others.

Considering immersive environments under this theoretical lens, these abstract constructs represent specific aspects such as additional assessment time that may be estimated by teachers wishing to use immersive environments (impacting effort expectancy), the dependence on the school network bandwidth which may not sufficiently stable (impacting performance expectations), etc. This perspective has been pursued by a diversity of research work, summarized by a recent meta-review of adoption and valuing of immersive environments for learning (Reisoğlu et al., 2017).

Of the various issues at stake, this work is delimited by the technological aspects of the process. It stems from the perspective that typically there is a shortcoming in looking at immersive technology as something ready. Instead, we envisage immersive environments and their supporting technology as something that has significant shortcomings and needs to change - as indeed it has changed year after year. For instance, when Duncan et al. (2012) presented a taxonomy of virtual worlds usage in education, it severed educational aspects (learning theories, learning environment) from technology, which was labelled as having a supporting role. That is, technology was not seen as an element that could entirely enable new forms of education or profoundly transform current ones. And above all being seen in a supporting role is not conducive as being the focus of transformation requirements, that is, being seen by what it could be, rather than what it currently is.

Thus, we side by Hevner (2007) by considering artefacts - in this case, immersive technology - as embodiments of knowledge, which transform the entire context into which they come into existence, and in that process generate new knowledge. In doing so, the intent and assumptions behind their creation change, impacting their subsequent development and transformation.

The research community can thus look at immersive environments as something mutable, something whose change is caused not only by the business and technological environment but also by the expectations, requirements, and vision of educational actors. In doing so, rather than report on how to adapt educational contexts and practices to what immersive environments are now, the community may contribute significantly to their evolution, and ultimately lead to better learning. In order to support this change in perspective, we developed and validated a questionnaire to identify research priorities amongst communities of researchers in immersive environments (Gaspar et al., 2018), whose scope encompasses access, content production, and deployment issues, as explained in section 2.2., and applied it in a survey to the Immersive Learning Research Network (iLRN) community. This paper presents the outcome and is structured as follows. First, we present the concept of immersive environments which scopes this survey. Then we summarize the literature on adoption challenges of immersive learning technology. We proceed by presenting the target population of the survey - the iLRN community, the data collection method and the characteristics of the respondents. Then we present the results and discuss them in view of the current literature. Finally, we draw conclusions in support of establishing research priorities in this field.

2 Background

2.1 Immersive environments

The concept of immersive environment, from a technological perspective, is elusive, and may be considered a synonym or a subset of simulators or videogames. And indeed, while some simulators are not immersive (for instance, numerical or diagram-based representations of systems operation), many clearly are, such as flight simulators and others. Videogames present a similar conceptual span. However, both concepts also leave out some range of immersive environments: simulators do not span non-interactive environments, and videogames do not span non-entertainment environments.

So, we opted instead to define immersive environments by starting with a more restricted concept and complement it. We took on "virtual worlds" as this narrower concept. Virtual worlds - as a concept - have been subjected to throughout ontological analysis (Nevelsteen, 2017) and their diversity can be accommodated within immersive environments. As Dawley & Dede (2014) put forward, virtual worlds are immersive environments "*in which a participant's avatar, a representation of the self in some form, interacts with digital agents, artifacts, and contexts*". We expand this Dawley & Dede avatar-centric proposal, complementing it with augmented-reality (AR) or mixed-reality (XR) environments where there are no avatars. In such environments, the user is using the physical body to interact with the environment in which it is immersed: both the physical and the virtual environment become part of a choreographed or freeform interaction experience. Our argument is that there is no effective distinction between this AR/XR scenario and one where the user's viewpoint is "inside" the avatar, i.e., "first-person view". The user is virtually present in a virtual immersive environment through an avatar, and physically present in a mixed-reality environment through the physical body. Examples of immersive environments under this perspective include videogame virtual worlds such The Lord of the Rings Online, social virtual worlds such as Second Life, and even traditional text-based adventure games; but also, non-game immersive simulations such as flight simulators, and abstract immersive environments, such as immersive artistic experiences or immersive data visualizations.

2.2 Adoption challenges of immersive learning technology

Previous papers have raised arguments about the diversity of aspects to consider for widespread adoption of virtual worlds (Morgado, 2013; Morgado, Manjón, Gütl, 2015). These coalesced around three categories: making the technology available to educational actors; content production techniques; and large-scale deployment. These categories formed our baseline, in view of our perspective of immersive environments as an expansion of the concept of virtual worlds. This baseline was previously summarized in the paper presenting the development and validation of the questionnaire we used for this survey (Gaspar et al., 2018).

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.

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 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. For instance, considering the aspects analyzed in Merchant et al. meta-study (2014), expert involvement impacts the quality of the various kinds of feedback for the learning tasks: elaborate explanations, visual cues, and others. On the other hand, expert involvement 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.

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.

3 Collecting iLRN community's research priorities in immersive learning technology

3.1 Scope and aim

The Immersive Learning Research Network (iLRN) is an international association of researchers and practitioners (i.e., developers, educators) with an interest in "*collaborating to develop the scientific, technical, and applied potential of immersive learning*" (iLRN, 2015). Its website lists[4] a series of events held since 2014 where interested parties have showcased and discussed research interests and perspectives

[4] https://immersivelrn.org/past-events/

on immersive learning. We have drawn from these public events in June of 2018, to set the scope of our survey as put forth below (Definition 1).

Definition 1
iLRN community *is the set composed by: members of the iLRN executive committee*[5]*; organizers, program committee/scientific committee members, guest/keynote speakers, and paper/poster authors of events organized by iLRN between 2014 and June of 2018.*

To collect data about this community and their individual contacts, we gathered community members' names and affiliations from the online pages of the events on the iLRN website and gathered paper authors and e-mails from the events proceedings. For community members who were not paper authors, we gathered their contacts from their institutions' web sites or personal web sites, and from papers they authored in other outlets, found using Google Scholar. The overall iLRN community thus identified is summarized in Table 1. Since some members take one several roles (i.e, speaker and author on the same conference, or participating in several events, etc.), the total number of community members is 622, smaller than the sum of items.

Table 1. iLRN community overview

Event	Committee members	Organizers	Speakers	Authors
Executive committee	11			
iLRN 1st Meeting and Virtual Symposium November 20th – 22th, 2014. Corvallis, Oregon, USA	10	6	19	0
Special Session on Immersive Technologies and Learning at the 7th CEEC Conference September 24th, 2015. Colchester, UK	0	2	0	21
Immersive Learning Research Network Conference 2015, July 13th – 14th, 2015. Prague, Czech Republic	79	17	5	83
Special Session on Immersive Technologies and Learning at the 8th CEEC Conference September 30th, 2016. Colchester, UK	0	1	0	11
Immersive Learning Research Network Conference 2016, June 27th – July 1st, 2016. Santa Barbara, California, USA	66	24	7	98
Immersive Learning Research Network Conference 2017, June 26th – 29th, 2017. Coimbra, Portugal	100	30	6	135
Immersive Learning Research Network Conference 2018, June 24th – 29th, 2018. Western Montana, USA	74	34	5	127
Total community (excluding duplicates)	**622 individuals**			

[5] https://immersivelrn.org/about-us/people/

3.2 Questionnaire design summary

In this section the questionnaire design is described and discussed. We have applied the questionnaire developed and expert-validated by Gaspar et al. (2018), whose goal is to identify immersive environments' most relevant research topics among researchers and practitioners. That paper makes the questionnaire format available as an appendix. The questions included and the focus of their inclusion are summarized below considering what is intended to be achieved with the respective answers. A scheme of the questionnaire design is presented in Fig. 1.

