

Keyword analysis of immersive learning research about application areas and user experience

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It is crucial to explore the most appropriate domains for each technology to enhance the use of immersive technology in learning. This study aimed to examine the predominant fields of application and the user experience impact of various immersive technologies. To do so, this study collected relevant research articles from the Scopus database, focusing on those mentioning immersive technologies in their titles, keywords, or abstracts. The study identified patterns and trends using frequency-inverse document frequency (TF-IDF) analysis. Results showed distinct usage patterns and user experiences across AR, VR, MR, and XR technologies, highlighting their varied applications. These disparities have significant implications for integrating immersive technology in educational settings. The study's findings offer valuable insights and recommendations for researchers and learners interested in leveraging the potential of immersive technology.

Keywords: Field of Use, Immersive Technology, Keyword Analysis, Learning Study, User Experience

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Introduction

Education researchers have exhibited a profound interest in integrating immersive technology within educational contexts, primarily due to its ability to amalgamate virtual environments with various media, such as photographs and videos. This fusion enhances learners' understanding by facilitating interactive and engaging experiences. Despite significant efforts by researchers to develop innovative applications and augment educational efficacy, a critical component often overlooked is this inherently user-centered technology's user experience (UX).

User experience encompasses the full spectrum of sensations and responses elicited during a system's use (Kuhar & Merciumun, 2022). Given the diverse fields in which immersive technology is applied, the primary content and focus of user experiences can vary significantly. This study aims to refine the understanding of user experience by categorizing it into five distinct types, structured around three temporal stages (pre-usage, during usage, and post-usage) and three fundamental elements (user, system, and interaction) (Hellweger & Wang, 2015; Schulze, & Krömker, 2010).

Immersive technology, encompassing virtual reality (VR), augmented reality (AR), and mixed reality (MR), has the potential to transform educational environments. These technologies offer immersive experiences that can simulate real-world scenarios or create entirely new environments, providing learners with opportunities to engage in activities that would be impractical or impossible in traditional classroom settings (Di Natale et al., 2020). For instance, medical students can practice surgical procedures virtually, gaining valuable experience without the associated risks. Similarly, history students can explore ancient civilizations through virtual reconstructions, making learning more engaging and memorable.

However, successfully integrating immersive technology into education has its share of challenges. One significant challenge is ensuring these technologies are accessible and usable for all learners. This includes considerations of cost, availability of necessary hardware, and the varying levels of digital literacy among students and educators. Furthermore, the effectiveness of immersive technology in education heavily depends on the design of the user experience. A poorly designed system can lead to frustration, disengagement, and even physical discomfort, such as motion sickness in VR environments (Park & Lee, 2020). These challenges underline the need for careful planning and consideration when implementing immersive technology in educational settings.

User experience (UX) is a critical aspect of any technological application, particularly in education, where the goal is to facilitate learning and engagement. UX in immersive technology encompasses not only the usability of the system but also the emotional and psychological responses it elicits (Kuhar & Merchun,

2022). A positive user experience can enhance motivation, increase retention of information, and improve overall learning outcomes. Conversely, a negative user experience can hinder these goals and detract from the educational value of the technology. This underscores the urgency of addressing user experience in developing and implementing immersive technology in education.

To address the complexity of UX in immersive technology, this study categorizes user experiences into five types, considering three stages (pre-usage, during usage, and post-usage) and three elements (user, system, and interaction). Pre-usage factors include the user's initial expectations and preparations for using the technology. During usage, factors involve the actual interaction with the system, including interface design, ease of use, and the immersive quality of the experience. Post-usage factors encompass the lasting impressions and reflections on the experience, including knowledge retention and overall satisfaction.

Research Question

1. What are the annual trends in the research of various immersive technologies?
2. What are the main fields of use of various immersive technologies?
3. What are the key types and significant aspects of user experience in various immersive technologies?

