The Power of Immersive Technologies: A Sociopsychological Analysis of the Relationship between Immersive Environments, Storytelling, Sentiment, and the Impact on User Experience

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Best wishes for the future!

TO MYSELF

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Abbreviations

AR	Augmented reality
AI	Artificial intelligence
AVE	Average variance extracted
BBC	*The British Broadcasting Corporation*
CD	*China Daily*
CNN	*The Cable News Network*
CR	Composite reliability
DM	*The Daily Mail*
MAIN	Modality (M), Agency (A), Interactivity (I), and Navigability (N)
MEC	Measurement, effects, and conditions
MR	Mixed reality
NFT	Non-fungible tokens,
IVE	Interactive virtual environment
TTR	Type–token ratio
RNN	Recursive neural network
SEM	Structural equation model
UX	User experience
VIF	Variance inflation factor
VR	Virtual reality
XR	Extended reality

Preface

This dissertation initially focused on exploring the potential of immersive technologies for the distant future. However, the emergence of the COVID-19 virus in late 2019 disrupted the world, causing a pause in many areas. Nevertheless, the butterfly effect of the pandemic spurred the development of immersive technologies, resulting in the rise of the metaverse, web3, non-fungible tokens (NFT), and avatars, which are gaining increasing popularity. The excitement for the metaverse is growing in both academia and industry, leading to new avenues of research, digital marketing, video games, tourism, and social media. This dissertation explores this rapidly emerging technological revolution and its effects on user experience (UX).

Introduction

The metaverse is currently one of the most discussed topics worldwide. In 2021, the metaverse re-entered users' field of view. The word "metaverse" originally came from the American writer Neal Stephenson's novel *Snow Crash* (1992). In the novel, the main character lives in a virtual world through digital avatars. The virtual space is called the "metaverse" (Brown, 2021).

In recent years, there has been a growing interest in the metaverse, fueled by advancements in technologies such as virtual reality (VR) and augmented reality (AR) as well as the increasing popularity of online gaming and social media platforms. Companies such as Facebook, Roblox, and Epic Games are investing heavily in developing their own versions of the metaverse, which they believe will be the future of online communication and commerce.

At the end of 2021, Mark Zuckerberg proposed a vision for the next stage in the digital age. In his opinion, the metaverse is the next evolution of social connection, which will allow us to socialize, learn, collaborate, and play in ways that go beyond what we can currently imagine (Dwivedi et al., 2022). Immersive technologies such as those championed by the metaverse allow users to interact with a content environment through unique technical features and vivid presentations. According to Meta, the metaverse is a revolutionary digital world that will transform social connection as we know it. This exciting new world can be accessed and interacted with through a variety of immersive technologies, which form the foundation of the metaverse.

The metaverse is a complex ecosystem that is made up of various integrated technologies such as the 5G network, blockchain technology, artificial intelligence (AI), and immersive technologies. While much of the current research has focused on describing the potential of these technologies, there is no single instance or entity that is representative of the metaverse yet. Its definition and potential applications are not yet entirely clear. However, industry experts and researchers alike have reached a consensus that the metaverse will create new experiences and opportunities for traditional industries. As such, the metaverse is an area of ongoing research and exploration, with many exciting possibilities yet to be discovered.

Despite these concerns, the metaverse is likely to continue to be a trending topic in the years to come, as an increasing number of people embrace the possibilities of this emerging technology. The precise form that the metaverse will take as well as its long-term effects on our everyday life remain to be seen, but the concept has captured the imagination of people around the world and is set to play a significant role in shaping the future of the digital landscape.

Immersive technologies are the foundations of the metaverse, which have opened up new possibilities; however, their practical applications have also brought forth fresh challenges. Moreover, there is growing concern over the effect of immersive technologies on UX and whether such effects are advantageous or otherwise.

Immersive technologies are poised to further integrate the virtual and physical worlds, creating new possibilities for meaning and value generation. As elements of the real world become more

closely aligned with the virtual world, users can expect to experience a more seamless and integrated UX, blurring the line between the real and the virtual.

The metaverse is heavily dependent on immersive technologies such as VR and AR for establishing a fully immersive and interactive virtual environment (IVE). These cutting-edge technologies are essential in creating a seamless and captivating experience for metaverse users. By leveraging immersive technologies, the metaverse aims to offer an unprecedented level of interactivity and engagement. Users will be able to explore a vast and ever-evolving virtual world, engage in social activities, play games, attend virtual events, and even conduct business. In short, the metaverse has the potential to revolutionize how people interact with each other and engage with digital content.

Previous research has extensively explored the benefits and significance of immersive technologies, with a tendency to overemphasize their advantages (Paes et al., 2021). However, empirical evidence from user-centered research is insufficient in the various new application scenarios such as tourist attractions, education, retail, and industry. To address this gap, a Ph.D. project was undertaken to review past studies and employ empirical methods to compare viewer responses across diverse IVEs.

The analysis conducted in this project considers the use of various scenarios in the domains of the press industry as well as cultural experiences. It proposes user models that consider different IVEs, diverse scenes, and the sentiments of content in terms of UX factors. The aim of these user models is to provide optimal UX solutions for content creators and developers in IVEs. Moreover, this Ph.D. dissertation, to my knowledge, is the first to propose the concept of a “cultural metaverse.”

In summary, this dissertation undertakes the crucial task of examining UX in relation to IVEs. Through experimental studies that examine various IVEs and scenarios, this thesis provides a step-by-step analysis of UX in different immersive settings.

This Ph.D. thesis comprises three studies, from which four manuscripts were derived (see Table 1). Study 1 investigated viewer responses to digital news across different IVEs in the form of the regular 2D format on laptops, 360-degree video via mobile devices, and 360-degree video via VR headsets. Manuscript 1 reported on the role of presence and flow in these IVEs and how they affect enjoyment. Manuscript 2 described viewer responses when they view news videos of positive and negative sentiments in various IVEs.

Study 2 compared the cultural experience of an e-book AR (one-way delivery) with an innovative AR storytelling version (the interactive form) as a cultural metaverse scenario. Manuscript 3 introduced the concept of the cultural metaverse and measured multiple aspects of UX, including presence, flow, education, information utility, enjoyment, and engagement in cultural experiences.

Study 3 involved a sentiment analysis of the coverage of the COVID-19 pandemic by various news outlets, given that experiments were not possible during the pandemic. Manuscript 4

examined how three news outlets reported on the pandemic: *China Daily* (CD) from China, *Cable News Network* (CNN) from the US, and the *Daily Mail* (DM) from the UK. While it did not directly investigate UX in immersive environments, it provided a foundation for the second part of Study 1.

Table 1. The studies and manuscripts comprising this dissertation.

Study 1	Manuscript 1: Presence and Flow in the Context of Virtual Reality Storytelling: What Influences Enjoyment in Virtual Environments?
	Manuscript 2: Sentiment and Storytelling: What Affect User Experience and Communication Effectiveness in Virtual Environments?
Study 2	Manuscript 3: Storytelling and User Experience in the Cultural Metaverse
Study 3	Manuscript 4: Media Reports of the COVID-19 Pandemic: A Computational Text Analysis of English Reports in China, the UK, and the US

This Ph.D. dissertation aims to fill a critical gap in research on immersive technologies by investigating their social and human science applications in real-world scenarios, with particular emphasis on UX in IVEs across different cultural settings. While previous studies have explored various aspects of immersive technologies, including the impact of thematic content and UX models[1], few have investigated the complex relationship between these variables and their effects on UX.

Through this Ph.D. project, I seek to make a significant contribution to the field by developing user models that can help content creators and developers in media and culture create immersive virtual environments that offer optimal UX. In addition, the proposed concept of a "cultural metaverse" underscores the critical role of cultural experiences in the development of immersive technologies and the metaverse. By providing both theoretical and empirical insights, this dissertation offers a comprehensive understanding of the UX of immersive technologies in diverse cultural contexts.

The findings of this dissertation will not only advance research on immersive technologies but also offer practical implications for the development of immersive virtual environments that provide optimal UXs across different cultural settings. Moreover, the concept of a cultural metaverse has significant implications for the future development of immersive technologies,

[1] These previous studies are cited in later sections.

suggesting that incorporating diverse cultural experiences into these technologies is essential for creating more inclusive and meaningful virtual environments.

Theoretical background

The development of immersive technologies has allowed users to interact with content through unique technical features and vivid presentation forms such as VR and AR. Both VR and AR are already being used for cultural experiences in specific scenarios, showing their respective advantages. VR is defined as the digitally constructed representation of a natural or artificial environment (Loomis et al., 1999; Riva et al., 2007; Slater & Sanchez-Vives, 2016). VR relies on computer-generated content to construct a complete virtual environment. By offering a full IVE, VR technology can break down geographical barriers and provide an immersive experience that engages users in a profound way. AR is a technology that links the real and virtual worlds (Azuma, 1997; Ibáñez & Delgado-Kloos, 2018), enabling real-time interactions by combining computer-generated objects with the natural environment (Rese et al., 2017). AR technology superimposes computer-generated content onto the real-world environment, allowing users to perceive and interact with both the virtual and the physical worlds. While AR may not be as immersive as VR, it offers unique stimuli that enrich UX through interactive elements from both worlds.

Immersive journalism and 360-degree video

In the field of media and communication, journalists and documentary makers have long aspired to close the spatial and temporal boundaries between the audience and events. Recent advancements in VR provide powerful tools to accomplish this aim (Steed et al., 2018). VR is an advanced human–computer experience that simulates realistic presence in a natural or imagined environment (Burdea & Coiffet, 2003). The widespread availability of VR has prompted a growing trend in immersive storytelling. VR has the potential to support highly intricate narratives that can be customized to facilitate rich user interactions. In recent years, many news outlets have announced or released VR opportunities, with well-known outlets such as *The British Broadcasting Corporation* (BBC), *The New York Times*, and *The Washington Post* even launching 360-degree projects. In contrast to passively watching a story unfold on a screen, audiences can experience a complete 360-degree view of the environment with VR technology. Referred to as immersive journalism, this provides viewers with first-person experiences of events, locations, and stories (Vettehen et al., 2019). Immersive journalism encourages users to empathize with people and events in the news. It brings users closer to the characters, enabling them to share the same space virtually and inciting them to feel their emotions or situations more strongly. Therefore, industries such as digital marketing, tourism, and journalism often incorporate 360-degree video in VR experiences as an integral component of the cultural experiences, employing marketing strategies, showcasing the histories of tourist attractions, guiding visitors, and presenting news stories (Luca et al., 2022; Giotis & Papadionysiou, 2022; Oncioiu & Priescu, 2022).

Industry practitioners have identified multiple potential advantages of immersive material over more traditional formats (Vettehen et al., 2019; Slater & Sanchez-Vives, 2016). For example, users can have a better experience playing games, viewing movies, and performing other interactive media activities in IVEs than on traditional 2D screens (Sundar et al., 2017). One of

the most heated debates surrounding VR is whether immersion in storytelling can help people empathize with scenarios or situations they have never experienced (Barbot & Kaufman, 2020; Barreda-Ángeles et al., 2020; Sánchez, 2020), such as the encounters of refugees (Shin, 2018) and matters related to the promotion of environmental awareness (Ahn et al., 2014). Research has demonstrated that it is easier to be fully engaged while watching a video without external distractions because using a VR headset evokes a stronger emotional response (Johnson et al., 2018).

Owing to the significant differences between immersive journalism production techniques and those of traditional audio-visual storytelling, some researchers have noticed a gap in the transferability of the knowledge of these production techniques (Herrera Damas & Benítez de Gracia, 2022). While this 360-degree view enables viewers to be genuinely immersed in the storytelling, designing stories to provide such experiences is difficult. Therefore, this dissertation explores the key elements in immersive storytelling, particularly how they vary and influence each other in different immersive environments.

The use of immersive technologies in the cultural metaverse

Immersive technologies have been used not only in journalism but also in cultural sites, such as the reconstruction of historical environments and virtual museums (Barbieri et al., 2017; Smith et al., 2019). They can be used to recreate historical environments and events that are otherwise inaccessible to the public, such as ancient heritage sites long destroyed in certain areas. By using 3D modeling and VR technology, historians and archaeologists can create digital reconstructions that allow users to explore and interact with these environments as if they were really there (Ferdani et al., 2020). VR can be used to create virtual museums and galleries, which can be accessed from anywhere in the world. This allows people to experience and learn about art and cultural artifacts worldwide without having to travel or leave their homes. VR also provides complete IVEs where visitors can be fully immersed (Puig et al., 2020), thus enhancing their experience by facilitating interaction with museums' exhibits (Shehade & Stylianou-Lambert, 2020). Further, these technologies can provide an engaging way of experiencing art and culture, as users can interact with the exhibits in new and interesting ways. The use of VR in cultural experiences reduces the distance between visitors and exhibits in museums (Bruno et al., 2010) through advanced and realistic virtual simulation, thus providing visitors with a unique virtual experience by creating infinite possibilities. VR has thus opened up new possibilities for exploring and learning about history and culture and are likely to continue to play an important role in these fields in the future.

Some scholars have highlighted the duality of VR in cultural experiences. On the one hand, VR works as a tool to substitute for an in-person experience (Deng et al., 2019); it offers the real-world exhibition space as a virtual space with detailed visuals for scenes in places that cannot be physically visited (Kim & Hall, 2019). Thus, it enables visitors to feel as though they have visited the actual environments represented by the exhibitions (Cheong, 1995). On the other hand, VR is practical only for virtual spaces that provide a limited form of experiential content. While VR can provide detailed visuals and a sense of immersion in a virtual space, it may not be able to replicate

the full range of sensory experiences that one would have in a physical space. This could include the smells, sounds, and textures of a particular environment, which may not be fully captured in a virtual space. While VR can provide a sense of presence and enable visitors to interact with virtual objects, it may not be able to replicate the social dynamics and interactions that can occur in a physical exhibition space. Thus, while VR can provide a valuable tool for immersive cultural experiences, it is important to recognize its limitations and consider how it can best complement and enhance in-person experiences rather than replace them entirely.

Cultural venues are real spaces for displaying, appreciating, and learning about culture. Modern cultural venues are becoming integrated social learning spaces (Choi & Kim, 2017) by expanding into experiential spaces. AR's unique advantages prove its potential to create an interactive and enjoyable cultural experience (Jung et al., 2017). Additionally, AR addresses the limitations of VR, which does not change or replace one's real world, but rather augments it through information such as text, images, videos, and virtual avatars. This means that visitors can still have a sense of presence in the real world while also being able to access additional information and content through the AR experience. This can be particularly useful in cultural experiences where visitors may want to learn more about the exhibits or artifacts they are viewing.

In cultural experiences, AR can facilitate visitors' collaborative participation and active learning. For example, visitors can use AR to interact with exhibits and artifacts in new and interesting ways such as by overlaying the additional information or animations offered onto objects (Carmigniani et al., 2011). This can encourage visitors to explore and engage with the exhibits in a more active and participatory way, rather than just passively viewing them. Thus, AR has great potential to enhance cultural experiences and provide visitors with a more interactive and engaging way of learning about history and culture.

Among the extent literature, one study compared the impacts of various VR and AR devices in an immersive gallery experience at the National Gallery in London by examining UX, which included enjoyment, presence, cognitive, emotional, and behavioral engagement (Verhulst et al., 2021). The study confirmed that the equipment characteristics produced differences in the measured UX variables. Although the VR group and two AR groups had high UXs, Verhulst et al. (2021) mainly discussed the variation in immersion between devices and did not focus much on the other factors that could have affected UX. Another study examined the impact of VR and AR experiences on museum services and users' satisfaction at the Ara Pacis Museum in Rome (Trunfio, et al., 2022). VR and AR tools were explored to enhance multi-experiential value in cultural heritage by integrating traditional cultural content with other experiences, such as socialization, entertainment, and learning, allowing visitors to engage in a new type of value co-creation.

Microsoft put forward an industrial metaverse at the end of 2021 through its "industry + metaverse" model. Nishant Batra, the Chief Strategy and Technology Officer at Nokia, indicated that the metaverse of the future is one where physical space as well as human and digital realities are combined (Batra, 2022). Instead of keeping the metaverse in our homes and offices, we may take it with us everywhere we go. This metaverse will be equally present in the consumer, business, and industrial realms. This phenomenon inspired the introduction of the term "cultural metaverse"

in this thesis. The cultural metaverse goes beyond the scope of current experiences and is the future form of the cultural industry.

Cultural experiences have evolved in the metaverse system in cultural venues with two limitations. First, there is a clear boundary between the virtual and real worlds. Second, storytelling forms have not been well utilized for depicting cultural experiences; instead, information is typically narrated, which is a one-way method of delivery. Therefore, cultural space should attain its meaning from the real-world space, with storytelling bridging the gap between virtual and real spaces. To create a more meaningful and engaging cultural experience, it is important to bridge the gap between virtual and real spaces.

Instead of relying solely on the narration of information, cultural experiences in the metaverse system should focus on storytelling as a way of delivering content. Storytelling can be a more engaging and interactive way of presenting information, allowing visitors to connect with the exhibits and artifacts on a deeper level. Cultural venues should strive to attain meaning from the real-world space, using storytelling and other techniques to create a sense of connection between virtual and real spaces. This can involve creating virtual experiences that complement and enhance the real-world space or using virtual technology to provide visitors with a deeper understanding of the historical and cultural significance of these real-world spaces.

Several techniques such as multi-sensory stimulation, realism, interactivity, and immersion have been extended by AR storytelling. AR enables an augmented experience by using the camera function on smartphones or wearable devices. AR also enables a hybrid space that combines the characteristics of real and virtual spaces, creating an overlapping space that can be used to structure cultural experiences in new and interesting ways. This can be particularly useful in museums, galleries, and other cultural venues, where visitors may want to learn more about the exhibits and artifacts on display.

Users can encounter unique stimuli that affect their UX while using AR because of the diverse ways of manipulation and interplay between the virtual and real worlds (Salar et al., 2020). While VR and AR both have their advantages and can be used in different ways to enhance cultural experiences, AR is more suitable for museums and other cultural venues where users can continue being connected to a real context in the physical world. Unlike VR, which creates a completely immersive and isolated digital environment, AR allows visitors to augment their physical surroundings with additional digital content and information. This can help create a more seamless and integrated experience, where visitors can learn about the exhibits and artifacts while also remaining connected to the real-world context.