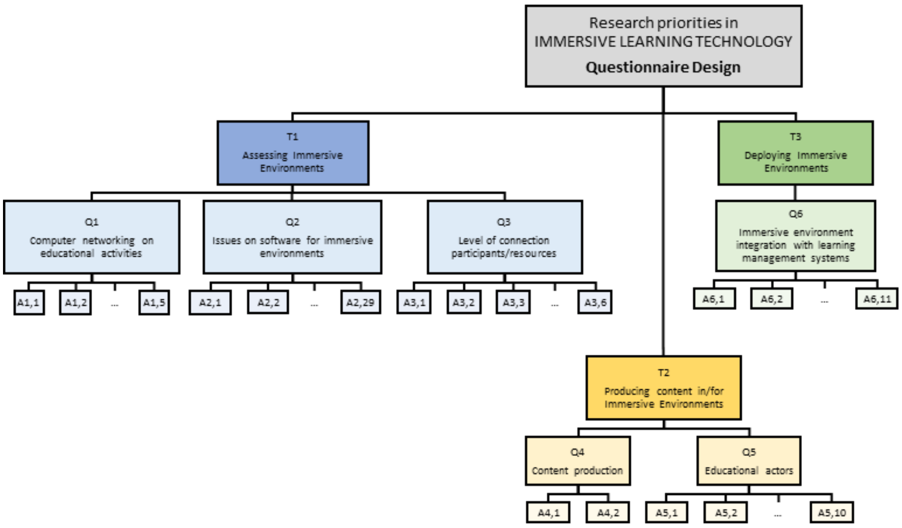

Fig. 1 Questionnaire design for assessing research priorities in Immersive Learning Technology

The first part of the questionnaire (topics 1-3) deals with the opportunity to collect information on the relevance level of some issues. The three topics under analysis are respectively:

T1 - Accessing Immersive Environments;

T2 - Producing Content in/for Immersive Environments and,

T3 - Deploying Immersive Environments.

Within each of the three topics (T1, T2, T3), several current issues are presented, and for each issue several potential research aspects are presented, in order to gather the generic evaluation for the main question:

"*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?*"

The answer possibilities are addressed into five categories, namely: Not relevant, a little relevant, somewhat relevant, very relevant and extremely relevant. Respondents can also select "unsure", in case they feel unable to make this judgement.

Considering T1, focused on user's access to immersive environments, the relevance of conducting research on three issues was accessed, namely:

Q1 – The impact of different distribution models of computer networking on educational activities (both at the individual and organizational levels);

There were five aspects under research relevance evaluation ($A_{1,1}$, …, $A_{1,5}$), which included consequences of client/server vs. peer-to-peer networking, as well individual and organizational levels of impact on educational activities. Respondents could also add other aspects in an open field.

Q2 – Issues related to the software being used for immersive environments;

There were nine aspects under research relevance evaluation ($A_{2,1}$, …, $A_{2,9}$), related to differences between using specific applications vs. commonplace Web browsers vs. interactive video streaming solutions, organizational aspects of these alternatives (installation, security, monitoring, hardware impact, feasibility in different learning contexts). Respondents could also add other aspects in an open field.

Q3 – The level of connection between participants and resources;

There were six aspects under research relevance evaluation ($A_{3,1}$, …, $A_{3,6}$), related to learning implications of "sharding" (users accessing parallel copies of immersive environments, rather than a common one), technological solutions for sharing resources, virtual personas and login procedures, and organizational issues (scaling and security, vendor lock-in). Respondents could also add other aspects in an open field.

Considering T2, focused on producing content in/for immersive environments, the relevance of conducting research on two issues was accessed, namely:

Q4 – Content production by technical experts;

There were two aspects under research relevance evaluation ($A_{4,1}$, $A_{4,2}$): the identification of technical workload and project risk connected with the selection of some production tools over others, and the impact on technical development flexibility of adopting some production tools over others. Respondents could also add other aspects in an open field.

Q5 – Participation of non-technical users (educational actors).

There were ten aspects under research relevance evaluation ($A_{5,1}$, …, $A_{5,10}$), related to the development processes of immersive environment content by non-technical users, the adequacy of current development tools and training methods for non-technical users, the creation or identification of tools for interactive objects and characters, the creation of choreographies and stories, the ability to user higher-level semantics, and collaborative content production. Respondents could also add other aspects in an open field.

Considering T3, focused on deploying immersive environments, the relevance of researching of conducting research on a single issue was evaluated, namely:

Q6 – Integration of immersive environments with learning management systems.

There were eleven aspects under research relevance evaluation ($A_{6,1}$, …, $A_{6,11}$), related to creating/identifying solutions for collecting student data and needs (progress, assessment, monitoring), acting upon them (extra resources, feedback, guidance, task adjustment), organizational aspects (system integration, data analysis perspectives, technical staff training, time coherence of the experience). Respondents could also add other aspects in an open field.

The second part of the questionnaire (topic 4) refers to personal information, namely gender, age (divided into 5 classes), academic qualifications (5 options) an open field of expertise, years of experience with immersive environments and/or virtual worlds (3 options), an open field for research area, the number of research papers on immersive environments and/or virtual worlds published in the past 3 years (5 options). Finally, the questionnaire finishes with an open question for final comments.

3.3 Data collection procedures

We implemented the questionnaire online using Google Forms. Then we proceeded to harvest e-mail contacts for members of the iLRN community presented in Table 1. Of the possible 622 individuals, we managed to collect 453 e-mail addresses, covering 72,8% of the population.

The questionnaire link was then sent to these e-mail addresses on June 6, 2018 via the official Immersive Learning Research Network mailing service, signed by the ILRN Leadership Committee, and referring further questions to Prof. Leonel Morgado. On June 21, 2018, personal reminders were sent by Prof. Leonel Morgado, from his academic e-mail encouraging participation. These were sent to all addresses, since the anonymous nature of the questionnaire prevented us from knowing which recipients had already responded. Further, verbal calls for participation were made during talks of the iLRN 2018 conference (June 24th – 29th, 2018. Western Montana, USA). The response period ran from June 6, 2018 to July 15, 2018 and resulted in 54 complete responses, corresponding to 8.7% of the population.

The Google Forms output in comma-separated values format was then imported into Microsoft Excel and tabulated for easier reading. Responses to open-ended questions were appended to the tables (example: Fig. 2).

	Question 1	Not relevant	A little relevant	Somewhat relevant	Very relevant	Extremely relevant	Unsure
1	Studying the consequences for the learning context of adopting immersive environments based on client-server vs. peer-to-peer networking.	3	6	12	21	10	2
2	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.	4	7	13	21	7	2
3	Analysing which educational management methods for teach-ers, trainers, and educational organizations using immersive environments would these alter-native network models imply.	0	9	7	20	16	2
4	Researching aspects impacting the daily work of network ad-ministrators, such as network behaviour of immersive envi-ronments (configurations, per-formance impact, security, costs).	5	3	18	19	6	3
5	Researching the relationship between network behaviour of immersive environments (con-figurations, performance impact, security, costs) and specific ed-ucational activities.	1	5	14	18	12	4
Other aspects:		From my perspective, the technology for delivery is not so much of interest; the focus should be on what the added value for users (i.e. teachers/students) is. If there is a pertinent link between delivery technology and that, then that may be of relevance.					
		I personally don't think that centralised vs de-centralised network configurations have that much of an impact on the learning process and outcomes - only very indirectly if for instance performance or response time were impacted.					

Fig. 2 Sample tabulation of results in Microsoft Excel

3.4 Respondents

The 54 respondents were mostly male (63%), with females comprising 37%. By age, there were no respondents 24 years-old (yo) or younger, and evenly split between 25-45 yo and older. 70% were aged between 36 and 54 yo (Fig. 3).

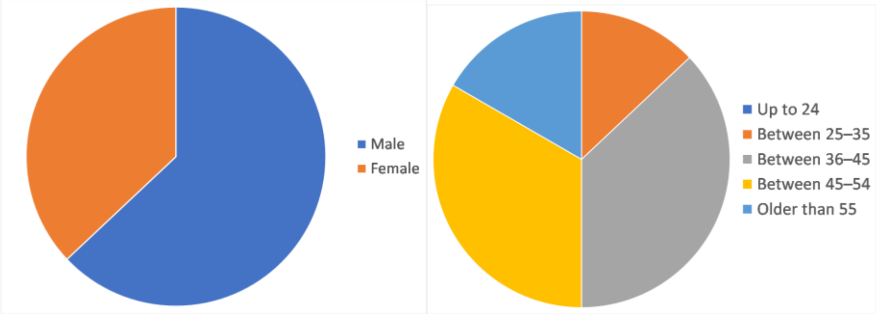

Fig. 3 Respondents distribution by gender (left) and age groups (right)

Regarding academic qualifications, 68.5% hold a doctoral degree (PhD/EdD), 27.8% hold a master's degree and 3.7% a graduate degree (BSc/BEd/BA/BEng or similar).