Literature Review

Immersive Technology

Immersive technology encompasses a broad spectrum of advanced technologies designed to immerse users in visual and auditory experiences that transcend the boundaries of physical reality (Flavián et al., 2019; Lee, 2021). Key technologies within this domain include Virtual Reality (VR), Augmented Reality (AR), Mixed Reality (MR), and Extended Reality (XR) (Aloqaily et al., 2023).

Virtual Reality (VR) creates simulated environments that disconnect users from the physical world. This is achieved through head-mounted displays (HMDs) that provide immersive visual and auditory stimuli, effectively transporting users into a virtual space (Perkins et al., 2020). VR applications span various fields, from gaming and entertainment to education and training, offering safe, controlled environments for experiential learning and practice.

Augmented Reality (AR) enhances the real-world environment by overlaying virtual elements. This integration allows users to simultaneously see and interact with real and virtual objects, enhancing their

perception and interaction with their surroundings. AR is widely used in applications ranging from mobile games, such as Pokémon GO, to professional fields like architecture and medicine, where it aids in visualization and planning (Anna, 2022).

Mixed Reality (MR) goes further by overlaying virtual elements onto the real world and integrating them so that virtual objects interact with the physical environment in real time. This creates a more cohesive and interactive experience, where users can manipulate and engage with virtual objects as if they were part of their real-world surroundings. MR has significant implications for remote collaboration, allowing for shared experiences and interactions regardless of physical distance.

Extended Reality (XR) is an umbrella term that encompasses VR, AR, and MR. It aims to broaden and deepen users' sensory experiences by seamlessly merging the virtual and real worlds. XR technologies strive to offer an immersive experience that feels unmediated and extends beyond conventional reality, creating new possibilities for entertainment, education, and professional training (Lim & Ji, 2023). The promise of XR lies in its ability to create highly engaging and personalized experiences that adapt to the user's context and needs.

In summary, immersive technology, through its various forms—VR, AR, MR, and XR—can revolutionize how we perceive and interact with the world. By providing enriched sensory experiences and enabling new forms of interaction, these technologies are poised to transform numerous fields, enhancing personal and professional experiences.

User Experience

User experience refers to an individual's feelings and reactions to technology or systems (Kuhar & Merciumun, 2022). In immersive spaces, user experience is generated through interaction with virtual objects or immersive environments. Immersive environments can create scenes that are not seen or are difficult to see in real life, eliminating the gap between user experience and practical application.

Flavián et al. (2019) defined user experience using virtual information and digital technologies as the cognitive, emotional, behavioral, sensory, and social responses during usage. Since immersive environments can enhance users' motivation and interest, and users' emotions, cognition, and responses are affected after using immersive technology, the usage process is very important for user experience. The usage stage can be divided into three stages: pre-usage, usage, and post-usage (Schulze & Krömker, 2010). Depending on the attitude and expectations towards the immersive environment, the feelings during use, and the gains and reflections after use, different user experiences are generated. The generation of user experience involves

three elements: people, interaction, and technology or systems (Hellweger & Wang, 2015). Different experiences can be obtained from different subjects and perspectives. The conditions of the technology or system are established before use, while interactions occur during use. Therefore, a user experience framework can be established (Table. 1).

Table 1
User experience framework

User Experience (UX) Framework				
pre-usage		usage		post-usage
people	machine	people	interaction	people

TF-IDF Analysis

Term Frequency-Inverse Document Frequency (TF-IDF) is a widely used technique in Natural Language Processing (NLP) for evaluating the importance of a word in a document relative to a collection of documents or a corpus (Liu et al., 2022). TF-IDF is specifically used as a tool in information retrieval and text mining for keyword analysis (Xu et al., 2023). It consists of two parts: Term Frequency (TF) and Inverse Document Frequency (IDF), which are statistical measures.

Term Frequency (TF) refers to the frequency of a specific word or phrase in a specific document. The more frequently the word or phrase appears in the document, the more important it is, and the more it represents the main idea of the document. Mathematically, the calculation of TF is as follows (Figure 1 left).