However, there have been no controlled studies that compare differences in AR storytelling. The existing research has compared the impact of VR and AR technologies on UX but not discussed or investigated the role of AR storytelling. Artifacts, functions, and storytelling produce an AR cultural experience in a hybrid space. For example, an exhibition can provide different story guides and reward mechanisms when visitors enter the museum. When visitors reach each step in the museum, they can obtain a hint of the next step; when all the goals are reached, visitors

can then claim the final reward. They can also choose their own tour maps and receive rewards. Hence, AR has the potential to provide a more seamless and cohesive digital experience in the cultural metaverse, helping visitors learn about history and culture while remaining connected to the cultural venues and the exhibits in the cultural metaverse. While VR still has its uses in other contexts, AR is likely to become the go-to digital tool for the cultural metaverse in the future (Cisternino et al., 2021; Zhou et al., 2022). As immersive technology continues to advance, we can expect to see even more innovative and exciting uses for it in the cultural metaverse.

Immersion and immersive storytelling

Immersion refers to the perception of being physically present in a virtual world. Immersive technologies are designed to create immersive experiences for users. As technology iterates and research deepens, scientists are beginning to explore the impact of users' responses in different immersive environments (Cheng et al., 2017; Jennett et al., 2008; Milgram, 1994). Immersion is the central concept used to measure IVEs. When individuals are fully engaged in an activity, they enter a state of complete isolation in the virtual world and encounter an immersive experience (Bowman & McMahan, 2007; Slater & Sanchez-Vives, 2016).

Storytelling is a powerful means of communication. It is the art of conveying narratives or events through words, images, and other forms of expression. At its core, storytelling involves the creation of a narrative that engages the audience and conveys a message or theme. It can take many forms, including books, films, plays, oral presentations, and digital media (Meadows, 2003). A good storyteller can captivate an audience and evoke emotions such as empathy, excitement, and suspense.

Immersive storytelling has emerged from IVEs. It creates an experience that deeply engages users or participants in a multi-sensory and interactive way, going beyond traditional media such as books, films, and television shows. By creating an environment that stimulates users' senses and emotions, immersive storytelling creates a more immersive and memorable experience for users, which captures their attention to the point where some describe themselves as "being there." Through VR, users feel like they are becoming a part of the story (Baños et al., 2000; Felnhofer et al., 2015). This experience, termed "immersion," is frequently thought to be a result of positive experiences. Some studies point to the pleasure of playing computer games as being due to immersion in a virtual world (Bracken & Skalski, 2006). The main reason for the popularity of VR and AR is their greater impact on immersion than traditional communication methods such as text, photos, and videos (Pull, 2008; Sundar et al., 2017). This objective is accomplished through the creation digital environments or augmentation the real world in a way that that makes users feel fully present and engaged in the experience. The key concepts that explain this immersive experience are "presence" and "flow." Presence can be understood as immersion in a virtual space, while flow can be interpreted as the immersive experience of a specific and optimal user response.

Presence has been characterized as the user's awareness of another person in a mediated environment (Jennett et al., 2008; Nicovich et al., 2005). It is the subjective perception of the

psychological experience in an environment created by computer technologies. VR technology helps build a highly realistic environment (Slater et al., 1994), wherein users experience a perceptive illusion of “being there.” Thus, many researchers believe that VR technology brings about a stronger sense of presence owing to the interactivity, vividness, and novelty that it offers (Steuer, 1992).

Csikszentmihalyi (1990, pp.239-260) described “flow” as an “optimal experience,” which is the psychological state of being fully engaged that individuals experience when completely immersed in an activity. It is often described as being “in the zone” or “losing oneself” in the experience. Flow occurs when the user is fully engaged in the activity or experience and can perform at their highest level of ability. Experiencing flow can allow users to perceive more enjoyment, satisfaction, and emotions (Webster et al., 1993). Flow can be experienced in a human–machine interactive experience. It allows a user to focus on the activity, specifically when a stimulus appears in an IVE (Nakamura & Csikszentmihalyi, 2002). In a 360-degree story, the sudden appearance of a person, an off-panel voice, or a sound effect may result in a high level of flow (Sherry, 2004; Weibel, 2011).

Immersive technologies create immersive experiences (Suh & Prophet, 2018). The level of immersion experienced by the user depends on the technology being used and how well it is designed to create a sense of presence and flow. Both presence and flow are important factors in determining the level of immersion experienced by a user in immersive environment. When users experience high levels of presence and flow, they are more likely to feel fully immersed in the digital environment and be able to interact with it in a natural and intuitive way. In immersive storytelling, users become active participants in the narrative, making decisions and interacting with the environment and characters. This can lead to a more engaging, memorable, and impactful immersive experience that leaves a lasting impression on users (Ahn et al., 2014).

Sentiment analysis in IVEs

Sentiment analysis has been widely applied to text analysis to examine how a text expresses opinions, emotions, and sentiments (Puschmann & Powell, 2018). It is not only used to analyze and interpret the emotional tone or sentiment expressed on social networks, online communication, and data journalism, but also adopted in journalism to analyze and evaluate the emotional tone of news content such as text, videos, and audio files. This subfield of natural language processing and machine learning uses algorithms to automatically identify and extract emotional information from news content and the sentiment of a given text as positive, negative, or neutral. Thus, sentiment analysis can be useful in determining how readers or viewers may react to the story, helping journalists shape their coverage.

All the elements of news videos such as captions, dialogues, and off-camera voices can express emotions. Sentiment analysis has been performed to objectively determine the sentiments expressed in a news video, including all these elements (Rameshbhai & Paulose, 2019). Research on the emotional impact of VR has revealed that using technology can enhance emotional experiences (Susindar et al., 2019). However, few studies have conducted a sentiment

analysis of immersive journalism, especially on the impacts of different technological conditions on the UX associated with positive and negative sentiments.

Experience economy theory

Journalism and the cultural metaverse as a product of cultural experiences

A cultural product is defined by three factors: satisfying consumers' intrinsic needs, eliciting good feelings, and being engaged in the experience. Journalism involves the creation, production, and distribution of news, information, and analyses about current events and issues that are of public interest. As such, it is a form of media that is closely tied to culture and society. Journalism is often consumed as a form of entertainment and serves as a reflection of the cultural zeitgeist, influenced by and reflective of the culture in which it is produced and consumed. Thus, journalism is a type of cultural experience.

Providing visitors with cultural experiences is a key function of the cultural metaverse. Cultural venues such as museums, art galleries, and concert halls are designed to showcase and promote different forms of art and culture. A space was provided for artists, performers, and curators to share their work with the public and for visitors to engage with different forms of artistic expression. This point has been emphasized in this dissertation. The cultural metaverse can offer a range of cultural experiences, including educational, inspiring, thought-provoking, and enjoyable experiences. In the cultural metaverse, visitors can be exposed to new ideas, perspectives, and ways of understanding the world around them. The cultural metaverse can also contribute to the preservation and celebration of cultural heritage and diversity. Visitors to cultural venues seek to create memorable images, arouse the senses, gain knowledge, and inspire thoughtful experiences (Pine & Gilmore, 1999, pp.1-26). Thus, the cultural metaverse can be thought of as a cultural experience product. Virtual tours, digital museums, and cultural experiences that integrate technology into physical spaces have all been attempted in the past. However, visitors now look for distinctive and unforgettable experiences as well as high-quality experiential products and services.

The use of experience economy theory in cultural experiences

Pine and Gilmore (1999, pp.1-26) delineated four dimensions of consumer experience: aesthetics, entertainment, escapism, and education. These four characteristics are related to their level of engagement (passive vs. active participation) as well as the connection that ties them to a certain performance or event (i.e., absorption and immersion) (see Figure 1).

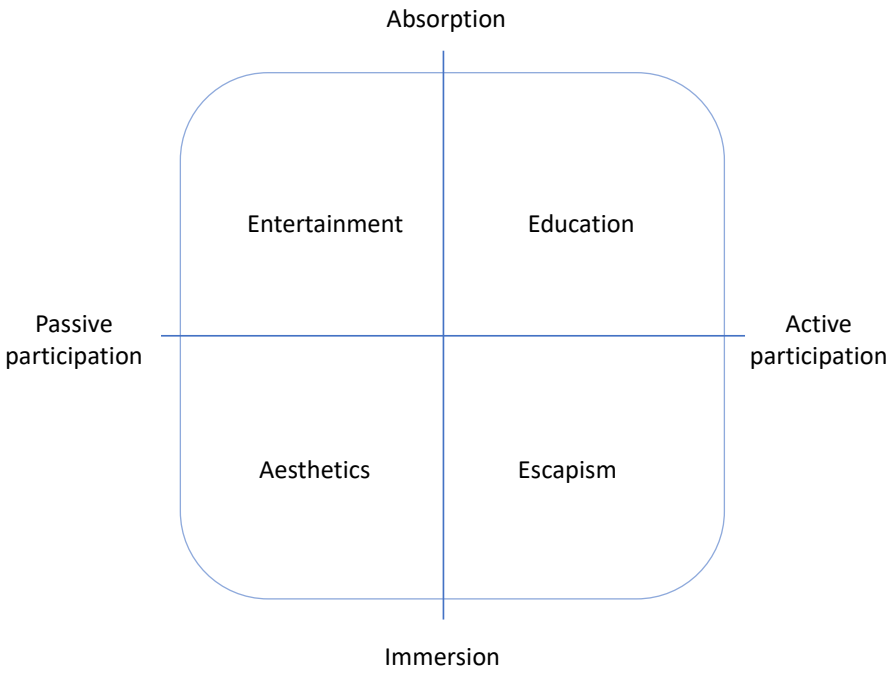


Figure 1. Four dimensions of experience (Pine & Gilmore, 1999, pp. 30).

Aesthetics is an experience that is visually and aesthetically pleasing, in which users immerse themselves in a scene and which is critical to creating a positive and memorable UX (Quadri-Felitti & Fiore, 2013). In experience economy theory, aesthetics is defined as consumers' perception of their immediate physical environment (Hosany & Witham, 2010) and their complete and enjoyable engagement in the real-world AR experience. Researchers have found that the aesthetic motive precedes the other three motives in the setting of immersive experiences (Dieck et al., 2018). Since immersive cultural experiences should first attract clients to supply them with feelings of entertainment, escapism, and education, aesthetics is an essential component of these encounters. Thus, aesthetics is associated with immersion, as participants immerse themselves in the allure of performances (Pine & Gilmore, 1999, pp.1-26). One study examined data taken from 500 visitors to cultural attractions and found that the aesthetic features of these attractions are essential factors influencing revisit intention and public appreciation (Hosany & Witham, 2010). In other words, when people are drawn to an immersive and aesthetically beautiful experience, other incentives follow. Consequently, aesthetics is critical in driving the experience economy.

The most fundamental requirement is for an experience to be entertaining (i.e., enjoyable, pleasurable, and engaging). A previous study investigating the potential of immersive technologies to generate entertainment value found that the need for amusement was the primary motivation for using immersive technologies, which was demonstrated to boost the perceived enjoyment of the user (Dwivedi et al., 2021). Meanwhile, entertainment encourages deeper

engagement in immersive technologies. Moreover, offering high-quality entertainment provides tourists with unforgettable memories (Hwang & Lyu, 2015).

Individuals seek entertainment as a means of escaping from the realities, busyness, or monotony of everyday lives. They embark on a quest for exhilarating and intellectually engaging activities that not only provide amusement but also serve as avenues for relaxation, offering solace from the demands of daily existence. Furthermore, these activities facilitate cognitive enrichment, enabling individuals to expand their mental horizons beyond the realm of mere entertainment. In essence, the pursuit of escapism embodies a profound desire for personal growth and mental expansion. Escapism allows individuals to momentarily detach themselves from the routines of their daily lives by immersion in an experience, providing an opportunity to enter a different world. Freud believed that “intrusive foreign bodies” could result in the diversion of emotional impulses (Freud, 2018, pp.105-117). In that vein, escapism is a defense mechanism against reality driven by the desire to maximize the enjoyable experience. individuals are actively engaged in the experience rather than just being onlookers, making escapism highly compatible with the cultural metaverse experience.

Education provides users with new information or skills. In the cultural context, education experience refers to the desire to learn something new and participate actively in the learning process. Participants must be enthusiastic about an event and believe that participating in such an experience will enhance their knowledge and abilities. Participants absorb what they want to know and learn from the experience, and the outcome of a communication experience depends on their attitudes. Interaction and immersion lead to a higher level of engagement with digital content than traditional communication (Jung et al., 2017; Dieck & Jung, 2017). The desire to gain knowledge and skills as the primary educational motivation drives participation in the experience (Oh et al., 2007).

These dimensions are related to the level of engagement of users, ranging from passive observation to active participation, as well as the degree of absorption and immersion in the experience. By understanding these dimensions, businesses can design and deliver experiences that engage and satisfy customers, and ultimately create value for them. The four dimensions of experience economy theory have already received widespread acceptance and validation from earlier investigations. One study drew on these four realms and examined how absorptive experiences influence immersive experiences, an overall VR tour experience, and intention to visit a museum (Lee et al., 2020). Another study used AR to enhance visitor experiences at science festivals. It explored how the four dimensions of the experience economy influence satisfaction and memory, ultimately leading to visitor engagement with science experiences at science festivals (Dieck et al., 2018). Furthermore, Sung (2021) examined the effectiveness of AR in holiday mobile application marketing by using the experience economy framework, finding that immersive brand experiences through AR have a positive effect on consumer responses. Thus, this dissertation applies experience economy theory to evaluate UX in the context of cultural experiences, which are considered as experience goods. This study proposes multiple factors influencing UX corresponding to the four dimensions above.

MAIN model

The MAIN model explains how the technological aspects of digital media influence user engagement and perception of content through cognitive heuristic cues. The Media Effects Research Laboratory at Pennsylvania State University conducted extensive research on digital media over decades and identified four affordances—modality (M), agency (A), interactivity (I), and navigability (N)—which have significant psychological effects on users and can stimulate cognitive heuristics related to credibility assessments due to their structural features (Sundar, 2008). Users gain divergent experiences by triggering cognitive heuristics, being there, interaction, and realism using two main technological affordances, namely, modality and interactivity (Sundar et al., 2017).

Modality (M) refers to the ability of digital media to present information through different senses such as visual, auditory, and haptic (touch) modalities. Immersive technology provides diverse multi-sense combinations in IVEs. Agency (A) is a concept related to the sources of media content, which vary widely for modern digital media. The ability of digital media to provide users with control over content, including user-generated content, and the technology itself is one main factor underlying agency. Interactivity (I) refers to the ability of digital media to allow users to actively engage with content rather than passively consuming it. Different interaction techniques can shape UX by triggering various heuristics. The interactive features in digital media promote UX and users' perceptions. Interfaces and storytelling, which provide adaptive or personalized information, can cue the contingency and own-ness heuristics. It determines the extent to which users can modify that environment in real time. Navigability (N) refers to the ease with which users can use digital media, such as finding information and moving between functions. The MAIN model suggests that the navigability tools provided by an interface can influence UX by triggering various heuristics. UX can vary based on the ease of information gathering and cues provided by the interface.

The MAIN model has been applied to various domains beyond credibility assessment, such as online advertisements and persuasive messages, where technological affordances can influence users' attitudes and intentions (Sundar, 2008). The model has also been used to extend existing concepts and theoretical frameworks, including the uses and gratifications perspective and study of heuristics. Its theoretical and methodological implications suggest that technological affordances can cue cognitive heuristics, affecting not only credibility but also perceptual and behavioral outcomes such as the effectiveness of a message's communication, UX, and gratification from digital media use.

Presence and flow are related heuristics relevant to immersive storytelling. Presence is triggered when a user is experiencing IVEs(Riva & Mantovani, 2014). Flow, an important factor related to the heuristic interaction, is triggered when a medium enables users to engage with the content. Conversely, immersive technologies may also trigger presence, which is related to heuristics, and allow users to feel a sense of "being there" (Riva, 2018). In addition, such technologies enable users to navigate the story environment by moving their heads in different directions, thereby providing a natural and intuitive interaction related to presence and flow. As previously stated, in

IVEs, where the user is watching an actual video scene, the sudden appearance of characters and sounds may incite positive flow. Realism asserts that “seeing is believing.” This heuristic is triggered when the mediated presentation closely approximates physical reality and provides an experience of empathy (Schutte & Stilinović, 2017). It can thus provide users with a unique sense of empathy for people and events. Indeed, an immersive environment can increase empathy for the characters presented in IVEs (Shin & Biocca, 2017).

Digital media designers often prioritize building up the affordances that initially captivate them to create an appealing UX. However, technological advancements alone do not always result in a significantly improved UX. Instead, utilizing digital media’s unique characteristic to tell compelling stories through advanced technology can sustain long-term interest and engagement. Otherwise, users may feel overwhelmed by the technology and vast amount of content available, leading to disinterest and disengagement. In this dissertation, the MAIN model was employed to carefully select the factors that could impact UX in IVEs (see Studies 1 and 2). Then, a structural equation model (SEM) was built to explore the relationships among these selected factors (see Study 1).

Theorizing UX in IVEs

Although UX originated in the field of human–computer interaction, its widespread adoption has since been transcended disciplinary boundaries and extended into various domains (Law et al., 2014). UX is a multifaceted concept that incorporates subjective, contextual, intricate, and dynamic elements. It results from a combination of the user’s internal state, including their motivation, mood, and expectations (McCarthy & Wright, 2004); the features of the system encompassing usability and functionality (Hassenzahl & Tractinsky, 2006); and environmental factors such as the organizational or social context and voluntary or involuntary nature of use (Hassenzahl & Tractinsky, 2006). UX encompasses users’ overall impression or perception of a product, system, or service following their interaction with it (Law et al., 2009). In the context of immersive cultural experiences, UX is a critical aspect that can significantly influence the acceptability of immersive journalism and the cultural metaverse among users. UX is inherently based on the perceptions and emotions of each user, making it highly individualistic and subjective. The way a user interacts with a product, system, or service can vary greatly from one person to another, and their experience and emotions associated with the interaction can be influenced by various factors such as their backgrounds, previous experiences, and personal preferences. Therefore, adopting a user-centered approach when designing and evaluating UX becomes indispensable. Designers and researchers need to understand and cater to unique users’ needs.

To create a realistic and interactive environment that emulates real-world experiences, IVEs incorporate elements that engage users within the created environment through immersive technologies. Consequently, the factors of presence and flow assume a crucial role in immersive technologies, as they determine the extent to which users perceive themselves to be immersed within a real-world environment upon entering IVEs. These factors are at the heart of creating a successful IVE experience that effectively engages and immerses the user, allowing them to feel fully present in the IVEs and completely absorbed in the tasks they are performing.