The respondents' years of experience with immersive environments are evenly distributed among the three categories: up to 5 years of experience (35%), between 5 and 10 years (28%), and more than 10 years of experience (37%). The distribution of published papers indicates that 24% of respondents had not published any paper in the field of immersive environments, 35% up to 3 papers in this field, 24% between 4-6 papers in this field, 4% between 7-9 papers in this field, and 13% published 10 or more papers in this field. Both aspects are illustrated in Fig. 4.

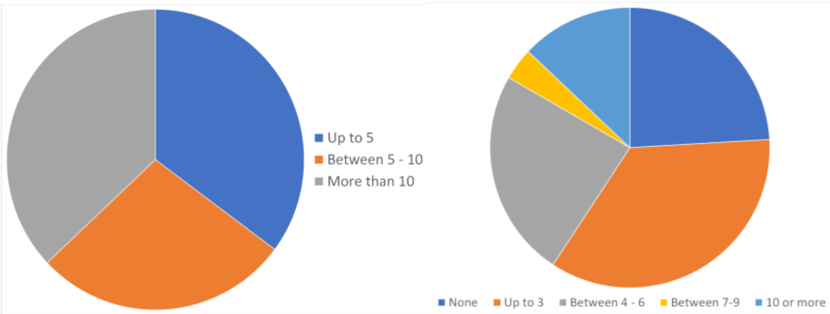

Fig. 4 Respondents' years of experience with immersive environments (left) and number of published papers in this field (right).

Their fields of expertise and research areas were extremely varied, almost entirely singular. Thus we grouped them by categories (Fig. 5): Game Studies ("design and development of serious games", "gaming environments", or similar), Digital Heritage (as such or similar, plus "history of art"), Human-Computer Interaction (as such, plus "computer graphics", "multimodal interfaces", "intelligent environments", and similar), Computer Science (as such, plus "artificial intelligence", "ICT", "distributed systems", "opinion mining", and similar), Educational Technology (as such, plus "technology-enhanced learning", "learning technology", "avatars and education", and similar), Immersive Technology ("augmented and virtual reality" and its variations, "immersive applications and experiences", and similar), Education and Didactics, 22% (as such, plus "immersive learning", "engineering education", "e-learning, learning", "motivation", "assessment", "autism", and similar), and others ("theoretical physics").

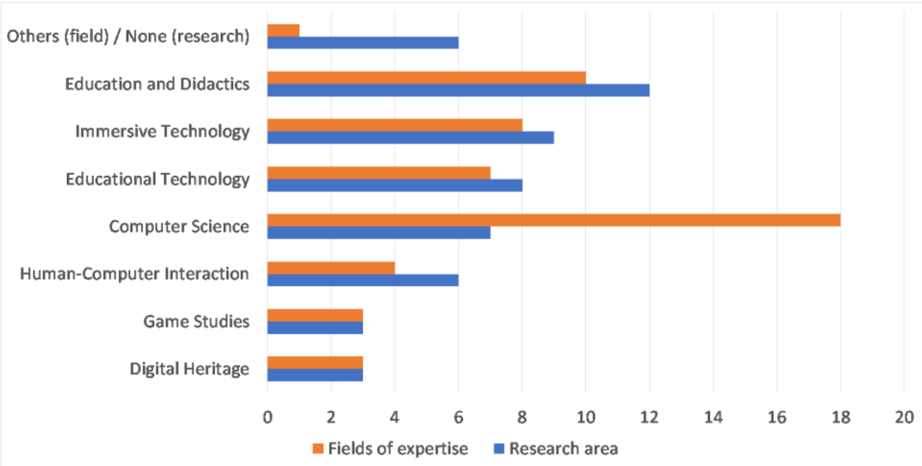

Fig. 5 Respondents' fields of expertise (orange/light) and current research areas (blue/dark).

As shown in Fig. 5, a large number of respondents stemmed from Computer Science as a field of expertise (33%), but only a fraction report working in areas of research with such a core technological focus (13%). The current research areas of respondents are similarly distributed between Education and Didactics (22%), Immersive Technology (17%), Educational Technology (15%), Computer Science (13%), and Human-Computer Interaction (11%), with a small number of respondents active researching in Game Studies (6%) and Digital Heritage (6%). 11% also reported not having currently an area of research.

Were we to consider that responders developed their research focus strictly within their specific fields, then for the 8 categories the correlation between Field of Expertise (which we will denote as X) and Current Research Areas (denoted by Y) would be very close to 1. However, if responders developed a more interdisciplinary or transdisciplinary research approach, this would not be verified. The differences visible in Fig. 5 hinted towards this latter possibility, which we test below.
For the correlation analysis we used the Spearman coefficient for a sample of data – r_s – a common non-parametric option as a correlation measure based on ranks. If each of the n measurements of one of the variables is denoted X_i , $i=1, \ldots, n$, then $R(X_i)$ may represent the rank of X_i , where each rank is an integer from 1 through n, indicating relative magnitude. The measurements may be ranked from high to low (e.g. rank 1 indicates the biggest number of respondents, rank 2 the next biggest

number of respondents, and so on, with rank n as the smallest one) or, otherwise, from low to high (rank 1 denotes the smallest one and rank n the biggest one). Similarly, each of the n measurements of the second variable may be denoted as Y_i (i.e. Y_1, Y_2, ... , Y_n), and $R(Y_i)$ denote the rank of Y_i , where the sequence of ranking (either order) is the same as for $R(X_i)$. The results for tied and non-tied data can differ, but only if a big number of ties occur. In tie cases, two or more data items have the same numerical value, and each of their ranks may be set equal to the mean of the ranks of the positions they occupy in the ordered data set. This is shown in Table 2. The values of the observed differences, d_i for each pair of ranks were also obtained and represented in Table 2.

Table 2. iLRN community respondents: fields of expertise and current research areas

Categories	Fields of Expertise X_i	Rank $R(X_i)$	Current Research Areas Y_i	Rank $R(Y_i)$	Diferences $D_i=R(X_i)-R(Y_i)$
Others / None	1	8	6	6.5	1.5
Education and Didactics	10	2	12	1	1
Immersive Technologies	8	3.5	9	2	1.5
Educational Technology	8	3.5	7	4.5	-1
Computer Science	7	5	8	3	2
Human-Computer Interaction	18	1	7	4.5	-3.5
Game Studies	4	6	6	6.5	-0.5
Digital Heritage	2	7	2	7	0

Considering n categories, the following equation was used to calculate the Spearman's correlation coefficient: $r_s = 1 - \frac{6\sum_{i=1}^{n}(d_i)^2}{n(n^2-1)}$

Thus, in our case, where $n=8$:

$$r_s = 1 - \frac{6\sum_{i=1}^{8}(d_i)^2}{n(n^2-1)} = 1 - \frac{6(23)}{8(63)} \approx 0.73$$

Notice that the results for tied and non-tied data are only noticeably different if there is a big number of ties. The r_S calculated from a sample of data is an estimate of ρ_S, the Spearman rank correlation coefficient that would be obtained from the entire population of data from which that sample came; ρ_S is known as the "Spearman's rho". A common desire in rank correlation analysis is to test the null hypothesis that there is no correlation in the population between the paired ranks, i.e. we wish to test the two-tailed hypotheses:

H0: ρ_S=0 versus H1: $\rho_S \neq 0$.

Published tables offer critical values of r_S for various sample sizes *n*, and several levels of significance α. If r_S is greater than the relevant critical value, then *H0* is rejected. A different way to write our hypothesis for the current case as described in table 1 is:

H0: There is no association between the Fields of Expertise and the Current Research Areas (i.e., respondents are mostly inter- or trans-disciplinary in their research)

versus

H1: There is association between the Fields of Expertise and the Current Research Areas (i.e., respondents stay mostly within their specific fields in their research)

For n=8 and for the significance level α=5% the Spearman's table for a bilateral test is 0.738. In this case rs =0.73<0.738 and so, at the significance level of 5%, we do not reject the null hypothesis that there is no association between the Fields of Expertise and the Current Research Areas. That is, we cannot reject that respondents are mostly inter- or trans-disciplinary in their research.

This supports the conclusion that in the iLRN community, according to this sample, the researchers are not restricted to conducting research only within their fields of expertise but rather that they are attracted to multidisciplinary areas.

4 Results

In this section, we present the answers collected from the 54 respondents for each issue (Q_j), j=1,…,6 of each topic (T_k), k=1,2,3 expressing how relevant they consider each aspect (A), as an area of interest for the global research community to pursue in the future. These are presented in the subsections, alongside charts (Figs 6-48).