TF can represent the main idea of a specific document, but certain words frequently appearing in any language or conversation will occupy a certain proportion of any document. Therefore, TF needs to be normalized to prevent bias toward longer documents (Xu et al., 2023). This is where Inverse Document Frequency (IDF) comes in. IDF evaluates the importance of the word across the entire document set, helping to reduce the weight of terms that frequently appear in many documents and increase the weight of terms that are unique or rare in other documents. The calculation method for IDF is as follows (Figure 1 middle).

The TF-IDF score of a term in a document is the product of its TF and IDF values. This score helps identify words important to a specific document but not common across all documents. It plays an important role in identifying relevant documents, extracting keywords, ranking documents by their content's

Keyword analysis of immersive learning research about application areas and user experience importance, and improving search engine performance (Sundaram et al., 2021). The calculation method for TF-IDF is as follows (*Figure 1 right*).

$$IDF_j = \log_{10} \frac{N}{N_j}, \quad TF - IDF_{ij} = TF_{ij} * IDF_j$$

Figure 1. TF-IDF calculated formula

Research Methods

We developed a search strategy inspired by Morgado and Beck's (2020) study and executed a search within the SCOPUS database. Our search formula comprised combinations such as ("AR" OR "augmented reality" AND "immersive learning"), ("VR" OR "virtual reality" AND "immersive learning"), ("MR" OR "mixed reality" AND "immersive learning"), and ("XR" OR "extended reality" AND "immersive learning"). The search scope was confined to articles published between 2015 and 2022.

To compute the TF-IDF values of each keyword, we processed the literature using the Python programming language. Initially, we separated the specified keywords using commas and semicolons. Subsequently, we tallied the total number of keywords and their frequencies. Then, we calculated the occurrences of each keyword within the literature about VR, AR, MR, and XR and across all literature. Finally, we determined the TF-IDF values by considering the occurrences of each keyword and their presence across multiple documents.

Result

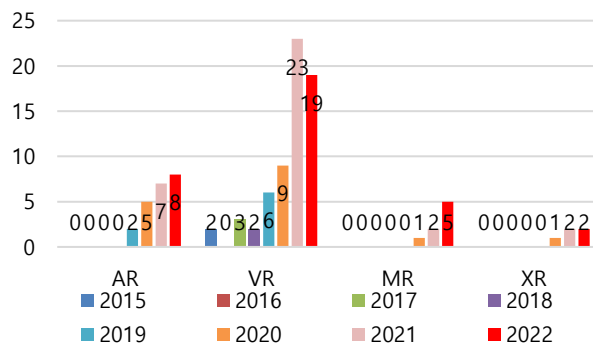


Figure 1. Year of Immersive Learning Studies

$$TF_{ij} = \frac{n_{ij}}{n_j}$$

Figure 2. Category of keywords

For question 1, this study presents the changes in the literature related to four immersive technologies, AR, VR, MR, and XR, from 2018 to 2022 in Figure 2. AR-related literature appeared in 2019 and has been increasing annually, reaching four times the number in 2022 compared to 2019. MR and XR-related literature appeared in 2020. With MR literature showing a rapid growth rate, XR literature, after growth, maintained the same level in 2023 as in 2022. VR literature appeared the earliest but remained at a low level until 2018. From 2018 to 2019, the growth rate of literature increased significantly, maintaining a high level in 2021 and 2022. VR literature exhibited a significant increase starting in 2019.

To answer research question 2, this study divides the keywords into three main parts: user experience (UX), field of use, and keywords unrelated to the theme (Figure 3). The largest proportion is the field of use, accounting for 68% of AR literature, 73% in VR, 58% in MR, and 65% in XR. Secondly, UX is the second most prominent category, accounting for 24%, 19%, 27%, and 12% in AR, VR, MR, and XR, respectively. The remaining parts include keywords unrelated to the topic, such as research themes, experiment participants, etc. XR keywords related to this field are divided into education, computer technology, and medicine according to the discipline. Due to the large number of keywords in the field of education, after discussion with co-researchers, it was further divided into educational technology and tools, educational environment, and educational method and strategy.