IVEs, including the cultural metaverse, are multidimensional extensions of experiential communication (Komarac & Ozretić Došen, 2022), designed to facilitate appreciation, learning, entertainment, and spreading culture. By expanding into the space of experience, the modern technological scene is transforming into an integrated sociocultural communication space. The subject of the experience is the “human” who enters the IVEs. Thus, depending on the context, empathy, understanding, credibility, and enjoyment were explored in Study 1, whereas education, information utility, enjoyment, and engagement were researched in Study 2.

Empathy is an essential factor in IVEs (Barbot & Kaufman, 2020; Ventura et al., 2020). Empathy can be heightened when Individuals have a deep understanding of the subjective experiences and circumstances of others (Herrera et al., 2018). Immersive storytelling stimulates empathy, thus reflecting the general effectiveness of communicating media content. In this context, immersive media content can communicate individual experiences or feelings to a broader user. In such an IVE, users may feel strongly about another person’s emotions or conditions based on feelings of “being there” or being close to those who are directly experiencing the events. When engaged through VR, empathy can also increase one’s perception of the credibility of IVEs. Empathy can strengthen the link between VR and physical reality, thereby resulting in greater levels of believability (Paiva et al., 2005). It is also triggered by personality traits and several social factors, including reading experience. However, constrained by experimental conditions and time, the many factors affecting individual empathy could not be controlled for in this study and remain as a fruitful avenue for future research in this field.

Credibility, as a central influencing factor in journalism, creates journalistic value (Kiousis, 2001). Viewers assess news value based on participation, representation, and presentation (Meijer, 2012). Information credibility refers to whether viewers believe that news content is trustworthy. In IVEs, viewers may feel strongly about another person’s emotions or situation based on a sense of “being there” or being close to those who directly experienced the event, leading to higher levels of credibility (Kang et al., 2019).

When presenting less relevant material to viewers, it is challenging to improve the public’s understanding of the news items. Research on 2D video news processing has shown that individuals often struggle to understand and remember events when they have trouble paying attention to the news item (Lăzăroiu et al., 2017). Immersive storytelling demands a greater allocation of cognitive resources than 2D journalism as well as a greater degree of processing. For example, the illusion of establishing a sensory presence through VR may require users to allocate substantial amounts of cognitive resources (Lăzăroiu et al., 2017). Although these processes facilitate presence and flow, they concurrently deplete the cognitive resources available for higher-level processes (Ferguson et al., 2020), including news comprehension.

Education and information utility play vital roles in enhancing cultural experiences. The absorption of knowledge is a primary objective for users participating in cultural experiences. For example, cultural venues are not mere repositories of displays but serve as vital educational institutions. Information utility refers to the provision of informative and educational content. Cultural venues offer valuable knowledge and interpretation about the objects on display and context of the place

or related history and cultural heritage. The objective of information utility is to enrich visitors' understanding, learning, and appreciation of exhibits. Cultural venues achieve this by presenting relevant and accurate information through such means as labels, audioguides, multimedia presentations, and guided tours. The information provided may encompass details about the historical, cultural, scientific, and/or artistic significance of the objects, the origin of displays, the context in which they were created, and their broader implications (Trunfio et al., 2022). Cultural experiences have recently begun to integrate innovative technologies and interactive elements. As immersive technologies such as VR and AR can captivate visitors, they enable users to explore and comprehend exhibits in engaging ways. Innovative applications reach beyond the boundaries of physical space, granting visitors access to supplementary information, multimedia resources, and interactive features (Trunfio, Campana & Magnelli, 2020).

Enjoyment or entertainment is an effect of media. A sense of enjoyment comes from the continuous use of cultural and media sources. Enjoyment is an important determinant for convincing audiences to consume journalism (Van Damme et al., 2019). Sherry (2004) proposed uses and gratifications theory and identified enjoyment as a critical driver of media use. Studies have shown that individuals who watch 360-degree news videos using VR headsets have higher presence, show greater enjoyment, and believe the news to be more credible (Cummings & Bailenson, 2016; Vettehen et al., 2019). Similarly, in retail, AR tends to improve flow, enjoyment, and other shopping experience outcomes (Barhorst et al., 2021). In cultural experiences, cultural venues support visitors seeking an enjoyable and entertaining experiences alongside information and learning opportunities (Choi & Kim, 2017).

Engagement is defined as the dynamic interaction between individuals and their environment. Engagement constitutes participation, focus, and persistence on a given task (Boyle et al., 2012). Shernoff (2012) suggested that engagement may rise when individuals interact using immersive technology. Active engagement in an IVE enhances the likelihood of positive experiences, goal attainment, and experiential learning. In UX, engagement is a critical factor that designers need to consider in immersive storytelling to create compelling and effective experiences. Some strategies of storytelling such as providing clear goals and feedback, creating opportunities for interaction and collaboration, and providing a challenging but achievable goal may influence users' engagement.

Combining presence, flow, enjoyment, and engagement creates an integral UX that facilitates the visitors–exhibits interaction through an immersive experience that is enjoyable, informative, and educational (Barhorst et al., 2021). Therefore, a cultural experience results from a co-created activity between the visitor and provider. The goal of the experience is to provide value to the visitor by enhancing the interaction between the visitor, content, and space (Verhulst et al., 2021).

Research objectives and questions

Research objectives

The primary objective of this dissertation is to explore user-centered design models in IVEs in line with the theory and empirical research. The research objectives of the three studies are as follows:

- To provide insights into the possible psychological and theoretical mechanisms behind UX quality based on the roles of presence and flow (Study 1, Manuscript 1).
- To examine viewer responses to news stories with various content, themes, and sentiments to optimize UX with disparate sentiments (Study 1, Manuscript 2).
- To explore the effects of immersive storytelling on cultural experiences and propose the preliminary concept of the cultural metaverse (Study 2, Manuscript 3).
- To conduct sentiment and text analyses of trending news reports, public opinion, and media effects research (Study 3, Manuscript 4).

Research questions

The first part of Study 1 aimed to fill the gap in the literature on VR storytelling by empirically comparing immersive storytelling conditions. This study aimed to provide insights into the possible psychological and theoretical mechanisms behind UX quality based on the roles of presence and flow, including the effects that contribute to enjoyment in IVEs. The following research questions were investigated:

RQ1.1: How do psychological and theoretical mechanisms relate in immersive journalism?

RQ1.2: To what extent do presence and flow impact other cognitive outcomes?

RQ1.3: What strategies can be implemented to enhance user enjoyment in IVEs?

In IVEs, participants may experience the characters' emotions as well as their own more intensely when they share the same spatial domain as those characters. However, few studies have conducted sentiment analyses on immersive journalism, particularly focusing on UX related to positive and negative sentiments under different technological conditions. Therefore, the second part of Study 1 selected two news stories for the sentiment analysis and explored changes in UX and communication effectiveness under different technological conditions. The following research questions were addressed:

RQ1.4: What factors influence viewers to watch negative emotional content in IVEs?

RQ1.5: What factors influence viewers to watch positive emotional content in IVEs?

RQ1.6: How does the impact of viewing positive and negative emotional content differ in different IVEs?

To go beyond the empirical study on VR in journalism and explore the potential of immersive technologies to create a cultural metaverse, Study 2 addressed two gaps in the existing body of knowledge: the lack of research on the cultural metaverse on AR storytelling in cultural experiences and the absence of practical real-world studies. Hence, the study sought to address the following research questions:

RQ2.1: What are the advantages of using innovative AR storytelling in the cultural metaverse?

RQ2.2: What factors influence UX in the cultural metaverse?

Study 3 examined the similarities and differences in the ways in which the media of three countries covered the COVID-19 pandemic. It analyzed the news reports using text analysis and tested the effectiveness of sentiment analysis. This study addressed the following research questions:

RQ3.1: What did the three media outlets report at the COVID-19 pandemic?

RQ3.2: How did the sentiments expressed in the headlines of news stories about the pandemic change?

Research design

Study 1

Participants

Participants were recruited voluntarily from various departments at universities in Switzerland and randomly divided into three groups based on the type of storytelling medium presented to them: cardboard VR headsets, flat-screen pads with 360-degree viewing capabilities, and 2D videos with laptops. The VR-based and 360-degree news stories were accessible through a mobile application, while the 2D videos were accessible through *The New York Times* online news site. In the first (second) part of Study 1, 131 (263) samples were analyzed.

Materials

Two news clips, “The Displaced” and “Under a Cracked Sky,” were selected as the materials for Study 1 for four key reasons. First, both stories were produced by *The New York Times* and presented in all three storytelling mediums, ensuring content consistency, and minimizing distractions across the three conditions. Second, both stories had a typical news clip length of approximately 11 minutes. Third, the stories had different themes. “The Displaced” depicts the lives of three refugee children, Hana, Oleg, and Chuol, who were forced out of their homes due to war. The story uses scenes to narrate their plight. Conversely, “Under a Cracked Sky” is a part of The Antarctica Series[2] that features two divers who explore some of the clearest and coldest waters on Earth, narrated at McMurdo Station, Antarctica. The story mainly comprises deep-sea images and takes the viewer on a journey through its beauty. Finally, the sentiment expressed in each clip differed, which enabled us to examine the various factors in each condition. “The Displaced” elicits negative responses such as the sadness and hardship faced by the refugee children. By contrast, “Under a Cracked Sky” evokes a more benign response, as viewers learn the secret behind the most transparent water on Earth.

Procedure

The participants were required to be at least 18 years old in compliance with the recommendations of the ethics committee. As an incentive, they were offered handmade gifts (no payment was provided). Random assignment was employed allocate participants to one of the three storytelling mediums: regular 2D format on laptops, 360-degree video via mobile devices, and 360-degree video via VR headsets. However, participants were not allowed to choose whether to watch the negative or positive story, as their groups were determined by the experimental place and time

[2] The Antarctica Series is a series of four news documentary films taking viewers on, above, and below the ice of Antarctica. The material used in this study is only one news film.

they chose. Before watching the news stories, a staff member introduced and explained the experiment to the participants. After viewing each story, they completed a questionnaire anonymously. The entire experimental procedure took approximately 20 minutes (Figure 2).

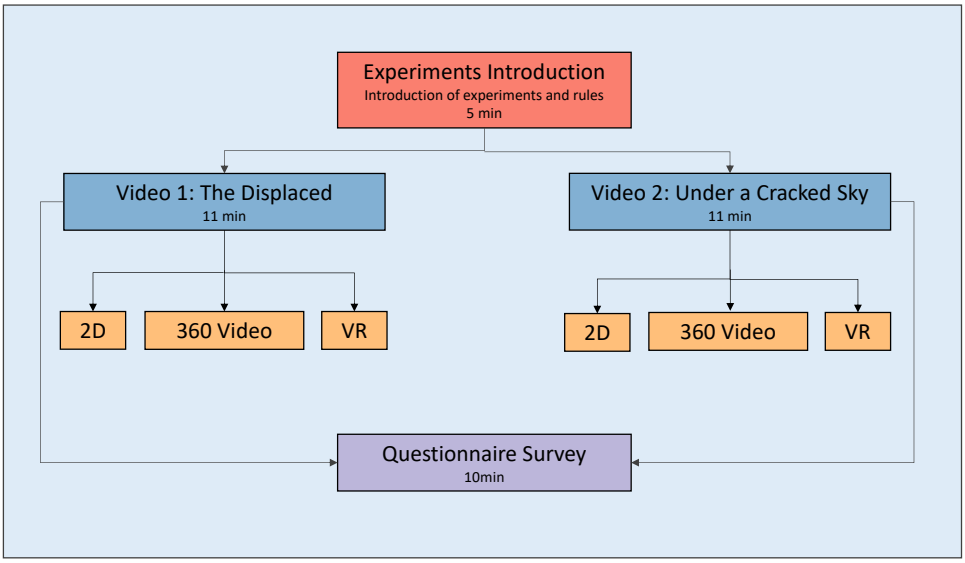


Figure 2. Study 1 framework.

Measures

The study utilized multi-item scales to assess the variables, which were adapted from validated scales used in previous studies[3]. To ensure applicability across the different experimental content and environments, the scale descriptions were modified. The participants rated their responses on an 11-point Likert-type scale ranging from 0 (strongly disagree) to 10 (strongly agree) (Leung, 2011). Pre-testing was conducted to eliminate any unqualified items. Ultimately, all the variables in the scales were deemed reliable.

The subjective experiences of users in various technological conditions were evaluated by examining presence. Presence was measured based on the MEC (Measurement, Effects, and Conditions) Spatial Presence Questionnaire (Vorderer et al., 2004), which was modified to suit the experiment (Baños et al., 2000; Shin, 2013), resulting in a six-item scale. Flow was assessed using a previously published scale (Novak et al., 2000), which was revised for conciseness, resulting in a six-item scale. Empathy was measured using the five-item scale from Davis (1983).

[3] I detail the sources of the scales used for the different influences in the following paragraphs.

Understanding was measured using a five-item scale based on existing concept measures (Busselle & Bilandzic, 2009), with some changes to suit the study. Credibility was measured using the same six items from a study that explored the impact of traditional and technological features on the credibility of online news platforms (Chung, Nam & Stefanone., 2012; Vettehen et al., 2019; Kleemans et al., 2014). Finally, the enjoyment scale consisted of five items based on previous questionnaires (Green et al., 2004; Vettehen et al., 2019; Lin et al., 2002).

The study's test reliability was analyzed before the experiment was conducted. Following the pre-test, a final sample was used for data processing. The convergent validity and consistency reliability of the model were tested using the R semTools package (Zinbarg et al., 2005). Items that failed the test were removed and the results indicated acceptable reliability. Most of the products had factor loadings with higher absolute values than the original model and the goodness-of-fit indices were within acceptance levels. The R car package was employed to avoid collinearity by examining the variance inflation factor (VIF). In the first part of Study 1, the SEM was structured using the R Lavaan package. In the second part of Study 1, sentiment analysis was conducted using a JavaScript code and calling Stanford CoreNLP API to determine the sentiments expressed objectively in the news videos. The significance of all the variables were determined using an ANOVA test with an α level of 0.05 to examine the variables. The ANOVA was supplemented with an LSD post-hoc test to examine the variance between the individual conditions in each news story. A multiple regression analysis was finally conducted to test the relative contribution of the predictors in the models.

Study 2

Participants

The participants were randomly recruited from museum visitors, resulting in a sample of 368 individuals. The study included individuals of various ages, reflecting the demographics of museum visitors, and all the participants were at least 18 years old, consistent with the recommendations of the ethics committee. Most of the participants had a bachelor's degree or higher. Before participating in the AR experiment, participants were given a brief introduction of the study's methodology and purpose and asked to provide their consent. Most of the participants were relatively new to immersive technologies in cultural experiences, with 87% reporting previously using an AR application in a cultural venue twice or fewer.

Materials

This study investigated potential AR applications for museums. The AR applications were created using the Unity engine; one application served as an AR e-book that provided the participants with a 3D view of the exhibit guides and the other application served as an AR storytelling application that encouraged two-way communication between the participants and exhibits in both virtual and physical spaces. A positioning box on the smartphone screen was overlaid with the corresponding object in real space. The participants were then prompted on their smartphones to use AR tools to find six AR exhibit presentation panels in the museum's real space, each

containing icons that would trigger the appearance of “crystal fairies.” Each completed part provided clues for locating the next exhibit. Both the AR e-book and the AR storytelling applications were designed to operate on local network departures and incorporated story clues for object recognition.

Procedure

All museum visitors were invited to participate in the AR cultural experience. However, the participants were not able to choose between being part of the control group (using the AR e-book application) or being part of the experimental group (using the AR storytelling application). The choice of group was dependent on the timing of their visit to eliminate self-selection bias. The AR applications were alternated between the AR e-book application and AR storytelling application according to the order of visitors’ arrival. Before entering the museum, a staff member introduced the experiment and provided announcements to the participants, who then voluntarily agreed to participate by completing a questionnaire anonymously.

The questionnaire was available in both English and Chinese languages, and participants were not required to disclose any personal identifying information. No incentives or payment were offered to the participants. To accommodate 30 participants simultaneously, the experiment was conducted using 30 devices. The staff spent approximately 10 minutes explaining the purpose and procedures of the experiment to potential participants. The duration of the museum visit was determined by the participants themselves and the questionnaire, which took roughly 8–12 minutes to complete, was filled out on their mobile devices upon concluding their visit (Figure 3).

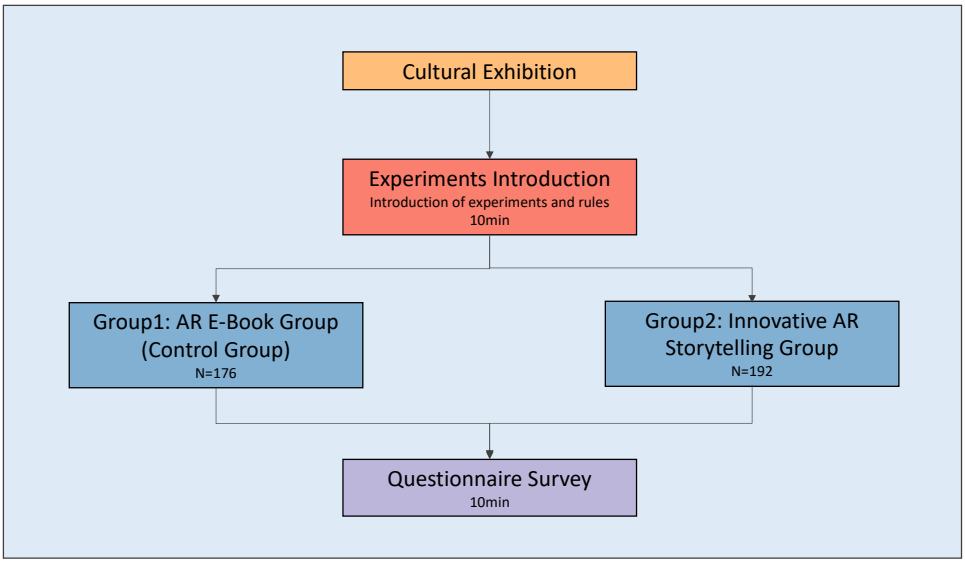


Figure 3. Study 2 framework.

Measures

The questions were divided into two main sections: user demographic variables and six aspects of UX (presence, flow, education, information utility, enjoyment, and engagement). The first section asked the respondents for general demographic information, including gender, age, and level of education. In the second section, the participants rated their overall experience using an 11-point Likert scale (0–10) (Leung, 2011). The questionnaire design incorporated questions used in previous studies[4] and drew from existing research on the reliability and validity of UX questionnaires in IVEs (Tcha-Tokey et al., 2016).