4.1 T1 - Accessing Immersive Environments

Q1 - The impact of different distribution models of computer networking on educational activities (both at the individual and organizational levels)

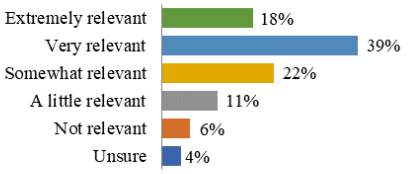

Figure 6

A1: Studying the consequences for the learning context of adopting immersive environments based on client-server vs. peer-to-peer networking.
Most respondents (57%) consider this aspect as very/extremely important. 22% find it somewhat relevant, and 17% find it little/not relevant. 4% unsure (Fig. 6).

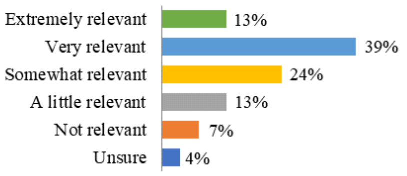

Figure 7

A2: 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.
The majority of the respondents (52%) consider this aspect very/extremely important. 24% find it somewhat relevant, and 20% find it little/not relevant. 4% unsure (Fig. 7).

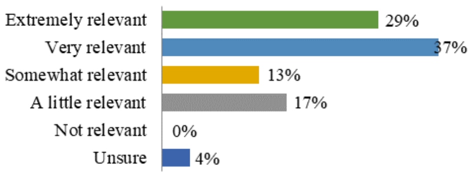

Figure 8

A3: Analysing which educational management methods for teachers, trainers, and educational organizations using immersive environments would these alter-native network models imply.
Most respondents (66%) consider this aspect very/extremely relevant. 13% find it somewhat relevant. 17% find it little/not relevant. 4% unsure (Fig. 8).

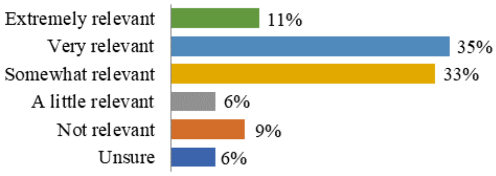

Figure 9

A4: Researching aspects impacting the daily work of network administrators, such as network behaviour of immersive environments (configs., performance impact, security, costs).
46% of the respondents find this aspect very/extremely relevant. 33% find it somewhat relevant. 15% find it little/not relevant. 6% unsure (Fig. 9).

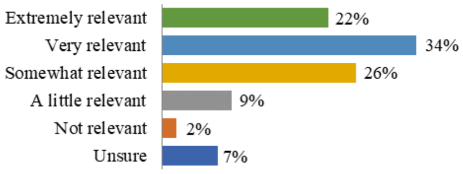

Figure 10

A5: Researching the relationship between network behaviour of immersive environments (configs., performance impact, security, costs) and specific educational activities.
Most respondents (56%) consider this aspect very/extremely relevant. 26% find it somewhat relevant. 11% find it little/not relevant. 7% unsure (Fig. 10).

Q2 - Issues related to the software being used for immersive environments

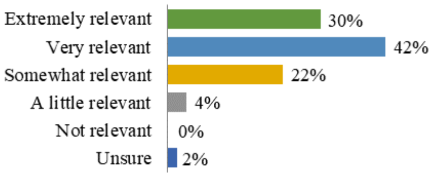

Figure 11

A1: Identifying the value of being able to use standard browsers for accessing the immersive environment rather than installing specific applications.
Most respondents (72%) consider this aspect very/extremely relevant. 22% find it somewhat relevant. 4% find it little/not relevant.2% unsure (Fig. 11).

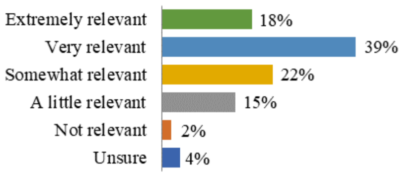

Figure 12

A2: Analysing the feasibility of requiring the use of applications that need be installed in users' or school's machines.
The majority of respondents (57%) consider this aspect very/extremely relevant. 22% find it somewhat relevant and 17% find it little/not relevant. 4% unsure (Fig. 12).

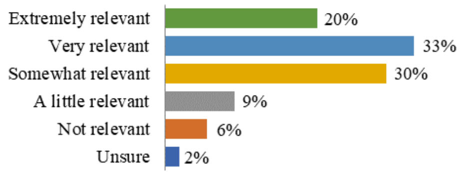

Figure 13

A3: Studying the risk of software conflicts or hardware shortcomings of immersive environment software.

The majority of respondents (53%) consider this aspect very/extremely relevant. 30% find it somewhat relevant and 15% find it little/not relevant. 2% unsure (Fig. 13).

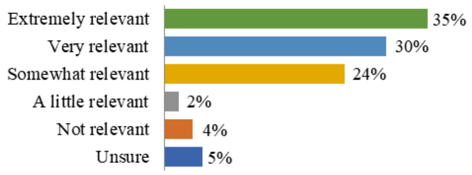

Figure 14

A4: Identifying security vulnerabilities and tactics used for malicious exploit of these network-aware applications.

Most respondents (65%) consider this aspect very/extremely relevant. 24% find it somewhat relevant. 6% find it little/not relevant. 5% unsure (Fig. 14).

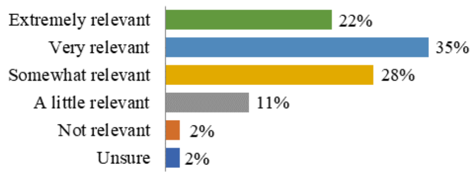

Figure 15

A5: Identifying methods to streamline installation and updating of immersive environment software.

The majority of respondents (57%) consider this aspect very/extremely relevant. 28% find it somewhat relevant and 13% find it little/not relevant. 2% unsure (Fig. 15).

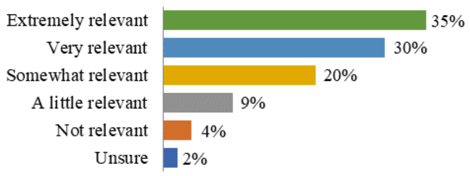

Figure 16

A6: Identifying methods to manage, monitor, track, and debug immersive environment software.

Most respondents (65%) consider this aspect very/extremely relevant. 20% find it somewhat relevant and 13% find it little/not relevant. 2% unsure (Fig. 16).

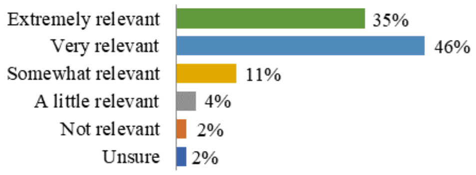

Figure 17

A7: Studying the operational behaviour of immersive environments on Web browsers (e.g., usability, interfaces, vulnerabilities).

Most respondents (81%) consider this aspect very/extremely relevant. 11% find it somewhat relevant and 6% find it little/not relevant. 2% unsure (Fig. 17).

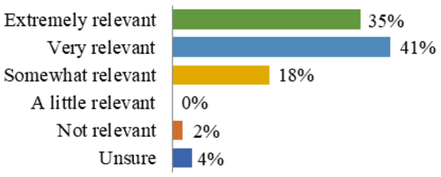

Figure 18

A8: Identifying learning contexts where using video streaming can render immersive environments feasible.

Most respondents (76%) consider this aspect very/extremely. 18% find it somewhat relevant. 2% find it little/not relevant. 4% unsure (Fig. 18).

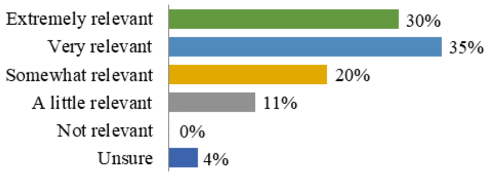

Figure 19

A9: Identifying learning contexts where using video streaming is not feasible for using immersive environments.

Most respondents (65%) consider this aspect very/extremely relevant. 20% find it somewhat relevant and 11% find it little/not relevant. 4% unsure (Fig. 19).

Q3 - The level of connection between participants and resources

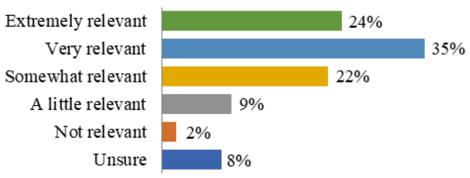

Figure 20

A1: 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).