Then, these categories are used to classify the keywords of AR, VR, MR, and XR (Table 2). In VR, engineering keywords appear most frequently, reaching 12.5%. In AR, most keywords are related to educational methods and strategies, reaching 16.7%. While in MR and XR, medical and educational environment keywords dominate, accounting for 26.7% and 27.3%, respectively. Due to the limited number of MR and XR studies, TF-IDF analysis was only performed on VR and AR research keywords.

Table 2
Field of use of immersive technology in AR, VR, MR, XR literature

	AR	VR	MR	XR
medicine	8	16	4	0
engineering	3	19	1	2
computer technology	2	13	2	1
educational environment	5	7	2	3
educational method and strategy	9	13	3	2
educational technology and tool	2	10	0	0
others	25	74	3	7

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As shown in Table 3, the TF-IDF analysis of AR and VR literature lists the ten keywords with the highest TF-IDF values. The top ten keywords with the highest TF-IDF values in AR literature belong to educational methods and medical fields (Table 3 left). Among the top ten keywords with the highest TF-IDF values in VR literature (Table 3 right), engineering and educational methods appear three times, with the top two keywords with the highest TF-IDF values belonging to educational technology and tools. From the TF-IDF analysis, the main application fields of AR technology are educational methods and medical fields. At the same time, VR is widely used in engineering, educational technology, and tools, overlapping with AR.

Table 3
TF-IDF of the field of use in AR literature (Left) and VR literature (Right)

Keywords	TF-IDF	Keywords	TF-IDF
collaborative learning	0.067045	media in education	0.035696
medical education	0.053716	educational technology	0.035696
asthma	0.044086	digital storytelling	0.026565
pediatric asthma	0.044086	industry 4.0	0.026565
asthma education	0.044086	improving classroom teaching	0.026565
gamification in learning	0.044086	fluid mechanics	0.026565
dyslexia	0.044086	virtual laboratory	0.026565
learning scenario	0.044086	online learning	0.023798
deep reading	0.044086	digital learning	0.023798
reading materials	0.044086	medical education	0.019066

To answer research question 3, Table 4 categorizes the keywords related to UX of AR, VR, MR, and XR into five categories based on the theoretical background (pre-usage people, pre-usage machine or system,

etc.). The most common keywords in AR and VR literature are related to the state of the pre-usage machine or system (e.g., immersive environment, accuracy, effectiveness, etc.), accounting for 57.9% and 51.3% of the user keywords in AR and VR, respectively. There are also some differences: AR focuses more on the post-use state of users, accounting for 15.8%, in addition to machines and systems. The second most common keyword in VR UX is about the pre-usage state of people.

Table 4
Type of UX for immersive technology in AR, VR, MR, XR literature

	AR	VR	MR	XR
pre-usage, people	1	10	1	2
pre-usage, machine or system	11	20	2	0
usage, people	2	3	1	0
usage, interaction	1	4	1	0
post-usage, people	3	2	2	0

With limited data on MR and XR, keywords related to machines' pre-usage state and individuals' post-usage perception appear most frequently in MR literature. XR, on the other hand, has only two keywords related to the pre-usage state of participants. Conducting TF-IDF analysis on keywords related to user experience in AR and VR. Among the top ten keywords in AR (Table. 5 left), six are related to the pre-usage state of machines, and three are related to the post-usage people. In VR (Table. 5 right), there are four keywords related to the pre-usage system or system and the pre-usage people.