The study utilized various questionnaires to measure the six aspects of UX. To assess presence, the MEC Spatial Presence Questionnaire and items from other studies were used to construct a four-item scale, with modifications made to tailor it to the AR cultural experience (Baños et al., 2000; Vorderer et al., 2004; Weibel, 2011). The flow scale was constructed based on four items proposed by Bachen et al. (2016). For the education scale, four items were taken from two studies (Manthiou et al., 2014; Quadri-Felitti & Fiore, 2013). Information utility was measured using four items from Bhattacherjee and Sanford (2006). Enjoyment was assessed using three items from the scales proposed by Schlinger (1999) and Kleemans et al. (2014), with the item descriptions modified to suit the experimental environment. To measure engagement, three items from two studies were used (Bekele & Champion, 2019; Busselle & Bilandzic, 2009).

To avoid the risk of misinterpreting the questionnaire items and providing stereotyped responses, its reliability and validity were analyzed. The Cronbach's alpha coefficient, composite reliability (CR), and average variance extracted (AVE) were tested using the R semTools package (Zinbarg et al., 2005). To examine collinearity, the VIF was tested using the R car package. A regression analysis for statistical significance was conducted using an ANOVA when the regression coefficients of the independent variables were not equal to 0. The items that failed the test were removed, and the results showed that the questionnaire structure had credible reliability and validity. Levene's test for equality of variances and a t-test for independent samples were conducted using the R car package. The hypotheses were tested using a multiple regression analysis. The predictors were examined through a stepwise regression analysis, which were entered at the 0.05 significance level and removed at 0.01.

Study 3

Data collection

The mainstream media is a reliable source of data on public attention towards COVID-19. For Study 3, three media outlets that reported on the COVID-19 pandemic were selected as research

[4] The sources of the scales utilized to measure various influences are elaborated upon in the subsequent paragraphs.

objects, namely, CD, CNN, and DM. The data on media coverage were collected between January 9, 2020 (the first report about the pandemic) and March 31, 2020 (i.e., the period of the early outbreak of COVID-19).

Data analysis

A computational text analysis approach was used to study the initial media coverage of the pandemic. Python version 3.7 software was used for data processing and analysis. Three methods were used: the type–token ratio (TTR) was used to measure lexical diversity, word frequency analysis was used to capture the coverage of keywords such as “COVID-19” and “pandemic,” and sentiment analysis was used to classify news report headlines as positive, neutral, or negative (Pang & Lee, 2005). A recursive neural network (RNN) based on the grammatical structure of the Stanford Sentiment was employed to construct the representation of the entire sentence and measure sentiment based on the meanings of longer phrases (Socher et al., 2013). Sentiment analysis was conducted objectively using a JavaScript code and calling Stanford CoreNLP API.

Results

Study 1

The results of Study 1 showed no significant differences between age, gender, and previous VR experience across all three conditions, suggesting successful randomization. In the first part of Study 1, the participants of the 360-degree video via mobile devices and 360-degree video via VR headsets groups reported significantly higher levels of presence than those who watched the 2D videos. Similar results were found for flow, where the 360-degree video via mobile devices and 360-degree video via VR headsets groups reported higher levels than the 2D group. However, the results did not support the influence of the storytelling medium on credibility, showing that 360-degree video via mobile devices had higher credibility than 360-degree video via VR headsets, which both had higher credibility than 2D video. The participants in all the groups reported significant results for presence, flow, empathy, understanding, and enjoyment, with empathy having the weaker effect.

The results of the first part of Study 1 also showed a positive correlation between presence and flow. Presence explained 45.3% of the variance in flow. Furthermore, both presence and flow were found to positively impact enjoyment. The participants perceived that presence and flow positively contributed to credibility and empathy in the news story. However, presence had a negative impact on understanding, while flow had a positive albeit weak one. Finally, the findings indicated that presence (38.9%), flow (60.7%), and credibility (14.3%) contributed to story enjoyment, while understanding (-16.1%) and empathy (-6.5%) had negative relationships with enjoyment (Figure 4).

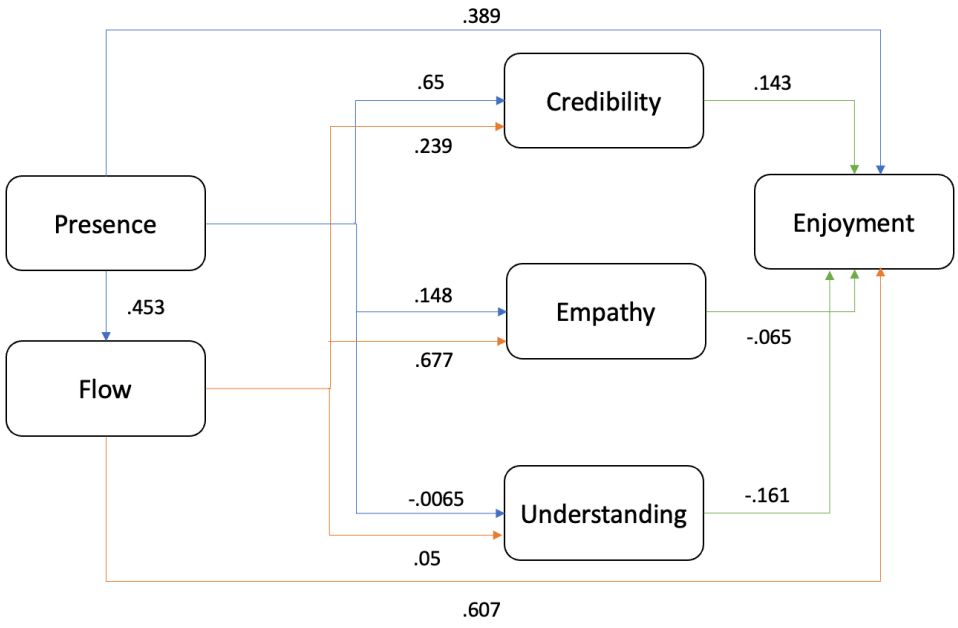


Figure 4. The representation of the SEM.

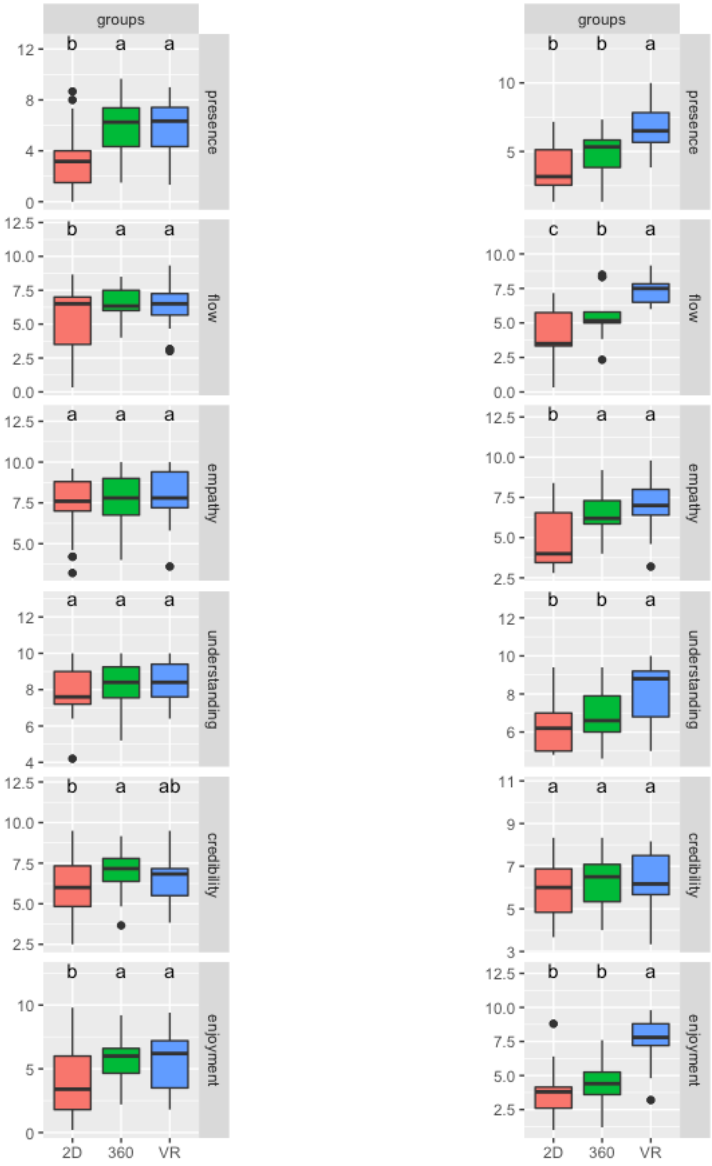
The second part of Study 1 analyzed the captions, dialogues, and off-camera voice in the two news clips (“The Displaced” and “Under a Cracked Sky”) to obtain the results for anger, anticipation, disgust, fear, joy, sadness, surprise, and trust (see Table 2). The findings showed that the sentiment in the selected videos was significantly different, with “Under a Cracked Sky” being much more positive than “The Displaced.”

Table 2. The results of the sentiment analysis.

	Anger	Anticipation	Disgust	Fear	Joy	Sadness	Surprise	Trust
The Displaced	8.06%	12.90%	4.84%	29.03%	11.29%	11.29%	8.06%	14.52%
Under a Cracked Sky	2.90%	20.29%	2.90%	7.97%	16.67%	10.87%	7.97%	30.43%

The study revealed that for both news clips, the variables exhibited higher scores for the 360-degree video via mobile devices and 360-degree video via VR headsets than for the 2D format. The study found that “Under a Cracked Sky” had a greater impact on presence, flow, and enjoyment than “The Displaced.” The differences in the variables of presence, credibility, and enjoyment after viewing “Under a Cracked Sky” were more significant across the IVEs compared with “The Displaced.” However, for “The Displaced,” these differences were not significant. The 360-degree video via mobile devices and 360-degree video via VR headsets consistently scored higher than the 2D format across all the variables. Except for credibility, all the variables were significant for “The Displaced” while “Under a Cracked Sky” showed greater differences in the variables of presence, flow, empathy, understanding, and enjoyment. However, the difference in credibility was more significant for “The Displaced” than for “Under a Cracked Sky.” The analysis confirmed that the immersive environment had a more significant influence on viewing positive news than negative news (see Figure 5).

Finally, a multiple regression analysis was used to test the predictors’ contribution to the models. In the “The Displaced” model, presence and flow were not significant, while understanding, credibility, and empathy significantly contributed to enjoyment. In the “Under a Cracked Sky” model, presence and empathy were not significant, whereas flow, understanding, and credibility significantly contributed to enjoyment.



(a) Video 1: The Displaced (b) Video 2: Under a Cracked Sky

Figure 5. Effects of IVEs on presence, flow, empathy, understanding, credibility, and enjoyment.

Study 2

The influence of technology and material stimuli on users' cognitive and emotional responses may vary depending on individual differences. Therefore, the significance of the characteristics of the participants was examined, including gender, age, and education, in two experimental groups. One group engaged with the AR E-book (Group 1) and the other engaged with the AR storytelling application (Group 2). None of these characteristics differed significantly between the two groups ($p > 0.05$), indicating that randomization was successful.

After conducting pre-tests, the final sample was used for data processing. Reliability was assessed by measuring the Cronbach's alpha coefficient, which was found to be greater than 0.8 for all the items. The CR values were higher than 0.8, indicating statistical significance. Discriminate validity was supported by the fact that the AVE for all the items was above 0.5, which was higher than all the squared correlations between the constructs. This evaluation provided strong evidence for the reliability and validity of the model, as each dimension variable had a higher variance than the observed items. The VIF results indicated no collinearity present in the model.

The study findings revealed significant differences between the two groups in terms of presence, flow, education, information utility, enjoyment, and engagement of UX. The means and standard deviations were examined for all the UX variables in both groups. The participants in Group 2 reported significantly higher presence and flow scores than those in Group 1. Additionally, education, information utility, and enjoyment were all significantly higher in Group 2 than in Group 1. Overall, Group 2 showed significantly higher scores across all the variables of UX than Group 1 (see Figure 6).

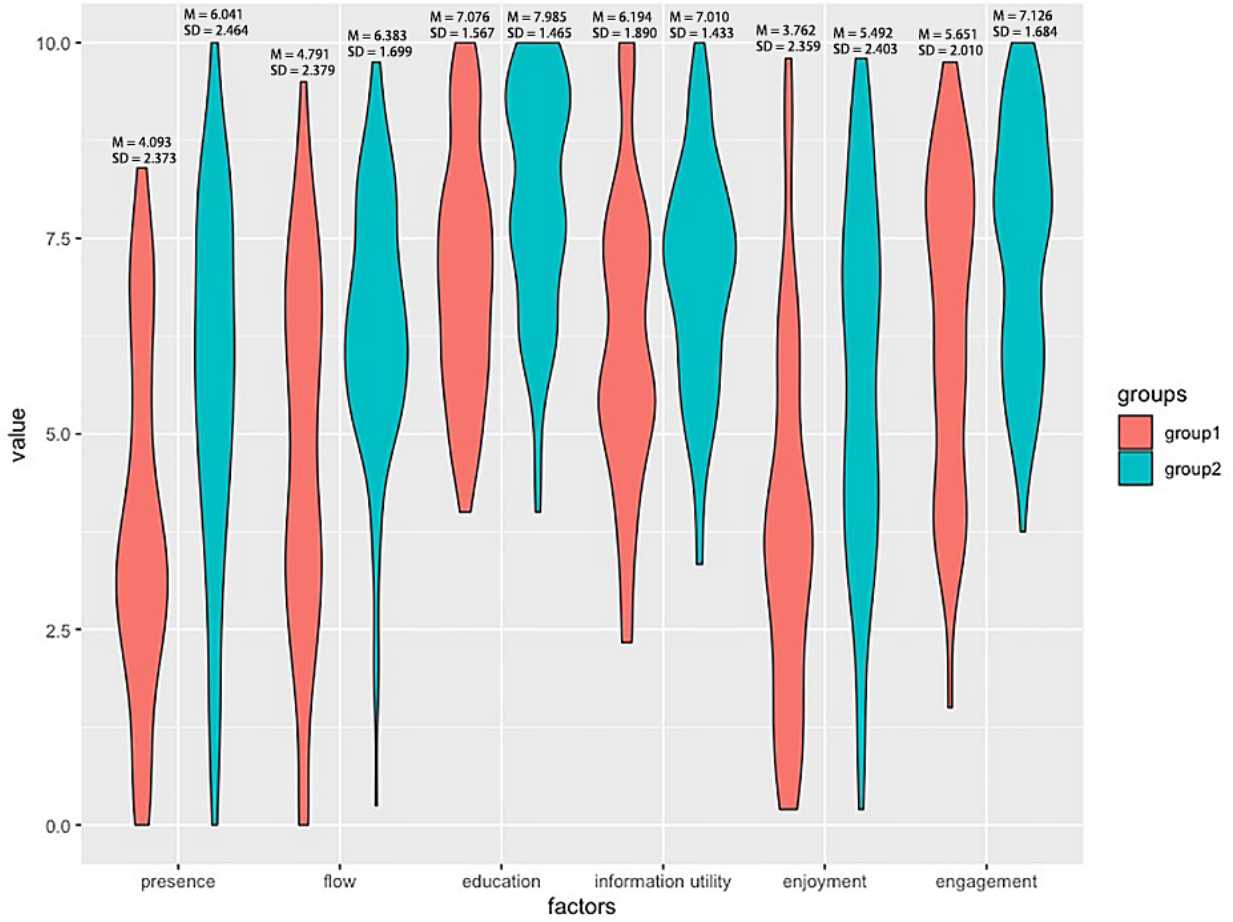


Figure 6. The score distributions for presence, flow, education, information utility, enjoyment, and engagement in Groups 1 and 2.

Among the potential predictors, only presence was not found to be statistically significant ($p = .563$, 95%CI: [-.056,.102]). Therefore, an updated regression model was tested using the four significant predictors: flow, education, information utility, and enjoyment. The model accounted for 63.3% ($R^2 = 0.633$) of the total variance in engagement, indicating that these four independent variables significantly influenced engagement. There was no collinearity among flow (VIF = 1.922), education (VIF = 1.250), information utility (VIF = 1.354), or enjoyment (VIF = 1.855). Therefore, there was sufficient evidence that flow ($\beta = .388$, $p < .0001$), education ($\beta = .324$, $p < .0001$), information utility ($\beta = .149$, $p < .0001$), and enjoyment ($\beta=.144$, $p<.001$) are key factors that mainly influence engagement.

Study 3

Study 3 divided the study period into two subperiods based on the occurrence and development of the COVID-19 pandemic: the localized outbreak in China from January 9, 2020, to February 21, 2020 (Stage 1) and the global pandemic from February 22, 2020, to March 31, 2020 (Stage 2). During Stage 1, there was a positive correlation between the number of CD reports and number of new cases in China. In Stage 2, the number of reports by CNN and DM positively correlated with their own country's new cases, while the number of CD reports did not change with the number of new global cases.

The reports of CD showed a significant surge from January 9 to February 2, after which the number of reports remained steady until March 31. For DM, the number of reports increased from January 22 and spiked again on February 23, with a gradual rise thereafter. While CNN's reports did not change significantly during Stage 1, there were considerable increases in the number of reports posted on January 29, February 4, and February 10. The overall trend was relatively similar to that of DM.

Compared with CD and CNN, DM reports contained the most words; however, the TTR was the lowest for DM compared with the other two sources. The TTR results for CNN and CD were similar; however, CNN's TTR was more concentrated than that of CD (see Figure 7).

The news reports on the pandemic mainly focused on four themes: 1) the pandemic situation and confirmed cases of COVID-19, 2) disease control measures, 3) travel restrictions, and 4) health and medical treatment concerns (RQ3.1).

According to the RNN model results for sentiment analysis (Socher et al., 2013), the headlines about the pandemic were mainly negative. During Stage 1, the three media outlets had relatively consistent negative sentiments. In Stage 2, the situation in China improved and CD thus reduced its negative sentiment, while CNN's negative sentiment was significantly lower than that of CD and its reports were relatively optimistic. Overall, CNN had a positive attitude towards reporting and did not rely heavily on evoking emotions. However, DM expressed the highest degree of negative emotions during Stage 1 using exaggerated emotional vocabulary, which slightly decreased during Stage 2 but remained at a high level (RQ3.2).