The majority of respondents (59%) consider this aspect very/extremely relevant. 22% find it somewhat relevant and 11% find it little/not relevant. 8% unsure (Fig. 20).

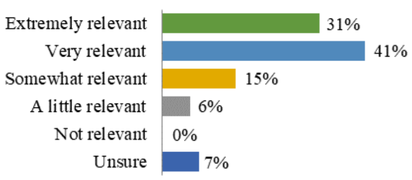

Figure 21

A2: Creating / Identifying technological solutions to enable resources to be shared across different immersive environments.

Most respondents (72%) consider this aspect very/extremely relevant. 15% find it somewhat relevant and 6% find it little/not relevant. 7% unsure (Fig. 21).

A3: Creating / Identifying technological solutions to enable users to access different immersive environments without requiring new login procedures.

50% of the respondents consider this very/extremely relevant. 30% find it somewhat relevant and 15% find it little /nothing relevant. 5% unsure (Fig. 22).

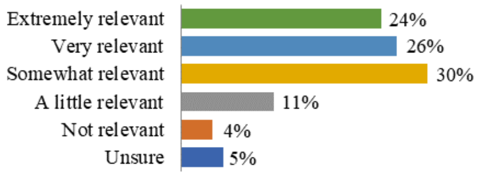

Figure 22

A4: Creating / Identifying technological solutions to enable users' virtual personas (i.e. avatars) to access different immersive environments.

A majority of respondents (61%) consider this aspect very/extremely relevant. 24% find it somewhat relevant, and 11% find it little/not relevant. 4% unsure (Fig. 23).

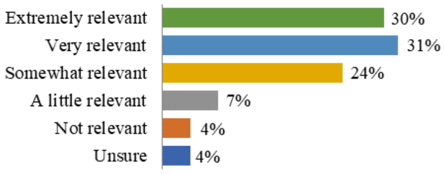

Figure 23

A5: Studying scaling and security issues, at the technological level, of sharing users and resources across different immersive environments.

Most respondents (66%) consider this very/extremely relevant. 22% find it somewhat relevant, and 8% find it little/not relevant. 4% unsure (Fig. 24).

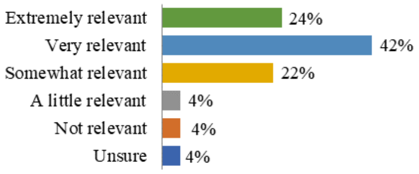

Figure 24

A6: Studying the relevance, for 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.

The majority of respondents (59%) consider this aspect very/extremely relevant. 24% find it somewhat relevant, and 13% find it little/not relevant. 4% unsure (Fig. 25).

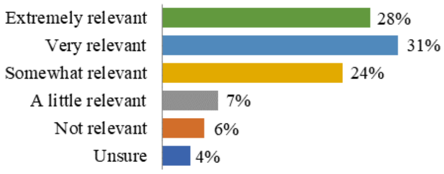

Figure 25

4.2 T2 - Producing Content in/for Immersive Environments

Q4 - Content production by technical experts

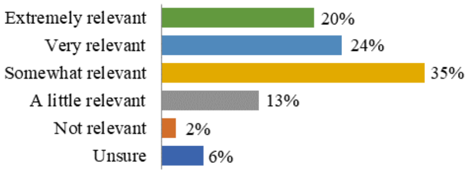

Figure 26

A1: Identifying the impact on technical workload and project risk of adopting some production tools over others (for content production by experts).
A minority of respondents (44%) consider this aspect very/extremely relevant. 35% find it somewhat relevant, and 15% find it little/not relevant. 6% unsure (Fig. 26).

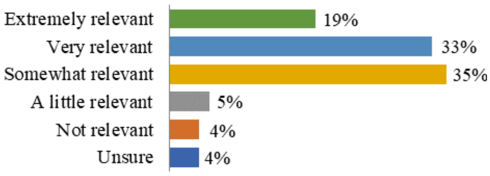

Figure 27

A2: Identifying the impact on technical development flexibility (e.g., changes, updates) of adopting some production tools over others (for content production by experts).
The majority of respondents (52%) consider this aspect very/extremely relevant. 35% find it somewhat relevant, and 9% find it little/not relevant. 4% unsure (Fig. 27).

Q5 - Participation of non-technical users (educational actors)

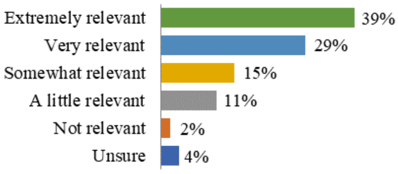

Figure 28

A1: Studying the development processes of immersive environment content by non-technical users.
Most respondents (68%) consider this aspect very/extremely relevant. 15% find it somewhat relevant, and 13% find it little/not relevant. 4% unsure (Fig. 28).

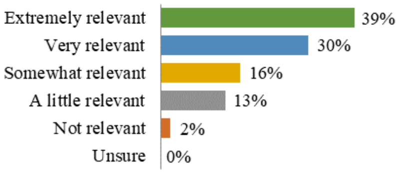

Figure 29

A2: Studying the adequacy of current development tools for immersive environment content geared towards non-technical users.
Most respondents (69%) consider this aspect very/extremely important. 16% find it somewhat relevant, and 15% find it little/not relevant. 0% unsure (Fig. 29).

A3: Designing training methods for development tools of immersive environment content geared towards non-technical users.

Most respondents (74%) consider this aspect very/extremely relevant. 15% find it somewhat relevant, and 9% find it little/not relevant. 2% unsure (Fig. 30).

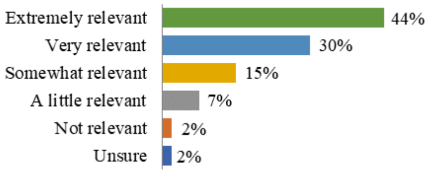

Figure 30

A4: Creating / Identifying development tools that enable non-technical users to create interactive behaviours for objects in immersive environments.

Most respondents (79%) consider this aspect very/extremely relevant. 15% find it somewhat relevant, and 2% find it little/not relevant. 4% unsure (Fig. 31).

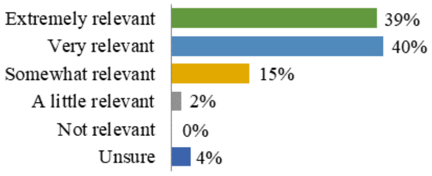

Figure 31

A5: Creating / Identifying development tools that enable non-technical users to create interactive virtual characters for immersive environments.

Most respondents (72%) consider this aspect very/extremely relevant. 20% find it somewhat relevant, and 4% find it little/not relevant. 4% unsure (Fig. 32).

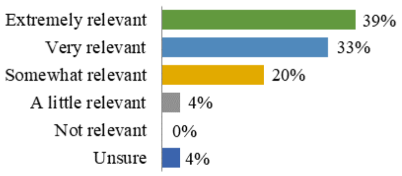

Figure 32

A6: Creating / Identifying development tools that enable non-technical users to define virtual characters' behaviours by demonstrating what is intended and generalizing from that demonstration.

The majority of respondents (61%) consider this aspect very/extremely relevant. 24% find it somewhat relevant, and 8% find it little/not relevant. 7% unsure (Fig. 33).

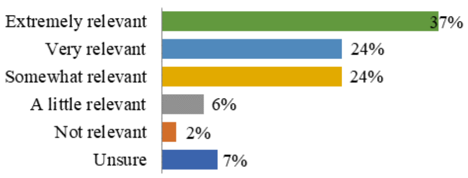

Figure 33

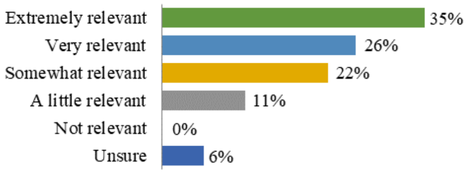

Figure 34

A7: Creating / Identifying development tools that enable non-technical users to create choreographies of groups of virtual characters for immersive environments.

The majority of respondents (61%) consider this aspect very/extremely relevant. 22% find it somewhat relevant, and 11% find it little/not relevant. 6% unsure (Fig. 34).