Table 5
Type of UX in AR literature (Left) and VR literature (Right)

Keywords	TF-IDF	Keywords	TF-IDF
immersion	0.067045	immersive learning environment	0.034205
immersive learning environment	0.048183	motivation	0.030466
system usability	0.044086	virtual environment	0.023798
playful experiences	0.044086	simulation	0.023798
digital environment	0.044086	technology acceptance	0.020311
immersive learning experiences	0.044086	haptic devices	0.015648
usability	0.037421	engagement	0.015648
academic achievement	0.037421	gender	0.015648
sustainable technologies	0.037421	affective processing	0.015648
digital technologies	0.037421	emotion	0.015648

Discussion

The literature concerning Mixed Reality (MR) and Extended Reality (XR) is notably limited, with publications in these areas emerging primarily since 2020. In contrast, the research on Virtual Reality (VR) and Augmented Reality (AR) is more extensive, having experienced a significant increase in output since 2019. Billewar et al. (2022) point out that Corona has led to a rise in e-commerce popularity. The COVID-19 pandemic and the consequent rise in remote and virtual learning environments may also spur the VR and AR trends.

The applications, key characteristics, and significant aspects of VR, AR, MR, and XR are interrelated and highlight each technology's unique capabilities and considerations. VR technology creates entirely virtual environments, effectively simulating challenging or impossible scenarios to replicate in real life. This capability makes VR particularly valuable in fields such as engineering, where complex simulations can provide crucial training and experimentation opportunities without real-world risks (di Lanzo et al., 2020). However, VR's immersive nature can profoundly impact individuals, including potential symptoms like dizziness and nausea with prolonged use (Lavoie et al., 2021). Therefore, focused research on participants' pre-usage conditions and human-machine interactions during VR experiences is essential to mitigate these effects and enhance user comfort and safety.

AR overlays virtual elements in the real world, making it accessible across various devices, including smartphones and tablets (Ziker et al., 2021). The research on AR has been substantial, with scholars exploring methods and strategies for effectively deploying this technology in educational and professional contexts. Unlike VR, AR research focuses more on learners' perceptions and experiences after the interaction (Cabero-Almenara et al., 2019). This shift in focus directly influences the development of educational technologies and strategies, emphasizing the importance of evaluating the impact of AR on users' post-interaction performance and satisfaction.

MR combines virtual and real-world elements, allowing users to interact directly with virtual objects integrated into their physical environment (Anna, 2022). This capability prompts research attention toward the system's state and the users' post-usage experiences. MR's hands-on interaction demands highly intuitive user interfaces and seamless integration of virtual objects, which places significant demands on system design and functionality (Ziker et al., 2021). Ensuring a positive user experience in MR applications involves addressing technical and experiential aspects, including system reliability and user feedback mechanisms.

XR is an umbrella term encompassing VR, AR, and MR. It aims to enhance users' perception of reality by seamlessly merging virtual and real-world experiences (Rauschnabel et al., 2022) . XR applications emphasize the importance of users' pre-usage states, as these can significantly affect their overall experience and perceived reality during immersive interactions. XR's ability to extend and enhance reality perception underscores the need for comprehensive research into the factors influencing users' initial conditions and subsequent experiences during and after using the technology.

While VR excels in creating vast or intricate virtual environments, it is crucial to consider participants' conditions before and during use, focusing on the significance of human-machine interactions. AR, MR, and XR technologies, which blend virtual and real-world elements, each present unique challenges and opportunities for research and application:

- **AR:** Its versatility and accessibility necessitate careful examination of user interactions and their impact on post-performance outcomes.
- **MR:** Due to its direct interaction capabilities, it requires intuitive and responsive user experiences, placing high demands on system design and user interface development.
- **XR:** Expands reality perception, highlighting the profound impact of users' pre-usage states on their overall immersive experience.

In conclusion, while VR adoption and research have advanced rapidly, AR, MR, and XR technologies continue evolving, offering distinct benefits and challenges. Comprehensive research into user experiences across all stages of interaction—pre-usage, during usage, and post-usage—is essential for optimizing the development and application of these immersive technologies. Researchers and developers can create more effective, user-centered immersive experiences that enhance learning, training, and various other applications by addressing each technology's unique requirements and impacts.

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