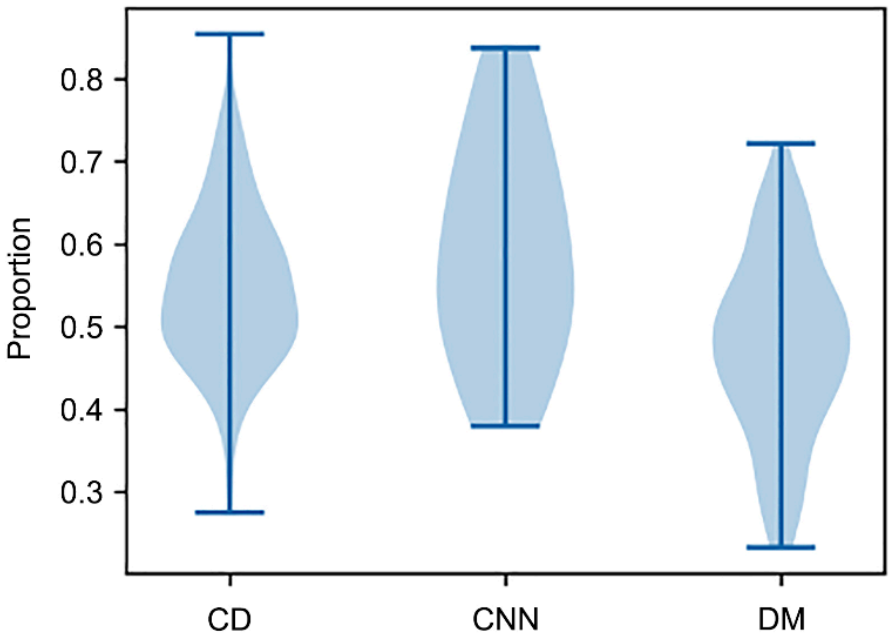


Figure 7. Measures of lexical diversity using the TTR.

Discussion

The metaverse concept has evolved from science fiction to reality and continues to evolve owing to technological advances. Technological development primarily aims to enhance the human experience and cater to human needs, serving as the main impetus behind its advancement. The cultural metaverse is a new virtual and real-world fusion of Internet applications and cultural experiences resulting from the integration of multiple new technologies and specific storytelling. The metaverse forms a new venue, which is not necessarily entirely virtual, but may also be a new space formed by superimposing virtual space on real space. It is an immersive experience, provided that VR and AR technologies deliver, closely integrating the virtual world with real-world scenarios. Each user can produce and edit content or tour routes with fully self-driven and iterative capabilities. This dissertation complemented existing studies by examining the associations among UX, digital content, and storytelling using VR and AR in IVEs.

Three studies were conducted on immersive technologies and the cultural metaverse. The first part of Study 1 investigated UX in relation to IVEs in immersive journalism and cultural experiences and its findings supported that a UX model of immersive journalism was associated with relationships between presence, flow, empathy, understanding, credibility, and enjoyment, with the roles of presence and flow especially emphasized.

The second part of Study 1 adopted the sentiment analysis approach, which is feasible to analyze textual data (Study 3). In the same IVEs, users had different experiences when viewing positive or negative digital content. Two conceptual models for positive and negative sentiments were then constructed.

Study 2 demonstrated that experiencing AR in a cultural scene could build a conceptual cultural metaverse. The analysis of the UX of an innovative AR storytelling tool showed that more positive user engagement could be fostered, leading to more positive behavioral responses in the cultural metaverse.

In summary, the vision of the Internet held by society a decade ago differs significantly from its current form. The concept of the metaverse is poised to undergo a similar developmental trajectory as the Internet, manifesting in various forms across different stages of technological advancement. This will culminate in its gradual integration into various aspects of daily life, supplanting existing applications and affording greater convenience, interactivity, and entertainment value, thereby engendering novel user habits and lifestyles.

Psychological and theoretical mechanisms based on the roles of presence and flow in IVEs

The first part of Study 1 contributed to the existing knowledge of journalism in IVEs. It demonstrated how applied immersive technology affects UX and provided evidence for the effectiveness of applied technology strategies in journalism and cultural experiences. As

anticipated, an immersive environment yielded heightened levels of presence, flow, empathy, credibility, and enjoyment. Compared with the traditional 2D video (characterized by a low-level immersive environment), presence and flow were more pronounced in the VR and 360-degree video (high-level immersive environment). While all the factors were associated with presence, the VR and 360-degree video outperformed the 2D video in UX. The emergence of flow revealed even more significant outcomes. Moreover, this research found that presence and flow are fundamental values in IVEs that offer users multi-modal interactive capabilities. Previous research has suggested that flow is independent of technical quality in IVEs and is instead affected by the user's own will, emotion, and disposition (Shin, 2018). The study's findings validated that technical quality plays a role in the manifestation of both presence and flow.

The findings contributed to the theoretical understanding of UX in IVEs by proposing an SEM to verify the paths of presence and flow on empathy, credibility, understanding, and enjoyment. The SEM showed that presence and flow play pivotal roles in fostering enjoyment, while also influencing the other variables (RQ1.2). Presence exhibited positive effects on credibility, flow, enjoyment, and empathy in the SEM model, whereas flow had positive effects on empathy, enjoyment, and credibility. This model highlighted that the technical quality of an immersive device directly affects UX and significantly influences the level of enjoyment. Some studies have suggested the existence of direct or indirect relationships among immersion, presence, and enjoyment (Johnson et al., 2018; Sylaiou et al., 2010), and the results of the first part of this study verified that this relationship was complex and multidimensional, with manifold influences and mutual interactions. Presence affected mobility and positively impacted enjoyment. At the same time, credibility, empathy, and understanding impacted enjoyment. Further, credibility, empathy, and understanding were also influenced by presence and flow from different immersions and worked together to facilitate enjoyment (RQ1.1).

The finding that empathy negatively affected enjoyment corroborated the overarching assertion of existing research (Barreda-Ángeles et al., 2020) that immersive journalism, which evokes presence, can be advantageous for enhancing empathy and enjoyment among an audience, whereas empathy and enjoyment are incompatible to a certain degree. One potential explanation is that IVEs activate additional elements of heuristics unrelated to presence, which negatively impact empathy.

Moreover, presence (flow) exhibited a weak negative (positive) effect on understanding. These findings, which partly concurred with those of previous research (Grabe et al., 2003; Lang et al., 1999; Skalski et al., 2009), are associated with a decrease in the cognitive resources available for processing information. In a 2D video, the degree of information density is low; however, in a 360-degree environment, achieving a full view can be cognitively demanding and this may overload the information processing system, especially for users unfamiliar with the 360-degree view in IVEs. However, flow prompted and guided by the sudden appearance of characters and voices can help users focus on the relevant information, thus having a slight positive impact on understanding.

Furthermore, the findings emphasized the contribution of journalism credibility to enjoyment. They suggested that immersive journalism can generate a deep feeling of presence and flow in immersive environments, thereby amplifying audience enjoyment and bolstering the credibility of news subjects. Hence, the combination of presence and flow holds great potential for actively engaging and enlightening the audience about current events, which would ultimately build greater public trust in news outlets.

Study 1 contributed to our understanding of the relationship between users and technology in immersive journalism. These factors can be used to predict and improve widespread user acceptance of immersive news storytelling. Immersive storytelling has become a new service strategy in journalism and is also a useful method for creating immersive news stories. The most important practical finding was the effect of the immersion environment and cognitive processes on enjoyment (RQ1.3).

UX of disparate sentiments in IVEs

The second part of Study 1 investigated the impact of different sentiments in IVEs on viewers' enjoyment during the viewing process. Specifically, the study explored the relationship between different variables in the three conditions based on the type of video and found that viewing positive videos had a more significant impact on the variables than viewing negative ones (RQ1.6). The theoretical contribution of the study lies in the two individual models proposed. In the negative sentiment model, understanding, credibility, and empathy directly contributed to enjoyment (RQ1.4), while flow, understanding, and credibility contributed to enjoyment in the positive sentiment model (RQ1.5).

This study also highlighted the importance of sentiment in the ways in which people interact with news stories. The experimental data collected in the second part of Study 1 supported the conclusion that news stories with positive and negative sentiments require different means to enhance users' responses and improve communication effectiveness. Furthermore, the findings validated immersive journalism as a powerful form of communication that induces the optimal states of presence, flow, understanding, empathy, credibility, and enjoyment.

Sentiment analysis can be used to determine the sentiments expressed in news stories and technology can contribute to positive and negative sentiments in news stories. Immersive storytelling is an ideal tool for demonstrating the impacts of human activity on the environment, especially for news stories with positive sentiment. Focusing on enhancing viewers' immersive experience, using images, sounds, and other visualization methods can improve the effectiveness of communication. By contrast, news stories that express negative sentiments are more likely to evoke natural empathy from viewers, and the impact of technology on communication effectiveness, in this case empathy, can provide viewers with the experience of "being there" and being immersed in the story.

Understanding is the key factor for conveying a news story and evoking empathy is more challenging in news stories with positive rather than negative sentiment. Immersive technology

can be a useful tool for immersing viewers in the IVEs of positive news stories. The design of immersive journalism using immersive storytelling should be in accordance with the emotions expressed by the themes. In this regard, developers and journalists must balance overloaded information processing and sentiment expression with the enjoyment of the immersive experience from the user perspective.

UX in the cultural metaverse

The findings of Study 2 raised our understanding the role of AR in cultural experiences, specifically in the context of the cultural metaverse. Study 2 explored the psychological, behavioral, and technological factors that influence participants' engagement with AR cultural experiences and demonstrated how AR can be the primary form of the cultural metaverse. This study therefore extended previous work by exploring the relationship between different UX factors and engagement, a topic that has been understudied in the field[5].

The innovative AR storytelling applications used in this study scored higher on all the factors that induced visitors' presence, flow, education, information utility, enjoyment and engagement compared with the AR e-book application (RQ2.1). These findings are consistent with previous studies that have shown AR technology enhances immersion and UX in cultural experiences (Rese et al., 2017; Suh & Prophet, 2018). The results suggested that AR can be an effective immersive storytelling tool that creates positive UX and should be promoted accordingly. However, further research is needed to explore how to design AR storytelling and optimize two-way interactive communication content for UX in IVEs.

An e-book AR group as opposed to an audio guide control group was used to control for the effects of technology to isolate the impact of different immersive technologies on engagement outcomes. The results demonstrated that flow and education were the primary factors influencing engagement in AR storytelling of cultural experiences (RQ2.2). This design of the AR storytelling application was based on prior research that has found that flow was the main factor contributing to engagement (Weibel, 2011). The AR storytelling application provided absorption, entertainment, challenges, and rewards to enhance flow and receive high engagement. The design was supported by the findings of Csikszentmihalyi, Abuhamdeh, and Nakamura (2014) that identified "perceived skills and challenges," "a clear goal," and "immediate feedback" as significant factors. These design features were the main reasons why the innovative AR storytelling application received higher flow than the AR e-book.

Although presence is a critical factor in both VR and AR, it was not found to be significant in the regression model used in this study. The results of the part and partial correlations were somewhat different, suggesting that the correlation between the variables may be the primary

[5] These studies have already been cited in the previous section.

reason for this result. Future research could explore the interplay of presence and other variables by designing different interaction content in the same technical environment.

Education is a significant factor influencing engagement, and the study's results provided empirical support for the findings of previous research (Georgiou & Kyza, 2018; Laato et al., 2021; Shernoff, 2012). Information utility is related to education. They confirmed that cultural experiences have a strong educational attribute, which is the primary purpose of visiting museums (Bell & Smith, 2020), and that education and information utility positively contribute to engagement.

Practitioners are developing applied technology strategies in cultural experiences. The findings of this study provided guidance for implementing immersive novel technological solutions that promote visitor engagement with exhibitions in the cultural metaverse. Specifically, the findings highlighted the essential features of storytelling when using AR technology. Practitioners should strive to offer more affordances for interaction, such as interactive rewards to promote visitor engagement. The feasibility of this solution was confirmed by comparing the data from two experimental groups. In this study, most of the visitors were interested in the innovative AR storytelling application and interacted with the exhibits. Although the present experiment did not incorporate participation intention and sharing intention as directly observed variables, it sought to ascertain their willingness to register for other special exhibitions. The results indicated that people using innovative AR tools exhibited a significantly higher registration rate for special exhibitions, surpassing that of E-book AR tools by 23%. Furthermore, the participants in the innovative AR Group demonstrated a substantially greater inclination to assist their friends in registering for special exhibitions, exceeding those in the E-book AR Group by 37%. The results indicate the potential effectiveness of immersive storytelling and interactive design in promoting future long-term participation intention and fostering a culture of sharing intention. Therefore, practitioners should incorporate immersive technologies and immersive storytelling in the visit process to foster informative and enjoyable experiences in the cultural metaverse.

Computational methods for sentiment and text analyses

Study 3 advanced existing knowledge on the computational methods of text analysis. The approach adopted to analyze the textual data and build the theory provided support for new methodologies for scholars examining news communication and text analysis. Furthermore, the findings offered two dimensionalities of sentiment analysis for news: the entire headline and words in the headline. As a practical implication, the findings can aid health departments in exchanging information, guiding accurate public awareness, and eliminating public fears about misconceptions of health crises such as pandemics. Specifically, computational text analysis helps understand media reports about the pandemic and promotes the communication of health information.

Sentiment analysis serves as a valuable instrument for examining the sentiment conveyed in news articles and on social media. Among its advantages, it can discern users' sentiments and opinions expressed across social media platforms, gauge public sentiment about social issues, and evaluate customer feedback derived from online reviews. Its application can thus help

decision-makers evaluate social and market sentiment, detect emerging trends, and make data-driven decisions. Moreover, sentiment analysis can also be applied across diverse domains (as demonstrated in Study 1). The resulting increase in the understanding of human emotions and opinions holds significance for both academia and industry.

Limitations and future research

The three studies presented in this dissertation had several limitations. First, the experimental design suffered from using only a limited number of news story themes, which is a common issue in this type of research. Second, the COVID-19 pandemic posed challenges to participant recruitment, resulting in smaller sample sizes and fewer themes, thus limiting the statistical power of the study. Third, the questionnaire was time-consuming to complete, which may have led to possible errors if the participants did not understand the questions.

Regarding cultural experiences, the current study had limitations related to the population sample in Study 2. As the exhibition was themed on technology and digitization, the visitor population tended to be highly educated individuals interested in digital culture and technology. This limited the generalizability of the findings to other visitor profiles. Moreover, owing to the geographical limitations of this venue, the cultural background of the population was relatively homogeneous. Future studies could extend the population to include AR users in other cultural contexts to obtain more accurate and generalizable results. In addition, future research could examine cultural experiences that display different cultural content.

Despite continuous developments in applied technology, implementing immersive technology in VR and AR to improve UX in the cultural context is still in its infancy. Despite for entertainment purposes, few empirical field-based studies have examined immersive technologies in cultural experiences. In the future, researchers could examine the effects of more advanced immersive technologies and forms in different types of cultural settings. Practitioners lack sufficient knowledge of technology and strategies in an immersive context, and more practical research is needed to reveal the UX model in multiple scenarios. Generating knowledge in this area could help practitioners enhance UX in different cultural experiences, thereby contributing to building the cultural metaverse.

Furthermore, privacy issues are becoming increasingly significant in immersive applied technology. Investigating this topic in future research, as cultural experiences generate an increasing amount of personality data, would be worthwhile.

Finally, although AI technology has been used in diverse industries, studies on the cultural experience of IVEs are scarce. For example, avatars can be connected to ChatGPT[6] and interact with users in the metaverse to provide real-time personalized interaction. Exploring the combined use of immersive technologies and the cultural metaverse to predict users' favorite forms using AI would be an interesting avenue to pursue in future research.

Information technology is rapidly evolving, and the realm of immersive technologies extends beyond VR and AR. Emerging concepts, such as extended reality (XR) and mixed reality (MR),

[6] ChatGPT is a natural language processing tool driven by AI technology.

have sparked debates regarding their definition and implementation. None of these technologies will bring an end to the immersive technology field. Instead, we can anticipate the continual emergence of innovative immersive technology products. The enduring element throughout this evolution is the fundamental centrality of “human” as users and the primary focus of immersive technology services.

Conclusion

This dissertation addressed several gaps in the estimation of UX and IVEs and introduced the concept of the cultural metaverse. It established that highly IVEs play a crucial role in promoting presence and flow, which leads to an increase in UX. This finding highlighted the importance for practitioners to implement ways to provide high-quality digital content with high immersion to improve UX. Storytelling in IVEs is vital in this regard, and it should be matched with topical or hematic sentiment to optimally shape UX.

The thesis demonstrated that AR is a suitable tool for cultural experiences in the cultural metaverse, despite being less immersive than VR. This is because AR technology provides immersive experiences that boost visitor engagement. The key takeaway from this dissertation is that immersive technology leads to positive UX. Practitioners should gradually develop strategies and design immersive storytelling to implement user interaction and optimize immersive cultural experiences.

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Appendix A

Presence and Flow in the Context of Virtual Reality Storytelling: What Influences Enjoyment in Virtual Environments?

Shuran Yang, Wenxiang Zhang

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Presence and Flow in the Context of Virtual Reality Storytelling: What Influences Enjoyment in Virtual Environments?

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Abstract

Virtual reality (VR) has widely been implemented in a variety of industries, with immersive storytelling now gaining popularity in the field of journalism. In this regard, there are many important questions about which direction modern journalism should take as a whole. To test the feasibility of immersive storytelling, this study developed a cognitive experience model containing paths for presence, flow, credibility, empathy, understanding, and enjoyment. A total of 131 participants were divided into three groups and exposed to either VR, 360-degree videos, or two-dimensional (2D) videos, then asked to rate their experiences. With the exception of understanding, results showed that the VR and 360-degree videos were more highly evaluated in each path when compared with 2D videos. In this case, technical attributes did not greatly affect the study variables. However, presence played a vital role in news promotion, while flow was positively affected by presence; flow also affected other variables when combined with presence. Finally, a structural equation model was tested and the weights of the different influences on the enjoyment impact were presented. In sum, this study found that immersive storytelling improved both presence, flow, and credibility, which jointly and positively affected enjoyment. Understanding negatively affected enjoyment. Empathy had little effect on enjoyment in the model.

Keywords: virtual reality storytelling, presence, flow, enjoyment, SEM

Introduction

Virtual reality (VR) is of increasing importance in many fields of scientific research, particularly, including psychology, sociology, and the humanities. Studies have shown that it is crucial for any VR application to help users achieve a maximum sense of presence.[1] In this regard, immersive virtual environments (IVEs) offer spaces that recreate familiar spatial and social contexts.[2] In recent years, many news outlets have announced or released VR opportunities, with well-known outlets such as British Broadcasting Corporation, The New York Times, and Washington Post even launching 360-degree projects. Referred to as immersive journalism, this provides viewers with first-person experiences of events, locations, and stories.[3] Immersive journalism encourages users to empathize with people and events in the news.