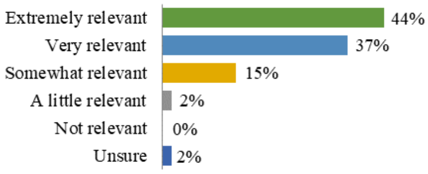

Figure 35

A8: Creating / Identifying development tools that enable non-technical users to create interactive stories with multiple virtual characters for immersive environments.

Most respondents (81%) consider this aspect very/extremely relevant. 15% find it somewhat relevant, and 2% little/not relevant. 2% unsure (Fig. 35).

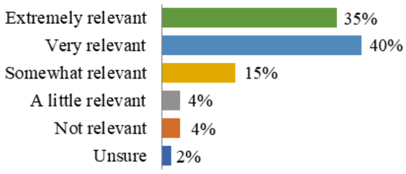

Figure 36

A9: Creating / Identifying development 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.

Most respondents (75%) consider this aspect very/extremely important. 15% find it somewhat relevant, and 8% find it little/not relevant. 2% unsure (Fig. 36).

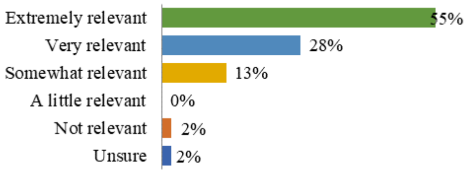

Figure 37

A10: Creating / Identifying development tools that enable non-technical users to produce content collaboratively.

Most respondents (83%) consider this aspect very/extremely important. 13% find it somewhat relevant, and 2% find it little/not relevant.2% unsure (Fig. 37).

4.3 T3 - Deploying Immersive Environments

Q6 - Integration of immersive environments with learning management systems

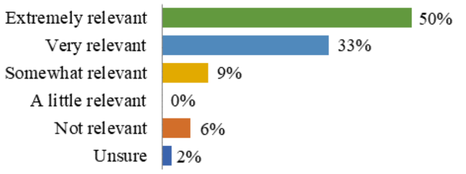

Figure 38

A1: Creating/Identifying solutions for tracking student progress while doing assignments in immersive environments.

Most respondents (83%) consider this aspect very/extremely relevant. 9% find it somewhat relevant, 6% find it little/not relevant. 2% unsure (Fig. 38).

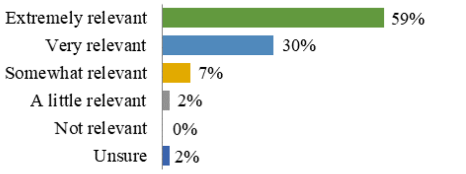

Figure 39

A2: Creating/Identifying solutions for teachers/trainers to be able to identify learning support needs and provide extra resources directly within immersive environments.

Most respondents (89%) consider this aspect very/extremely relevant. 7% find it somewhat relevant, 2% find it little/not relevant. 2% unsure (Fig. 39).

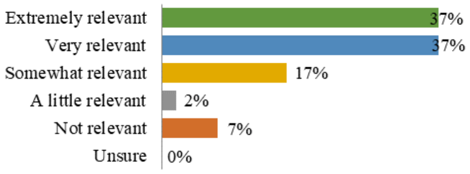

Figure 40

A3: Creating/Identifying solutions for learning management systems to collect student assessment data from immersive environments.

Most respondents (74%) consider this aspect very/extremely relevant. 17% find it somewhat relevant, and 9% find it little/nothing relevant. 0% unsure (Fig. 40).

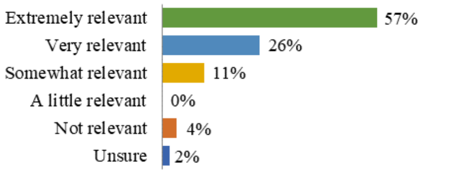

Figure 41

A4: Creating/Identifying solutions for learning management systems to provide feedback and guidance to learners directly within immersive environments.

Most respondents (83%) consider this very/extremely relevant. 11% find it somewhat relevant, and 4% find it little/not relevant. 2% unsure (Fig. 41).

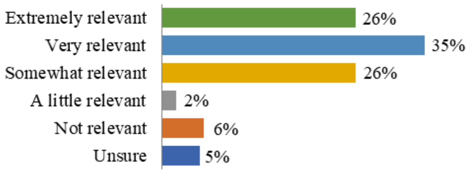

Figure 42

A5: Creating/Identifying solutions enabling learning management systems to manipulate the content of the immersive environment.

The majority of respondents (61%) consider this aspect very/extremely relevant. 26% find it somewhat relevant, and 8% find it little/not relevant. 5% unsure (Fig. 42).

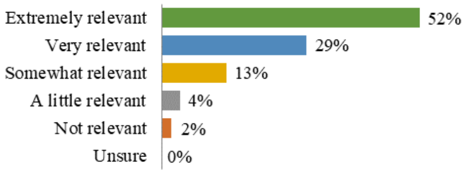

Figure 43

A6: Creating/Identifying solutions enabling learning management systems to adjust tasks within an immersive environment according to the learner's knowledge or skill levels.

Most respondents (81%) consider this aspect very/extremely relevant. 13% find it somewhat relevant, 6% find it little/not relevant. 0% unsure (Fig. 43).

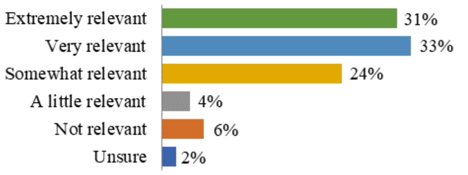

Figure 44

A7: Ascertaining the sets of requirements for improving the integration of immersive environments with learning management systems.

Most respondents (64%) consider this aspect very/extremely relevant. 24% find it somewhat relevant, 8% find it little/not relevant. 2% unsure (Fig. 44).

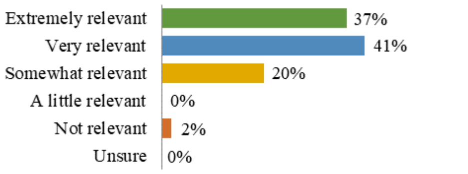

Figure 45

A8: Creating/Identifying solutions for recording what happens within an immersive environment from the users' perspective.

Most respondents (78%) consider this aspect very/extremely relevant. 20% find it somewhat relevant, 2% find it little/not relevant. 2% unsure (Fig. 45).

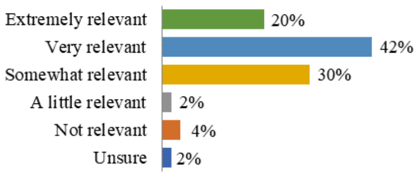

Figure 46

A9: Creating/Identifying solutions for recording what happens within an immersive environment from a user-independent perspective.

The majority of respondents (62%) consider this aspect very/extremely relevant. 30% find it somewhat relevant, and 6% find it little/not relevant. 2% unsure (Fig. 46).

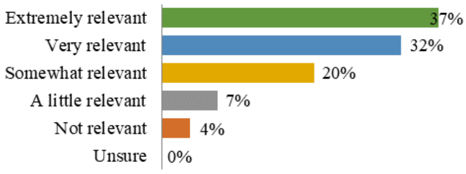

Figure 47

A10: Identifying technical support staff training needs to support the deployment of immersive environments at organizations.

Most respondents (69%) consider this aspect very/extremely relevant. 20% find it somewhat relevant, and 11% find it little/not relevant. 0% unsure (Fig. 47).

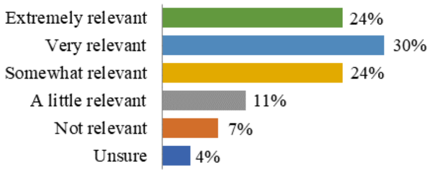

Figure 48

A11: Ensuring that all users within an immersive environment witness the same occurrences at the same time.

The majority of respondents (54%) consider this aspect very/extremely relevant. 24% find it somewhat relevant, and 18% find it little/not relevant. 4% unsure (Fig. 48).

5 Analysis and Discussion

5.1 Overall

We ranked all aspects, by considering their combined responses for “extremely relevant” and “very relevant”. As a first tiebreaker, we considered the number of “somewhat relevant” responses. As a second tiebreaker, we considered the smallest number of “Not relevant”. We did not use “Unsure” answers for ranking. The resulting rank is presented in table 2. We present it visually in Fig. 49, color-coded per topic.

Table 2. Ranking of aspects per relevance as an area of interest for the global research community to pursue in the future

Rank	T	Q	A	Aspect	Very+ Extremely	Tie-break 1 (Somewhat)	Tie-break 2 (smaller Not)
1	3	6	2	Creating/Identifying solutions for teachers/trainers to be able to identify learning support needs and provide extra resources directly within immersive environments.	89%	7%	
2	2	5	10	Creating/Identifying development tools that enable non-technical users to produce content collaboratively.	83%	13%	
3	3	6	4	Creating/Identifying solutions for learning management systems to provide feedback and guidance to learners directly within immersive environments.	83%	11%	
4	3	6	1	Creating/Identifying solutions for tracking student progress while doing assignments in immersive environments.	83%	9%	
5	2	5	8	Creating/Identifying development tools that enable non-technical users to create interactive stories with multiple virtual characters for immersive environments.	81%	15%	
6	3	6	6	Creating/Identifying solutions enabling learning management systems to adjust tasks within an immersive environment according to the learner's knowledge or skill levels.	81%	13%	
7	1	2	7	Studying the operational behaviour of immersive environments on Web browsers (e.g., usability, interfaces, vulnerabilities).	81%	11%	
8	2	5	4	Creating/Identifying development tools that enable non-technical users to create interactive behaviours for objects in immersive environments.	79%	15%	
9	3	6	8	Creating/Identifying solutions for recording what happens within an immersive environment from the users' perspective.	78%	20%	
10	1	2	8	Identifying learning contexts where using video streaming can render immersive environments feasible.	76%	18%	
11	2	5	9	Creating/Identifying development 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.	76%	15%	
12	3	6	3	Creating/Identifying solutions for learning management systems collect student assessment data from immersive environments.	74%	17%	
13	2	5	3	Designing training methods for development tools of immersive environment content geared towards non-technical users.	74%	15%	
14	1	2	1	Identifying the value of being able to use standard browsers for accessing the immersive	72%	22%	

				environment rather than installing specific applications.			
15	2	5	5	Creating/Identifying development tools that enable non-technical users to create interactive virtual characters for immersive environments.	72%	20%	
16	1	3	2	Creating/Identifying technological solutions to enable users to access different immersive environments without requiring new login procedures.	72%	15%	
17	3	6	10	Identifying technical support staff training needs to support the deployment of immersive environments at organizations.	69%	20%	
18	2	5	2	Studying the adequacy of current development tools for immersive environment content geared towards non-technical users.	69%	16%	
19	2	5	1	Studying the development processes of immersive environment content by non-technical users.	68%	15%	
20	1	3	5	Studying the relevance, for 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.	66%	22%	
21	1	1	3	Analysing which educational management methods for teachers, trainers, and educational organizations using immersive environments would these alternative network models imply.	66%	13%	
22	1	2	4	Identifying security vulnerabilities and tactics used for malicious exploit of these network-aware applications.	65%	24%	7%
23	3	6	7	Ascertaining the sets of requirements for improving the integration of immersive environments with learning management systems.	65%	24%	11%
24	1	2	9	Identifying learning contexts where using video streaming is not feasible for using immersive environments.	65%	20%	0%
25	1	2	6	Identifying methods to manage, monitor, track, and debug immersive environment software.	65%	20%	7%
26	3	6	9	Creating/Identifying solutions for recording what happens within an immersive environment from a user-independent perspective.	63%	30%	
27	3	6	5	Creating/Identifying solutions enabling learning management systems to manipulate the content of the immersive environment.	61%	26%	
28	2	5	6	Creating/Identifying development tools that enable non-technical users to define virtual characters' behaviours by demonstrating what is intended and generalizing from that demonstration.	61%	24%	4%
29	1	3	4	Studying scaling and security issues, at the technological level, of sharing users and	61%	24%	7%

				resources across different immersive environments.			
30	2	5	7	Creating/Identifying development tools that enable non-technical users to create choreographies of groups of virtual characters for immersive environments.	61%	22%	
31	1	3	6	Studying the relevance, for 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.	59%	24%	
32	1	3	1	Creating/Identifying technological solutions to enable resources to be shared across different immersive environments.	59%	22%	
33	1	2	5	Identifying methods to streamline installation and updating of immersive environment software.	57%	28%	
34	1	2	2	Analysing the feasibility of requiring the use of applications that need be installed in users' or school's machines.	57%	22%	4%
35	1	1	1	Studying the consequences for the learning context of adopting immersive environments based on client-server vs. peer-to-peer networking.	57%	22%	11%
36	1	1	5	Researching the relationship between network behaviour of immersive environments (configurations, performance impact, security, costs) and specific educational activities.	56%	26%	
37	1	2	3	Studying the risk of software conflicts or hardware shortcomings of immersive environment software.	54%	30%	
38	3	6	11	Ensuring that all users within an immersive environment witness the same occurrences at the same time.	54%	24%	
39	2	4	2	Identifying the impact on technical development flexibility (e.g., changes, updates) of adopting some production tools over others (for content production by experts).	52%	35%	
40	1	1	2	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.	52%	24%	
41	1	3	3	Creating/Identifying technological solutions to enable users' virtual personas (i.e. avatars) to access different immersive environments.	50%	30%	
42	1	1	4	Researching aspects impacting the daily work of network administrators, such as network behaviour of immersive environments (configurations, performance impact, security, costs).	46%	33%	

43	2	4	1	Identifying the impact on technical workload and project risk of adopting some production tools over others (for content production by experts).	44%	35%

From the first ranked aspect to the last, there is no obvious gap or groupings, with relevance results decreasing almost linearly down the ranking. However, if we consider the aspects per topic, as Fig. 49 illustrates, different groupings emerge. These enable us to highlight the most relevant aspects overall.

In T1 - Accessing Immersive Environments, Group T1-1 is composed by four aspects whose combined responses for very/extremely relevant are greater than 70%:

- T1Q2A7, Studying the operational behaviour of immersive environments on Web browsers (e.g., usability, interfaces, vulnerabilities).
- T1Q2A8, Identifying learning contexts where using video streaming can render immersive environments feasible.
- T1Q2A1, Identifying the value of being able to use standard browsers for accessing the immersive environment rather than installing specific applications.
- T1Q3A2, Creating/Identifying technological solutions to enable users to access different immersive environments without requiring new login procedures.

The following T1 group visible in Fig. 49 comprises five aspects where 65%<=Very+Extremely<70% (Group T1-2). Group T1-3 comprises all other eleven aspects, where Very+Extremely<65%.

In T2 - Producing Content in/for Immersive Environments, Group T2-1 is composed by eight aspects whose combined responses for very/extremely relevant are greater than 65%:

- T2Q5A10, Creating/Identifying development tools that enable non-technical users to produce content collaboratively.
- T2Q5A8, Creating/Identifying development tools that enable non-technical users to create interactive stories with multiple virtual characters for immersive environments.
- T2Q5A4, Creating/Identifying development tools that enable non-technical users to create interactive behaviours for objects in immersive environments.
- T2Q5A9, Creating/Identifying development 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.
- T2Q5A3, Designing training methods for development tools of immersive environment content geared towards non-technical users.
- T2Q5A5, Creating/Identifying development tools that enable non-technical users to create interactive virtual characters for immersive environments.
- T2Q5A2, Studying the adequacy of current development tools for immersive environment content geared towards non-technical users.

- T2Q5A1, Studying the development processes of immersive environment content by non-technical users

The following T2 group visible in Fig. 49 comprises two aspects where 60%<Very+Extremely<65% (Group T2-2). Group T2-3 comprises the two remaining aspects, for which Very+Extremely<55%.

In T3 - Deploying Immersive Environments, Group T3-1 is comprised of a single aspect, T3Q6A2, with Very+Extremely=89%. Group T3-2 is composed by five aspects, which however are also high-relevance, with 74%<=Very+Extremely<85%:

- Group 1:
    - T3Q6A2, Creating/Identifying solutions for teachers/trainers to be able to identify learning support needs and provide extra resources directly within immersive environments.
- Group 2:
    - T3Q6A4, Creating/Identifying solutions for learning management systems to provide feedback and guidance to learners directly within immersive environments.
    - T3Q6A1, Creating/Identifying solutions for tracking student progress while doing assignments in immersive environments.
    - T3Q6A6, Creating/Identifying solutions enabling learning management systems to adjust tasks within an immersive environment according to the learner's knowledge or skill levels.
    - T3Q6A8, Creating/Identifying solutions for recording what happens within an immersive environment from the users' perspective.
    - T3Q6A3, Creating/Identifying solutions for learning management systems collect student assessment data from immersive environments.