It brings users closer to characters, enabling them to share the same space virtually and inciting them to feel their emotions or situations more strongly. Simulating certain factors can cause immersive journalism to seem real to the users.[4] New opportunities have created new challenges for immersive journalism. How does immersive journalism affect the user experience (UX)? Are these influences positive? There are many hypotheses about the possible effects of immersive journalism, but few studies have investigated the UX for news stories in IVEs.[5,6]

Research has shown that presence influences psychological outcomes in different environments, such as those related

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to reading, watching films, and playing games in VR.[7] Individuals may watch 360-degree videos using VR headsets, while desktop applications offer more benefits than plain text, even when the same stories are presented.[8] As such, presence is increasingly being explored as a mediator that increases other VR outcomes.[9] In fact, it is widely regarded as a contributing factor for increasing both empathy and embodiment.[4]

Culture and entertainment account for large shares of existing VR applications. Applications in other areas also use gamification elements to enhance user fun and enjoyment, making them critical enhancements. As news stories are essential components of cultural life for most people, journalism plays significant roles in both culture and entertainment. This makes immersive journalism an important research topic.[10]

Many studies have investigated the influences of VR technologies.[11–13] However, there has been a lack of focus on the cognitive process itself. At this stage, VR applications are mainly geared toward entertainment. In this context, it is important to measure the outcome of enjoyment.[14] This exploratory study aimed to fill this gap in the VR storytelling literature by empirically comparing different immersive storytelling components, with a focus on how they affect enjoyment. More specifically, this study investigated whether and how users felt the elements of presence and flow based on immersive journalism, in addition to whether presence and flow influenced the UX of enjoyment, whether presence and flow impacted other cognition-related outcomes-credibility, empathy, and understanding, and how user enjoyment could be improved.

As such, an experiment was conducted to compare the effects of VR, 360-degree videos offered through mobile devices, and two-dimensional (2D) videos among a sample of college students. In this context, participants either viewed VR with a cardboard headset, 360-degree videos on flatscreen pads, or watched traditional 2D videos. Results were then compared through a structural equation model (SEM).

Our findings provide insight into the possible psychological and theoretical mechanisms behind UX quality based on the roles of both presence and flow, including which effects contributed to enjoyment in IVEs.

Materials and Methods

Participants

The project accords with the ethical acceptability of research projects that did not involve minors, vulnerable, or persons incapable of judgment. No personal details were involved in this project. Before the experiment, participants have informed of the experiment purpose, data use. A total of 131 participants were randomly divided into three groups based on the presented storytelling medium, including cardboard VR headsets, flatscreen pads with 360-degree viewing capabilities, and 2D videos. The VR-based and 360-degree news stories were accessible through a mobile application, whereas the 2D videos were accessible through The New York Times online news site. Participants were voluntarily recruited from various departments at universities in Switzerland.

Stimuli

The experimental material presented to participants included two contemporary news stories, titled ''The Displaced,'' and ''Under a Cracked Sky.'' Both stories were $\sim$11 minutes long and published in various video versions from the New York Times, but the stories featured entirely different themes. ''The Displaced'' was designed to immerse users in the lives of three refugee children who were forced to leave their homes as a result of war. It was specifically chosen due to its critically acclaimed documentary status. Furthermore, refugees are a commonly presented news item in the context of social and political life in Europe, meaning that participants were familiar with the topic. At the same time, it pertains to issues that are likely to instill sympathy.

For example, the presented struggles were likely to cause adverse reactions and evoke empathy. In this context, emotional intensity is correlated with emotional valence, leading to other individual emotion variables and producing more pronounced responses and significant contrasts.[15] In addition, several studies have already used ''The Displaced'' to facilitate similar comparisons while refining related theories and models.[4,16] In contrast, ''Under a Cracked Sky'' is part of The Antarctica Series. Two divers who researched some of the most significant and frigid waters on Earth narrated the story at McMurdo Station, Antarctica. The story features images captured mainly in the deep sea and takes viewers on a journey through its beauty, evoking more benign responses. Thus, these two videos with different content were used to reduce the effect of the theme on the variables.

Research Model and Hypotheses Development

Different models were evaluated and integrated, including the Modality-Interactivity-Agency-Navigability (MAIN Model)[17] and presence and flow model.[1,2,18]

The MAIN Model is concerned with the technological aspects of digital media and claims that technological affordances trigger cognitive heuristic cues, or psychological reactions, in relation to the quality and credibility of media content.[17,19] Presence and flow are related heuristics relevant to virtual storytelling. Presence is triggered when a user is experiencing in IVEs. Once triggered, the users consider the authenticity of the experience when making their evaluations.[20] Flow is an important factor related to the heuristic interaction, which is triggered when a medium enables users to participate with the content. Therefore, the 360-degree video may trigger presence, which is related to heuristics and allow users to feel as if they are ''being there.''[21]

In addition, 360-degree video enables users to navigate the story environment. VR enables users to navigate the story environment by moving their heads in different directions, thereby providing a more natural and intuitive interaction, which is related to presence and flow. In VR and 360-degree video, where the user is watching an actual video scene, the sudden appearance of the characters and sounds can potentially incite a positive flow.

Realism is ''seeing is believing.'' This heuristic is triggered when the mediated presentation closely approximates physical reality and provides an experience of empathy.[22] ''It can give users a unique sense of empathy for people and events.'' Research has demonstrated that VR can increase empathy for the characters presented in IVEs.[23] Per the MAIN Model, heightening the senses of being-there, interaction, and realism can trigger positive heuristics, which contribute to users' assessments of content credibility.[17]

Based on the MAIN Model, this study features different models with presence and flow as the core research objects, which have been applied and tested by researchers.[24–26]

Therefore, a VR cognitive model (Fig. 1) was also built to examine the roles of presence and flow, thus enabling us to postulate the effects on enjoyment, which influences UX.

Presence and flow in immersive storytelling

Presence and flow affect enjoyment, particularly when combined with credibility, empathy, and understanding. These outcomes are associated with presence and flow, but also impact enjoyment. Furthermore, this study constructed a cognitive model that can be used to develop a relevant framework. While presence and flow positively affect enjoyment, credibility, empathy, and understanding, credibility, empathy, and understanding impact enjoyment in the context of the integrated model, which can be used to examine immersive environments (i.e., the core driver of VR storytelling). Presence was measured using items taken from three previous studies,[27–30] whereas six items were used to measure flow.[31] We developed the following hypothesis:

H1: Presence positively affects flow.

Enjoyment in immersive storytelling

Feelings of physical and mental happiness are derived from consistently used media sources, primarily in the form of entertainment.[32,33] In journalism, a competitive advantage is enhanced by understanding what audiences enjoy in terms of the preferred news contents, narrative styles, and equipment. Several models[2,34] have illustrated that presence has a positive influence on enjoyment. Users are able to enjoy a particular story if they have a strong sense of presence within the connected IVEs. This mechanism arises from arousal theory, and has been confirmed in studies on 2D news.[35]

Although some studies have already explored enjoyment based on results from 360-degree videos and VR journalism,[9,36] none have offered a precise model for explaining the related cognitive process while discussing other influences, especially including the improvement factor known as flow. In this study, enjoyment was assessed based on an existing adjective scale.[9,37,38] We developed the following hypotheses:

H2: Presence positively affects user enjoyment in the context of immersive journalism.
H3: Flow positively affects user enjoyment in the context of immersive journalism.

Credibility in immersive storytelling

Credibility is a central influencing factor in journalism.[39] There are three dimensions, including credibility of the source, credibility of information, and media reputation.[40] Both the credibility of media sources and reputation are subjective audience perceptions regarding the reliability and accuracy of news media outlets.[41] To reduce the number of variables, we chose The New York Times, which is well recognized by the general public and produces quality journalism. Therefore, credibility of the source and media reputation are ensured. Information credibility refers to whether the viewers believe news contents are trustworthy.

This article discusses credibility mainly in terms of direct informational trustworthiness. The news impacts audiences not only depending on how they read the contents, but also whether they trust the information.[42] In this study, credibility was assessed using both outcomes; we also investigated the credibility of online news sources based on conventional and technical features.[43] ''The news was objective,'' ''The source of the news video was sincere,'' ''The source of news video was reliable,'' ''I am knowledgeable about this topic,'' ''The news video was in-depth,'' and ''The news video was made by professional journalists,'' six items were used to measure credibility. In this case, we developed the following hypotheses:

H4: Presence positively affects how users assess credibility in immersive journalism.
H5: Flow positively affects how users assess credibility in immersive journalism.

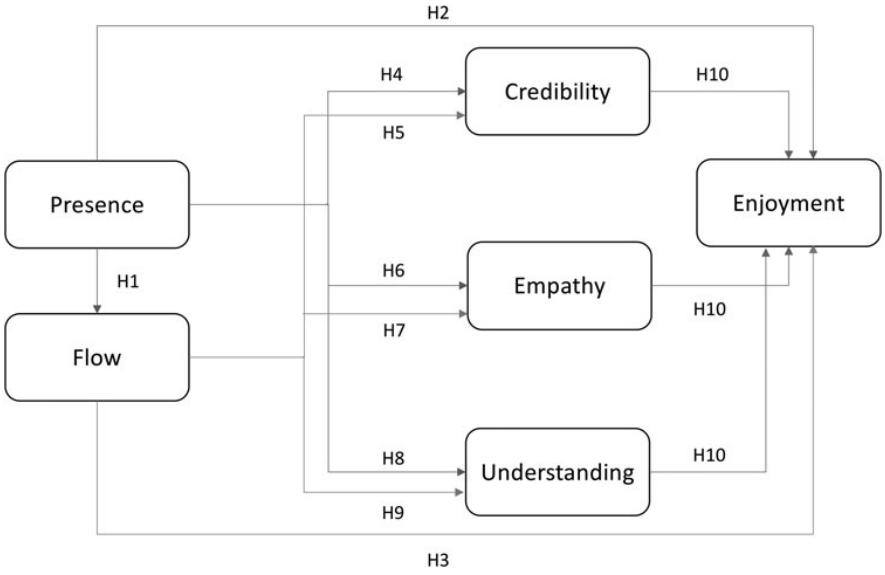

FIG. 1. Study model and hypotheses.

Table 1. Convergent Validity and Reliability Analysis

Variables	*Presence*	*Flow*	*Empathy*	*Understanding*	*Credibility*	*Enjoyment*
Cronbach's α	0.8526	0.7545	0.8409	0.8653	0.7797	0.8279
Composite reliability	0.8574	0.8076	0.8552	0.8703	0.7886	0.8391
AVE	0.5265	0.5366	0.5549	0.571	0.5443	0.5185

AVE, average variance extracted.

Empathy in immersive storytelling

Empathy is also an essential factor in immersive environments.[44,45] Individuals can empathize to greater extents when they understand the subjective experiences and circumstances of others.[46,47] VR storytelling stimulates empathy, thus reflecting the general effectiveness of news communication. In this contest, immersive journalism can communicate individual experiences or feelings to many users. In such an immersive environment, users may feel strongly about another person's emotions or conditions based on feelings of ''being there,'' or being close with those who are directly experiencing the events. When engaged through VR, empathy can also increase one's perceptions about the authenticity of IVEs. Empathy can strengthen the link between VR and physical reality, thereby resulting in greater levels of believability.[48]

Indeed, empathy is also triggered by personality traits and several social factors, including reading experiences. However, constrained by experimental conditions and time, the many factors affecting individual empathy could not be controlled. Instead, this study focused on reporting the effects of VR storytelling on empathy and enjoyment in the same way that some researchers have studied empathy in reading.[49] As such, the impacts of both presence and flow on empathy directly affect how users process news from a cognitive standpoint.[8,23] We developed the following hypotheses:

H6: Presence positively affects user empathy in the context of immersive journalism.
H7: Flow positively affects user empathy in the context of immersive journalism.

Understanding in immersive storytelling

It is difficult to improve the public understanding of video news when presenting information that is not highly relevant. Research on 2D television news processing has shown that individuals often struggle to understand and remember events when they have trouble paying attention to the news.[50] Compared with 2D journalism, VR storytelling results in a greater allocation of cognitive resources. VR journalism also requires a greater degree of cognition. For example, the illusion of establishing a sensory presence through VR may require users to allocate substantial amounts of cognitive resources.[51]

Although these processes facilitate presence and flow, they also reduce the available cognitive resources needed for higher cognitive processes,[52] including news comprehension. Recent research has shown that immersion negatively impacts news communication, which is achieved through presence.[8] In this study, we assessed relevant scale items using questions originally proposed by Busselle and Bilandzic[53] and made some changes to suit the situation.[54] We constructed the following hypotheses:

H8: Presence negatively affects how users understand immersive journalism.
H9: Flow negatively affects how users understand immersive journalism.

A few previous studies have explored the impacts of presence on different variables.[2,29,51] However, there is a gap in the literature concerning the flow of immersive journalism. The relationships between enjoyment, presence, and flow are not always direct, as they may also be influenced by other factors. We constructed the following hypothesis:

H10: Enjoyment is influenced not only by presence and flow, but also by credibility, empathy, and understanding.

Confirmatory factor analysis

Test reliability was analyzed before conducting the experiment. A final sample was used for data processing after the pretest. The R package ''semTools'' was used to test convergent validity and consistency reliability of model.[55] The Cronbach's α coefficient ranged between 0.75 and 0.85 and the average variance extracted of all the items is >0.5, implying satisfactory construct reliability. The Composite reliability ranged between 0.79 and 0.86, indicating that it is considered significant[56] (Table 1). After removing items that failed the test, results indicated adequate build reliability. The majority of products had factor loadings of higher absolute values than the original model. The goodness-of-fit indices were within acceptance levels.

Results

Randomization checks

Three conditions were related to several contextual variables in the first step of this study. None of the three conditions showed significant differences between age, gender, and previous VR experience (Table 2). These results suggested that randomization was successful.

Results also showed that the storytelling medium's main influence was on presence (i.e., when considering presence, flow, and credibility). In this regard, participants who watched 2D videos ($M = 3.6477$, $SD = 2.1770$) showed much weaker results for presence when compared with those who used VR ($M = 6.4489$, $SD = 1.8627$) and 360-degree videos ($M = 5.0523$, $SD = 2.2251$). Similar results were found for flow, which was higher in the VR ($M = 6.9848$, $SD = 1.2957$) and 360-degree video ($M = 6.0620$, $SD = 1.6543$) groups when compared with the 2D group ($M = 4.9697$, $SD = 2.3981$) (Table 3).

The data suggest that VR storytelling successfully induced high levels of almost all variables, except credibility. Results of credibility showed that 360-degree video and VR were higher than 2D video ($M = 5.7159$, $SD = 1.6341$), but the

Table 2. Participants Profile

	2D	360-Degree	VR	Total
Gender, %				
Female	45.45	55.81	50	50.42
Male	55.55	44.19	50	49.58
Age (years), %				
<20	6.82	0.00	9.09	5.30
20–25	9.09	18.06	40.91	22.87
26–30	59.09	41.86	34.09	45.01
31–35	15.91	25.68	9.09	16.86
>35	9.09	13.96	6.82	9.96
VR experience, %				
Never	45.45	46.51	45.45	45.80
1–5 Times	36.36	41.87	43.18	40.47
>5 Times	18.19	11.62	11.37	13.73
Total, *N*	44	43	44	131

2D, two-dimensional; VR, virtual reality.

360-degreevideo ($M = 6.5000$, $SD = 1.4750$) was higher than VR ($M = 6.2841$, $SD = 1.4251$). The boxplot (Fig. 2) illustrates the overall distribution and median of each variable score in the three groups, which was exported by R. A least significant difference test was used in the analysis of variance analysis. As shown in Figure 3, participants in all groups reported the most significant results for the sense of presence, flow, empathy, understanding, and enjoyment. The outcome of empathy was less than others but still showed significance.

The R package ''Lavaan'' was used to analyze the model. The model is a good fit to the data. Using the fitting criteria suggested[57] and considering the whole sample ($N = 131$), the model produced the χ^2/df of 1.86, an root mean square error of approximation of 0.06, an non-normed fit index of 0.92, and a comparative fit index of 0.94. They were within the appropriate ranges, thus indicating high internal consistency. The R package ''car'' was used to examine the variance inflation factor to avoid the influence of collinearity. The results (presence = 1.8386; flow = 2.1923; empathy = 2.193; understanding = 1.574; credibility = 1.541) indicated no existing collinearity in this model.

General findings from testing the hypotheses

The R package ''Lavaan'' was used to structure the model and test regression. As shown in Figure 4, the results of hypotheses tests demonstrated that presence was positively affected with flow (H1). Presence explained 45.3 percent of the variance in flow. Furthermore, presence and flow both influenced enjoyment and showed good support (H2 and H3).

Regarding the news story, participants perceived that presence and flow positively contributed to credibility (H4 and H5) and empathy (H6 and H7). However, presence negatively affected understanding (H8), and flow positively affected understanding (H9), although both not strongly. Therefore, H9 was not be supported. Finally, there was strong support for H10, which proposed that presence (38.9 percent), flow (60.7 percent), and credibility (14.3 percent) would contribute to story enjoyment. However, understanding (−16.1 percent) and empathy (−6.5 percent) were negatively related to enjoyment.

Discussion

In regard to future technology developments, VR will increasingly be implemented in a variety of industries. This research is particularly meaningful for professionals who are attempting to use VR technologies in the context of journalism.

As expected, VR news storytelling resulted in higher levels of presence, flow, empathy, credibility, and enjoyment. Compared with traditional 2D videos, presence and flow were also more pronounced through VR and 360-degree videos. Although all factors were associated with presence, VR and 360-degree video performed better in this regard than 2D video. Even more significant results emerged for flow. The intensity and commonalities of these effects show that existence and flow are the fundamental values that VR and 360-degree videos offer when compared with 2D videos. This means that multimodality and interactive capabilities are offered to users in terms of IVEs perception.

Previous research has inferred that flow is independent of the quality of technical logic in IVEs, and is affected by the user's own will, emotion, and disposition.[4] This study's experimental results confirmed the existence of a relationship with flow. As confirmed by H1, presence also had a positive effect on flow. Therefore, flow is not independent of technical quality. Rather, it is affected by existence, and influences other factors when combined with presence.