The following T3 group, T3-3, comprises the single aspect T3Q6A10 (Very+Extremely = 69%). T3-4 comprises aspects with 60%<Very+Extremely<=65%, and T3-5 comprises the single aspect T3Q6A11.

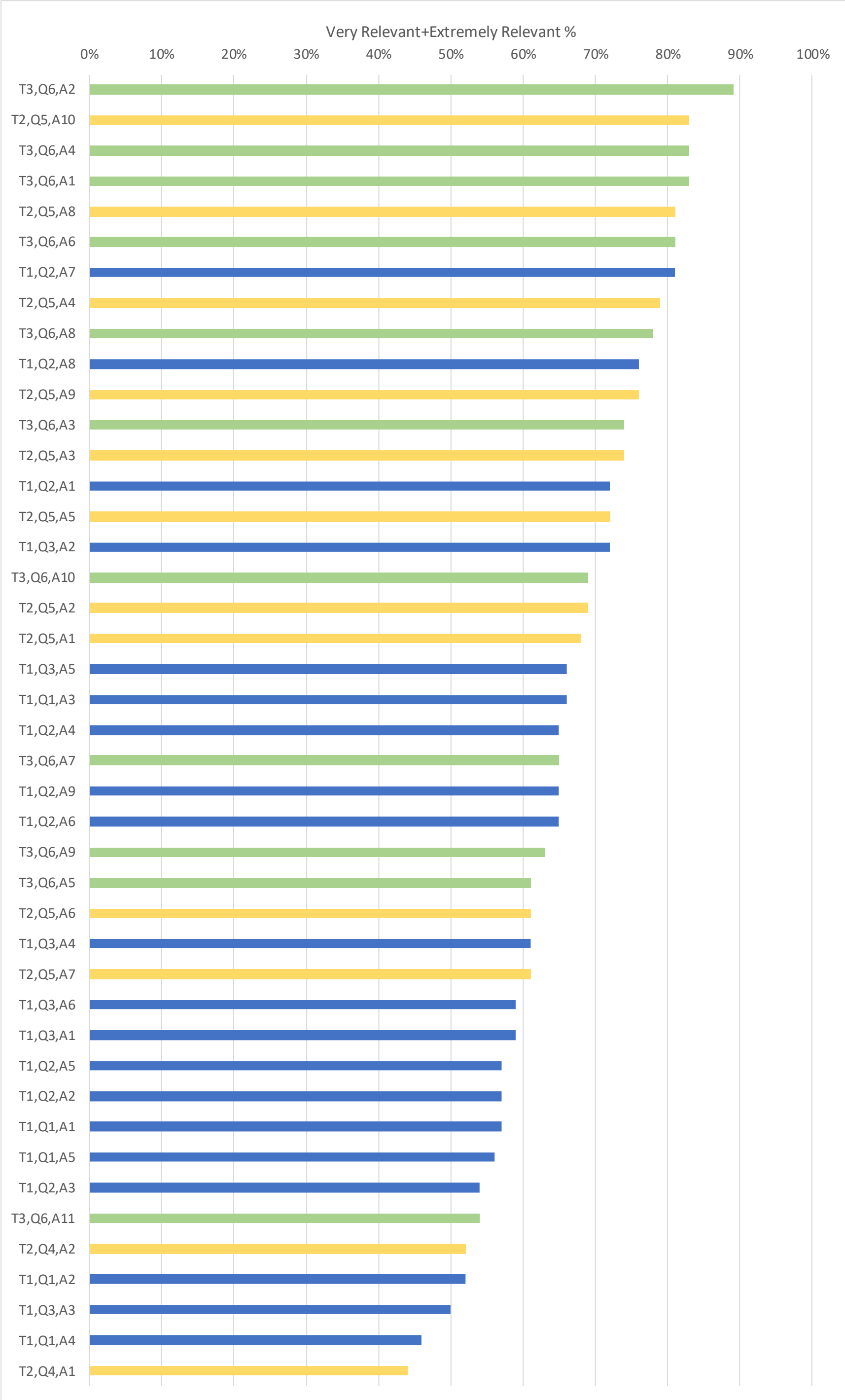

Fig. 49. Aspects ranked color-coded by topic: T1 blue; T2 light orange; T3 light green.

5.2 Per topic and issue

To compare the relative relevance of topics and issues, we averaged the very+extremely relevant responses for each, resulting in Table 3.

Table 3. Average relevance per topic (T) and issue (Q)

Topic & Issue	Average relevance
T1 - Accessing Immersive Environments	62%
T1Q1 - The impact of different distribution models of computer networking on educational activities (both at the individual and organizational levels)	55%
T1Q2 - Issues related to the software being used for immersive environments	66%
T1Q3 - The level of connection between participants and resources	61%
T2 - Producing Content in/for Immersive Environments	68%
T2Q4 - Content production by technical experts	48%
T2Q5 - Participation of non-technical users (educational actors)	72%
T3 - Deploying Immersive Environments	73%
T3Q6 - Integration of immersive environments with learning management systems	73%

The most relevant issues are Q6, dealing with integration with learning management systems and Q5, dealing with the participation of non-technical users in the content production process. The least relevant issues are Q4, dealing with aspects of content production by technical experts, and Q1, dealing with the impact on educational activities of different models of computer networking. Mid-relevance issues are Q2, dealing with the software being used, and Q3, dealing with the interconnection aspects (technology lock-in, sharing virtual resources, combining different environments).

6 Conclusions

We have surveyed the iLRN community of researchers and practitioners, involved in immersive learning, to ascertain the relevance and priority of various challenges to the adoption of immersive learning technology. This sampling technique has a certain inherent bias, which can be partly ascertained from the respondents' profiles, as discussed in section 3.4. While respondents were overall experienced and stemming from diverse research areas, there is a majority of respondents from a combination of technology and education backgrounds, with some areas contributing only lightly, such as Game Studies (6%) and Digital Heritage (6%), or not at all, such as Design. Besides being a relevant consideration on the results below, this also points to gaps in fields of membership of the iLRN community. However, as

determined in section 3.4, the respondents are not acting strictly within their fields, and relevant multidisciplinary activity occurs.
The outcome points towards higher relevance being placed on aspects that link immersive environments with learning systems or tasks, alongside aspects that empower non-technical users (educational actors) to produce content. Regarding linkage to learning systems, the emphasis is on enabling student tracking and support within the immersive environments, with highest-ranking aspects dealing with tracking or detecting students' needs for support, progress, and perspective within the environment, but also with assessment support, providing feedback, and adjusting immersive tasks in accordance with each student's needs. On content production, it is clear an emphasis on the need for creating new tools (or identify existing ones) for interactive content: The highest-relevance aspects in this regard point towards tools for creating interactive stories, interactive behaviours for objects, and interactive virtual characters. Among these, further highlighting the relevance of this line of inquiry, is the ability to express those interactions in higher-level semantics, such as "from home to work" instead of numerical coordinates. The least relevant tasks were those related to content development processes involving technical experts: identifying project workload, risk, and development flexibility.

A possible interpretation from these results is that the immersive learning research network community sees as more relevant the need for independence from technical developers, rather than optimize combined teams of developers and educators. It seems to emerge a desire to find solutions that empower educators and students to streamline their educational tasks and allow them to take control of these environments interactively. However, this focus is leaving in the mid-ground the relevance conferred upon facilitating technical aspects such as networking issues (including security and performance), and, in what at first glance appear contradictory, resource-sharing aspects. We wonder whether focusing more on empowerment than facilitation will be wise, but ultimately that was the outcome. A possible path forward for subsequent research may be to establish relationships between these aspects and theoretical models of technology adoption. For instance, better understand the relationship between student tracking and UTAUT's constructs of performance expectancy, effort expectancy, and facilitating conditions (Dwivedi et al., 2017). Such clarification might shed light on the actual role of each of the aspects in this process, and further contribute to establishing effective research and development goals in the field of immersive environments.

Our hope is that these results assist the global research community on focusing the research efforts in this field, to achieve widespread adoption of immersive learning technology and, ultimately, better learning.

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