Second, this project made a theoretical contribution by proposing an SEM to verify the paths of presence and flow on empathy, credibility, understanding, and enjoyment (Fig. 4). The model explained that presence (38.9 percent) and flow (60.7 percent) played a central role in facilitating enjoyment while influencing other variables. Compared with other factors, although understanding is related to both presence and flow, it negatively impacted the model and was substantially affected by technical factors, which is somewhat supports that VR may require users to allocate cognitive

Table 3. 2D, 360-Degree Video, VR for All Outcome Variables

	2D		360-Degree		VR	
	Mean	SD	Mean	SD	Mean	SD
Presence	3.6477	2.1770	5.0523	2.2251	6.4489	1.8627
Flow	4.9697	2.3981	6.0620	1.6543	6.9848	1.2957
Empathy	5.5833	2.6258	6.7674	1.9142	7.5909	1.7191
Understanding	7.1742	1.5921	7.6512	1.5135	8.5379	1.2435
Credibility	5.7159	1.6341	6.5000	1.4750	6.2841	1.4251
Enjoyment	3.8182	2.3287	5.0930	1.7223	6.9273	2.0383

2D, two-dimensional; SD, standard deviation; VR, virtual reality.

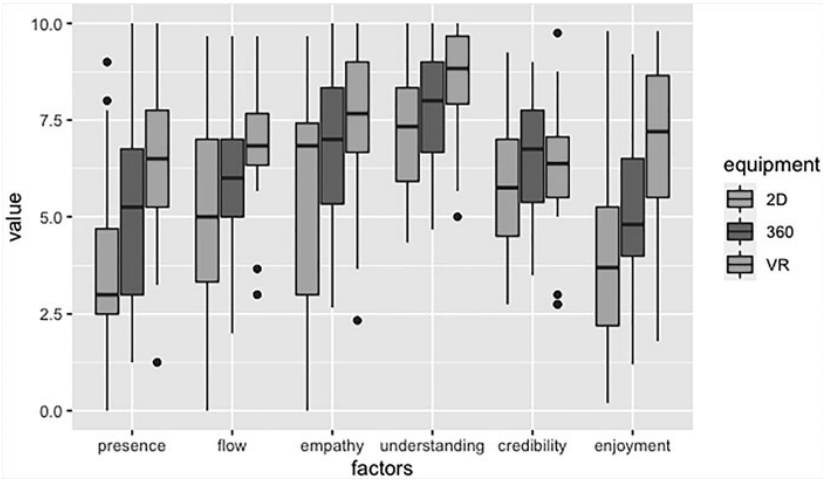

FIG. 2. Difference between the overall effects of 2D, 360-degree video, and VR. 2D, two-dimensional; VR, virtual reality.

resources.[58–60] In this regard, empathy also did not have a positive effect, but was weak and insignificant. On the contrary, credibility had a positive influence on enjoyment.

In general, an SEM approach was used to evaluate the integrated impacts of all variables. All paths were supported in the overall model. Combined, the linear regression component of SEM modeling between the influencing factors showed that presence and flow were the key factors affecting enjoyment. A crucial cognitive mechanism was obtained from the three sets of results: highly immersive devices influenced the users to perceive presence and flow, while technical quality directly affected the UX and largely determined the level of enjoyment; as an important factor of journalism credibility also contributed to enjoyment. Regarding VR, it is worth mentioning that there were significant differences between VR helmets and 360-degree videos.

As such, the technological quality directly affected the UX. Understanding seemed to affect enjoyment negatively. Partial support for the hypotheses that were inspired how to evaluate the SEM. Understanding is associated with having decreased cognitive resources remaining for cognitive processes. The 2D video was characterized by a low degree of information density. In the 360-degree environment, the process of achieving a full view to be able to look around in a way similar to reality may take cognitive resources. Users are not familiar with the 360-degree full view in IVEs, in which the information processing system can be overloaded. However, flow caused by the sudden appearance of characters and voices may remind the users to focus on special information, having a slight positive impact on understanding.

Some studies have suggested the existence of direct or indirect relationships between immersion, presence, and enjoyment.[61,62] The model implemented in this study verified that this relationship was complex, multidimensional, multi-influential, and involved mutual interactions. We, therefore, argue that presence affects mobility and positively

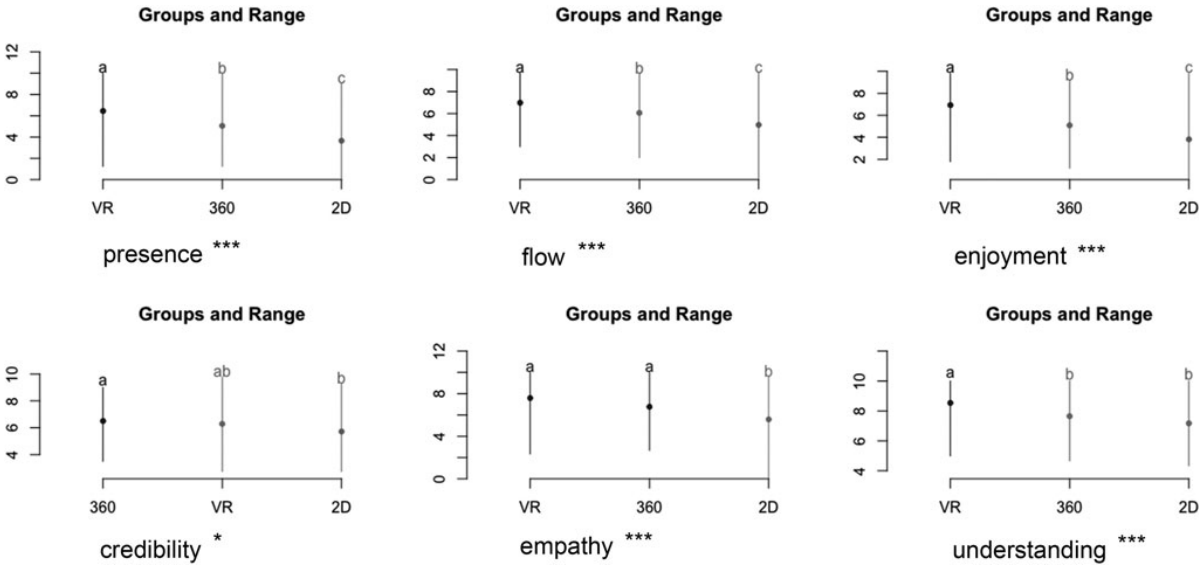

FIG. 3. Main effects of storytelling on key variables. *Note:* Fisher's LSD *post hoc* test. *$p < 0.05$, ***$p < 0.001$. LSD, least significant difference.

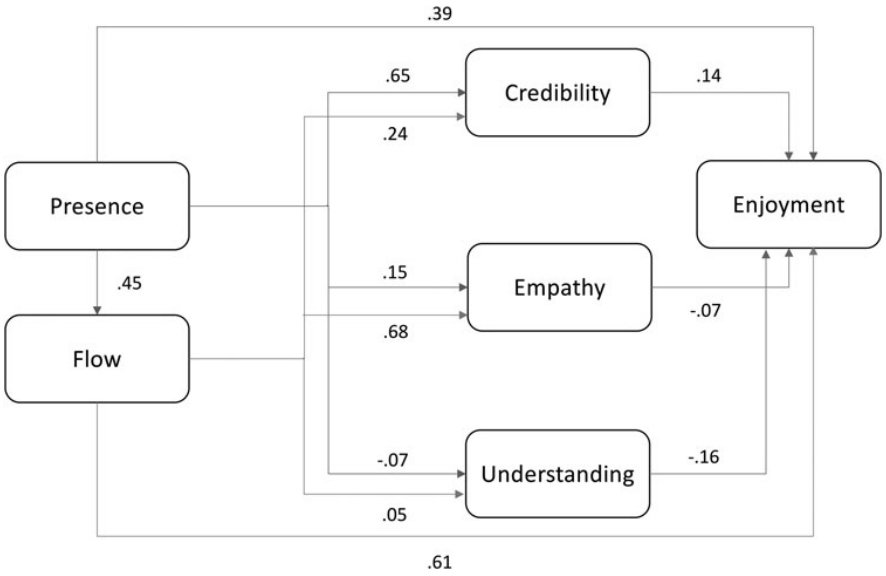

FIG. 4. The representation of the structural model.

impacts enjoyment. At the same time, credibility, empathy, and understanding also impacted enjoyment (H10). Furthermore, the elements of credibility, empathy, and understanding were also influenced by presence and flow from different immersions and worked together to facilitate in enjoyment.

In sum, the model used in this study established the existence of a relationship between users and technology in immersive news, thus increasing enjoyment. These factors can be used to predict and improve widespread user acceptance of VR news storytelling. Indeed, VR storytelling strongly supported a strong presence, flow, and credibility in terms of enjoyment; the apparent costs is understanding. VR storytelling has become a new service strategy in journalism and is also a useful method for creating immersive news. In this regard, VR developers and journalists are weighing and resolving the overloaded information processing and enjoyment of the VR experience from the user perspective. The most important practical finding was the effect of the immersion environment and cognitive processes on enjoyment.

Limitations

Empathy is given less weight in this model and, therefore, is not discussed much at length. However, this study's first limitation was in its measurement of empathy. This essentially depends on individual levels of empathy among participants themselves.[63] The lack of a baseline measurement for empathy may have caused deviations when determining how it influences other factors. The final empathy measurement result replaces this indicator. Moreover, although the sample size of this study provided enough statistical power, it lacked sufficient power for the additional analyses. This means that the possibility of false negatives exists, and the findings from these analyses should be treated with some reservation.

Future studies may apply increased sample sizes to more reliably detect potential effects. Finally, this study considered two different news stories, thus ensuring that there was no comparison for emotional intensity. Additional research on VR news storytelling should, therefore, investigate different emotional intensities and additional influencing factors. This will help refine the current model.

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Authors' Contributions

Shuran Yang is mainly responsible for the manuscript conception, methodology, software production, data collection, formal analysis, original draft, writing review, and editing parts; Wenxiang Zhang is responsible for data storage and validation.

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Appendix B

Sentiment and Storytelling: What Affect User Experience and Communication Effectiveness in Virtual Environments?

Shuran Yang

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Article

Sentiment and Storytelling: What Affect User Experience and Communication Effectiveness in Virtual Environments?

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Abstract: The use of virtual reality (VR) storytelling in cultural communication is increasing and has found its way into the journalism, tourism, museum, and exhibition industries. Earlier studies have examined VR storytelling to improve user experience (UX). However, there is still insufficient research on UX and communication effectiveness in an immersive virtual environment (IVE) in storytelling involving different sentiments. In this study, participants watched positive and negative news stories in three IVEs: 2D video, 360-degree video via mobile devices, and 360-degree video with a VR headset. The predictor variables of enjoyment and the impact of presence, flow, understanding, empathy, credibility, and enjoyment across the stories in IVEs were analyzed. Two models were constructed based on positive and negative stories. The findings show that predictor variables make different contributions to VR storytelling with different sentiments. The conclusions support IVE production in journalism based on sentiment to further improve UX and enhance communication effectiveness.

Keywords: virtual reality; storytelling; immersive journalism; sentiment analysis; user experience; communication effectiveness

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1. Introduction

The development of immersive technologies has allowed audiences to interact with a content environment through unique technical features and vivid presentations, such as virtual reality (VR) and augmented reality (AR). The literature shows that the use of immersive technologies in cultural experiences has economic, social, experiential, cognitive, cultural, historical, and educational value (Bekele and Champion 2019; Theodoropoulos and Antoniou 2022).

In the field of media and communication, journalists and documentary makers have long aspired to close the spatial and temporal gap between the audience and the events they portray, and recent advancements in VR technology offer potent tools for achieving this goal (Steed et al. 2018). VR is an advanced human–computer experience that simulates a realistic presence in a natural or imagined environment (Burdea and Coiffet 2003). The widespread dissemination of this technology has created a trend of communicating stories through VR. It has the potential to support incredibly complex narratives that are tailored to facilitate complex participant interactions. With VR, audiences can have a full 360-degree experience of a space rather than passively watching a narrative unfold in a frame. Digital marketing, tourism, museums, journalism, and other industries usually use 360-degree video VR as a primary aspect of the cultural experience, or to explain a marketing strategy, show the history of tourist attractions or guide visitors, and share news stories, depending on the nature of the industry (De Luca et al. 2022; Oncioiu and Priescu 2022; Giotis and Papadionysiou 2022).

Practitioners have identified multiple potential advantages of immersive material over more traditional formats (Hendriks Vettehen et al. 2019; Slater and Sanchez-Vives 2016). For example, users can have a better experience playing games, viewing movies, or performing other interactive media activities in an IVE than on a 2D screen (Sundar et al.

2017). One of the most heated debates involving VR is whether immersive storytelling can help people empathize with others who are facing situations the former have not experienced (Barreda-Ángeles et al. 2020; Laws 2017; Barbot and Kaufman 2020), such as refugees (Shin 2018), or matters related to the promotion of environmental awareness (Ahn et al. 2014). Does a story viewed through VR evoke a stronger emotional response than that viewed directly on a 2D screen? Studies have demonstrated that participants find it easier to become fully engaged while watching a video without external distractions using a VR headset, which in turn evokes a stronger emotional response (Johnson et al. 2018).

There are significant differences between immersive journalism production techniques and those of traditional audiovisual narratives, and some researchers have noticed a gap in different production techniques' ability to transfer knowledge (Herrera Damas and Gracia 2022). While a 360-degree view allows viewers to become genuinely immersed in a narrative, designing stories for this level of experience is not an easy task. Some contributions are based on the utilization of immersive storytelling; however, it is necessary to find ways to connect with the audiences (Herrera Damas and Gracia 2022). Some studies have focused on designing storytelling techniques in IVEs and compared the impact of positive and negative news stories on user experience (UX).

This study chose VR news stories with different emotional content. An extensive qualitative analysis was conducted on presence, flow, empathy, credibility, understanding, and users' (N = 263) enjoyment when viewing news with different emotional content in different immersive environments (2D video, 360-degree video via mobile devices, and 360-degree video with a VR headset). The study fills two gaps in the literature: the lack of sentiment analyses of immersive journalism and the lack of comparisons between UX and the communication effects of immersive journalism with different emotional content. The study's contribution lies in finding ways to help audiences connect to positive and negative content. The conclusions have implications for practitioners with regard to producing news content in IVE, expressing emotions differently through news, and using appropriate approaches to facilitate UX and improve communication effectiveness.

2. Theoretical Background

2.1. Experience Economy Theory

Advances in the field of VR have led to the development of immersive journalism, which uses immersive technologies to give viewers a first-person experience (de la Peña et al. 2010). Journalism that uses immersive technology creates an IVE that allows users to engage with news stories in an unprecedented way (de la Peña et al. 2010; Herrera Damas and Gracia 2022). Virtual storytelling captures viewers' attention to the point where some viewers experience a sense of "being there" (Sundar et al. 2017).

Immersive journalism conjures up vivid imagery, arouses the senses, and allows users to learn something new and engage in thought-provoking experiences. Pine et al. (1999) used three characteristics to define a cultural product: meeting consumers' innate needs, evoking emotions, and facilitating involvement in the experience. Thus, immersive journalism can also be considered a cultural experience product. The four dimensions of consumer experience are education, entertainment, aesthetics, and escapism.

Aesthetic experiences are key to creating positive and memorable user experiences, where users immerse themselves in a scene, event, or performance (Hosany and Witham 2010; Pine et al. 1999). Studies have shown that immersive technologies increase users' perceived enjoyment of an experience, and that the desire for entertainment is the most significant driver to use immersive technologies (Boyle et al. 2012). The most important concept in the experience context refers to participants' ability to enjoy recreational activities, which are a combination of visitor absorption, passive participation, and the fundamental need for an experience. People seek entertainment to escape reality and boredom, find exciting and interesting things to do to relax, and enrich their spiritual world through ways other than entertainment. Escapism is what allows people to forget reality by immersing themselves in an experience. Further, in cultural experiences, education is a desire to learn

something new and an experience of active participation. Interaction and immersion trigger a higher level of engagement with digital content compared to traditional communication (Jung et al. 2017).

2.2. UX Theory and Effectiveness of Communication in IVEs

IVEs allow audiences to feel that they have become a part of the story (Baños et al. 2000; Felnhofer et al. 2015). This type of experience is termed "immersive," and is often thought to be the result of positive experiences. The pleasure of playing computer games can be linked to immersion in a virtual world. The main reason for the popularity of VR is that it has a far more pronounced impact on immersion than traditional communication methods, such as text, photos, and videos (Sundar et al. 2017; Pull 2008). Earlier studies have also explored "presence" and "flow" in the context of immersion (Weibel and Wissmath 2011; Sherry 2004; Barreda-Ángeles et al. 2020; Baños et al. 2008).

"Presence" is characterized as the user's awareness of another person in a mediated environment (Jennett et al. 2008; Nicovich et al. 2005). It has been defined as a subjective perception of a psychological experience in an environment created by computer technology. VR technology helps create a highly realistic environment (Slater et al. 1994), wherein audiences experience a perceptive illusion of "being there." Thus, VR technology can create a stronger sense of presence due to the interactivity, vividness, and novelty that it offers (Steuer 1992; Azarby and Rice 2022).

Csikszentmihalyi (1990) described "flow" as an optimal experience, or a psychological state of being fully engaged, that individuals experience when fully immersed in an activity. Experiencing flow can allow audiences to perceive more enjoyment, satisfaction, and emotions (Webster et al. 1993). Flow can also exist in a human–machine interactive experience. Flow allows a user to focus on an activity, specifically when a stimulus appears in an IVE (Nakamura and Csikszentmihalyi 2014). In a 360-degree story, the sudden appearance of a person or object, an off-panel voice, or a sound effect could affect users' experience of flow (Sherry 2004; Weibel and Wissmath 2011). Weibel and Wissmath (2011) examined the role of presence and flow in the context of a virtual environment, and found that presence and flow influence enjoyment and performance in digital games. When an experience is delivered through a VR headset, it elicits feelings of presence and flow among audiences (Yang and Zhang 2022; Raimondi et al. 2022).

Communication effectiveness is key to high-quality journalism. Factors such as viewers' understanding, empathy, and credibility have the most direct impact on the effectiveness of communication (Lang et al. 1996; Lin et al. 2002). The main function of news stories is to increase the public's understanding of socially relevant information. The publisher's key goal is acceptance of the information and for the user to learn something new. This is a part of the education aspect of journalism. Thus, understanding is an important factor that shows communication effectiveness and UX.

News storytelling has changed with the development of technology. Communication techniques are strategic ways to hold viewers' attention or elicit specific psychological responses to achieve desired results (Ahn et al. 2014). Theodore Glasser proposed the concept of "enjoyment of news use" (Hermida and Thurman 2008). Using VR to offer viewers more information can evoke more enjoyment among them (Hendriks Vettehen et al. 2019).

VR can trigger emotional, physical, behavioral, and physiological responses, and has been referred to as an "empathy machine" (Barbot and Kaufman 2020). Empathy can be created to a greater extent through an understanding of the subjective experiences of others and their environment (Schutte and Stilinović 2017). In virtual storytelling, although an individual's level of empathetic engagement depends on their baseline empathy, audiences tend to show higher levels of empathy in IVEs (Shin 2018). VR storytelling can increase viewers' perception of realism and stimulate empathy, thus increasing the general effectiveness of news communication (Hassan 2020).

Credibility creates journalistic value. Further, viewers assess news value based on participation, representation, and presentation (Meijer 2012). In an IVE, viewers may empathize with another person's emotions or situation based on a sense of "being there," or being close to those who directly experienced the event, leading to higher levels of credibility (Kang et al. 2019).

Enjoyment is an important determinant in terms of convincing audiences to consume news content (Van Damme et al. 2019). Sherry (2004) proposed uses and gratifications theory, and identified enjoyment as a critical reason for media use. Audiences derive more value from the news when they enjoy it. Immersive technologies therefore provide new opportunities for digital journalism.

2.3. Sentiment Analysis in IVEs

Sentiment analysis, which has emerged from the computational linguistics and computer science fields, is increasingly used in a wide range of research areas, including the social sciences, as well as media and communications. In the field of social sciences, it was initially applied to social media, public relations, political forecasting, and diffusion of audience research. The goal of using sentiment analysis in the social sciences is to explore the tendency of information in the media to represent mood or emotion. In digital journalism, sentiment analysis has been used for social web topics, online communication, and data journalism, and applied to text analysis to examine how a text expresses opinions, emotions, and sentiment (Puschmann and Powell 2018). However, few studies have used sentiment analysis for video news, especially digital journalism in VR. In news videos, captions, dialogues, and off-camera voices can also express emotions. Thus, this study uses sentiment analysis to objectively determine the sentiments expressed in news videos, including sentiments expressed through captions, dialogues, and off-camera voices (Rameshbhai and Paulose 2019).

2.4. Research Hypotheses

VR has become a popular means of telling stories to bring the world closer to the viewer. While studies have investigated communication effectiveness and UX in IVEs, few have compared the diverse conditions and sentiments in IVEs. How is the UX affected when viewing immersive news with positive and negative emotions in different immersive environments?

Research on the emotional impact of VR shows that using technology can boost emotional experiences (Susindar et al. 2019). Further, studies have found that VR can be a potent tool to examine the effects of emotions. VR, mediated by a greater experience of presence and natural connectivity, is also linked to more positive affect changes than the 2D format (Yeo et al. 2020). Few studies have conducted a sentiment analysis of immersive journalism, especially on the impact of positive and negative sentiments on UX under different technological environments. Therefore, this study selects two news stories for a sentiment analysis and explores changes in UX and communication effectiveness under different technological conditions. This study proposes the following hypotheses:

H1: *In a negative news story, audiences will experience more presence, flow, understanding, empathy, credibility, and enjoyment via 360-degree videos than via a 2D format.*

H2: *In a positive news story, audiences will experience more presence, flow, understanding, empathy, credibility, and enjoyment via 360-degree videos than via a 2D format.*

H3: *Audiences will be more influenced by immersive technology in the case of a positive news story than in that of a negative news story.*

3. Materials and Methods

3.1. Stimuli

Two news clips, "The Displaced" (Video 1) and "Under a Cracked Sky" (Video 2), were chosen as stimuli for the following reasons. First, both stories were published by the New York Times in 2D and 360-degree video (via mobile devices) formats, as well as VR versions, thus minimizing distractions and keeping the story content constant across different devices. Second, both stories are approximately 10 min in length and conform to the general length of a news clip. Third, the stories have entirely different content. "The Displaced" is a narrative about three refugee children forced out of their homes by wars, with scenes showing the lives of the three protagonists, Hana, Oleg, and Chuol. "Under a Cracked Sky" is an excerpt from the Antarctica Series, in which the two protagonists guide viewers through the clearest and coldest waters on Earth at McMurdo Station, Antarctica. The story contains beautiful shots of the deep sea and takes viewers on a mysterious journey. Fourth, the two stories evoke different emotional responses. "The Displaced" elicits negative emotional responses related to the grief and hardships faced by the children of refugees; "Under a Cracked Sky" invites a more positive emotional response as viewers discover the amazing wonders of the most transparent water on Earth.

3.2. Procedure

Volunteer participants were recruited from different faculties of various universities in Switzerland (N = 263). The participants were at least 18 years old, which complied with the ethics committee's recommendations. Handmade gifts were offered to the participants as an incentive; no payments were provided. The participants were randomly assigned to three storytelling mediums (the regular 2D format on laptops, 360-degree video via mobile devices, and 360-degree video with a VR headset). However, the participants could not choose between the negative and positive stories as their groups were determined by the experimental place they chose. The experiment was introduced and explained by a staff member before the participants watched the news stories. The participants filled out an anonymous questionnaire after viewing each story. The entire experimental procedure took approximately 20 min (Figure 1).

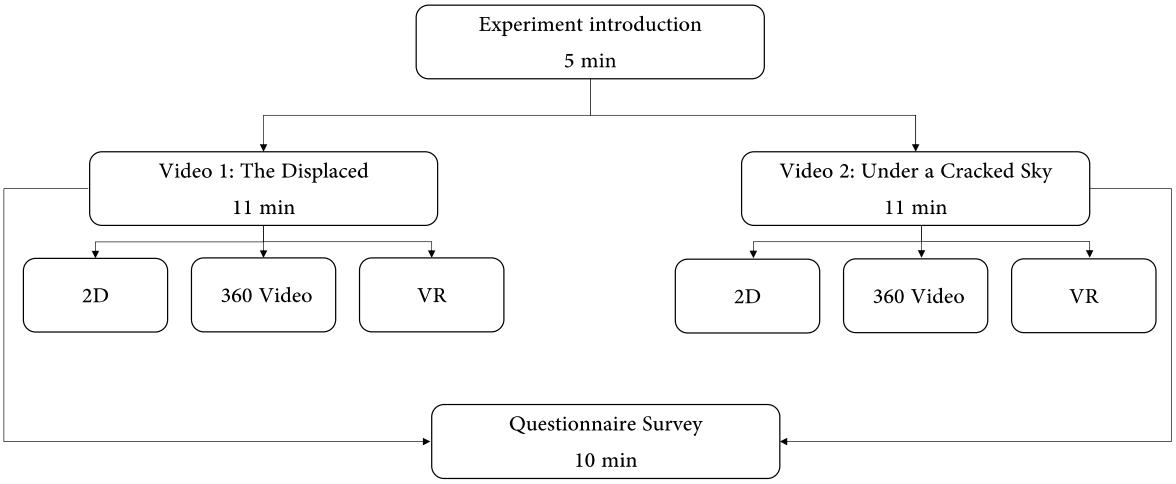

Figure 1. Experimental framework.

3.3. Data Processing

During the pre-experimental phase, dialogues, monologues, and voice-overs in the news stories were collected to determine the differences in sentiment between the two stories. A sentiment analysis is a general approach in natural language processing, based on a novel recurrent neural network using a Stanford sentiment tree library built on syntactic structures (Socher et al. 2013). The semantics of the sentiment tree constitute a deep

recursive model. The semantic space needs to build a representation of the whole sentence based on the sentence's structure. It calculates sentiment based on how words form the meaning of longer phrases. The computed values represent the attitudes and opinions in the subtitles and dialogues of each news story.

The questionnaires used in this study assessed the variables using multi-item scales adapted from scales validated in previous research. Descriptions were modified to make them suitable for the study's range of experimental content and environments. An 11-point Likert scale ranging from 0 (strongly disagree) to 10 (strongly agree) was used (Leung 2011). After pre-testing, unqualified items were removed. Lastly, the results of the analysis indicated that all the variables of the scales were reliable.

An analysis of presence and flow was conducted to evaluate audiences' subjective experiences under various technological conditions. Presence was measured based on the MEC spatial presence questionnaire (Vorderer et al. 2004), resulting in a six-item presence scale. Flow was measured based on Novak's scale (Novak et al. 2000), which was revised for conciseness. The resulting flow scale consisted of six items. Empathy was examined on a scale with five items taken from Davis (Davis 1983). Meanwhile, understanding was measured using five items based on existing concept measures (Busselle and Bilandzic 2009). Credibility was measured using six items from a study that explored the impact of traditional and technological features on the credibility of online news platforms (Chung et al. 2012; Hendriks Vettehen et al. 2019; Kleemans et al. 2014) The enjoyment scale consisted of five items based on previous questionnaires (Hendriks Vettehen et al. 2019; Green et al. 2004; Lin et al. 2002).

4. Results

4.1. Randomization Check

A total of 263 participants were recruited for the experiment and completed the questionnaires. The demographic data showed that 51.7% of the participants were female (N = 136) and 48.3% were male (N = 127). The age distribution was relatively concentrated as the participants were mainly recruited at universities in Switzerland. None of the three conditions showed significant differences between age, gender, and previous VR devices experience in the two story groups. These results suggest that the randomization was successful (Table 1).

Table 1. Sample demographics.

	"The Displaced"				"Under the Cracked Sky"			
	2D	**360**	**VR**	**Total**	**2D**	**360**	**VR**	**Total**
Gender								
Female	52.38%	55%	50%	52.46%	52.17%	50%	51.02%	51.06%
Male	47.62%	45%	50%	47.54%	47.83%	50%	48.98%	48.94%
Age								
18–20	4.76%	0%	2.5%	2.46%	0%	2.17%	4.08%	2.13%
20–25	16.67%	20%	30%	22.13%	6.52%	10.87%	14.29%	10.64%
26–30	64.29%	40%	45%	50%	56.52%	45.65%	61.22%	54.61%
31–35	14.29%	35%	15%	21.31%	19.57%	21.74%	10.2%	17.02%
>35	0%	5%	7.50%	4.1%	17.39%	19.57%	10.2%	15.6%
VR experience								
Never	52.38%	50%	45%	49.18%	43.48%	45.65%	40.82%	43.26%
1–5 times	35.71%	35%	40%	36.89%	36.96%	45.65%	46.94%	43.26%
>5 times	11.91%	15%	15%	13.93%	19.57%	8.7%	12.24%	13.48%
Total	N = 42	N = 40	N = 40	N = 122	N = 46	N = 46	N = 49	N = 141

4.2. Results of the Sentiment Analysis

The results for anger, anticipation, disgust, fear, joy, sadness, surprise, and trust were obtained by analyzing the captions, dialogues, and off-camera voices in the news videos (Table 2). The sentiment analysis of Video 1 was 45.16% positive and 54.85% negative, and the results were 71.05% and 28.95%, respectively, for Video 2. These findings show that

the sentiments generated by the selected videos were significantly different, with Video 2 being much more positive than Video 1.

Table 2. The result of the sentiment analysis.

	Anger	Anticipation	Disgust	Fear	Joy	Sadness	Surprise	Trust
Video 1	8.06%	12.90%	4.84%	29.03%	11.29%	11.29%	8.06%	14.52%
Video 2	2.90%	20.29%	2.90%	7.97%	16.67%	10.87%	7.97%	30.43%

4.3. Overall Results of UX and Communication Effectiveness

This study's data were analyzed using R and SPSS software for statistical computations. The significance of all the variables was determined using an analysis of variance (ANOVA) test with an α level of 0.05. The statistical significance of the differences was tested by evaluating whether the 95% confidence intervals (CIs) were exceeded.

To test H1 and H2, ANOVAs were computed to examine the variables of the two news stories with different technological conditions (2D video, 360-degree video via mobile devices, and 360-degree video with a VR headset). To examine the variance between individual conditions in each news story, the ANOVA was supplemented with a least significant difference (LSD) post hoc test. Figure 2 provides a comprehensive overview of the results of all the conditions considering both videos.

The one-way ANOVA was deployed to measure the results of the three conditions with Videos 1 and 2. For Video 1, the results showed a small variance between the three conditions on understanding ($p = 0.459$), empathy ($p = 0.343$), and enjoyment ($p = 0.021$), and a large variance on presence ($p = 0.001$), flow ($p = 0.007$), and credibility ($p = 0.004$). For Video 2, the results showed a larger variance between the three conditions than that for Video 1. The results of the LSD post hoc test were strongly significant ($p < 0.0001$) between the three conditions on presence, flow, empathy, and enjoyment. Understanding was also significant ($p = 0.006$), while a non-significant result was found between the three conditions on credibility ($p = 0.33$).

The results indicated that in Video 1 (negative story), the variables scored somewhat higher for the 360-degree and VR devices than for the 2D format. Thus, the results of the ANOVAs supported H1, especially regarding the aspects of presence, credibility, and enjoyment. The participants who watched Video 2 experienced more presence, flow, empathy, credibility, understanding, and enjoyment via 360-degree videos than those who watched Video 2 (positive story) in a 2D format. Thus, H2 was also verified.

Viewing Video 2 more significantly influenced presence, flow, and enjoyment than watching Video 1. The differences in presence, credibility, and enjoyment after watching Video 2 were more significant across the IVEs. However, they were not significant for Video 1. The other variables scored somewhat higher for the 360-degree and VR devices than for the 2D format. The results showed that all the variables garnered higher scores for the 360-degree and VR devices than for the 2D format. Other variables were significant for Video 1, except for credibility. Presence, flow, empathy, understanding, and enjoyment all differed more significantly for Video 2 than for Video 1. One exception was that the difference in credibility was more significant for Video 1 than for Video 2. The results of the analysis of the variables for the 2D format and 360-degree and VR devices confirmed that the immersive environment had a greater influence on viewing positive news than on viewing negative news.

A multiple regression analysis was used to test the predictors' contribution in the models. In the negative video model, presence ($p = 0.098$, 95%CI [−0.037, 0.098]) and flow ($p = 0.138$, 95%CI [−0.029, 0.138]) were not significant. An updated regression model of Video 1 was tested using other significant predictors: understanding, credibility, and empathy. The results of Video 1 indicated that five independent variables on enjoyment in the model explained 91.7% ($R^2 = 0.917$). There was no collinearity in the model for Video 1 among understanding (VIF = 1.065), credibility (1.580), and empathy (1.584).

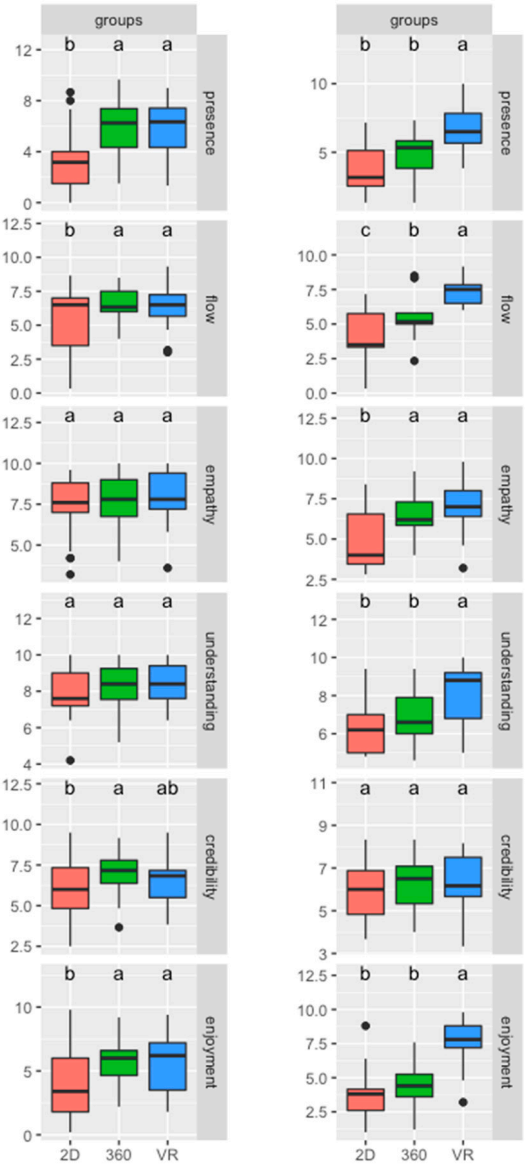

Figure 2. Effect of IVEs on presence, flow, empathy, credibility, understanding, and enjoyment. (**a**) Video 1; (**b**) Video 2.

In the positive video model, presence (p = 0.460, 95%CI [−0.042, 0.093]) and empathy (p = 0.944, 95%CI [−0.074, 0.079]) were not significant. An updated regression model of Video 2 tested flow, understanding, and credibility. The independent variables on enjoyment in the model for Video 2 explained 92.8% (R^2 = 0.928). There was no collinearity in the model for Video 2 among flow (VIF = 1.070), understanding (1.654), and credibility (1.580).

In the negative video model, understanding (β = 0.553, $p < 0.0001$), credibility (β = 0.522, $p < 0.0001$), and empathy (β = 0.198, $p < 0.0001$) contributed to enjoyment. In the positive model, flow (β = 0.207, $p < 0.0001$), understanding (β = 0.641, $p < 0.0001$), and credibility (β = 0.344, $p < 0.0001$) contributed to enjoyment.

5. Discussion

This study makes several important theoretical and practical contributions regarding UX and communication effectiveness in IVEs. First, the study examines immersive journalism, which has a unique character that can better heighten the state of presence, flow,

understanding, empathy, credibility, and enjoyment in UX and communication effectiveness compared to a 2D-viewing experience. The results confirm that the more viewers are immersed in an environment, the better their UX and the effectiveness of the communication. Second, the study confirms that enjoyment is influenced by different variables in positive and negative news. Sentiment is central to how people interact with things, and is integral to the practice of journalism itself (Stupart 2021). As a result, digital journalism content can be designed according to either the positive or negative sentiment models to communicate a desired viewpoint and enhance UX accurately.

Due to a lack of evidence on current storytelling in IVEs and the communication effectiveness of immersive journalism, practitioners have questioned the value and potential use of immersive journalism. This study contributes to the literature by validating the view that immersive journalism can be a powerful form of communication to induce optimal states of presence, flow, understanding, empathy, credibility, and enjoyment.

This study contributes to the literature on the sentiment analysis of immersive journalism. The findings suggest that sentiment analysis can be used to determine the sentiment expressed in news stories and to delve into how technology contributes to positive and negative sentiments in news stories. This study provides experimental data to support the conclusion that news stories with positive and negative sentiments require different strategies to enhance audience responses and improve communication effectiveness. Understanding makes the greatest contribution to enjoyment in any IVE and for any sentiment; this supports the notion that understanding is the key factor for telling a news story. Evoking empathy is more difficult in the case of news stories that express a positive sentiment than in the case of those with a negative sentiment, and it is more challenging to immerse viewers in the virtual environment of stories that express a positive sentiment.

The study makes practical contributions to journalism and production design. Immersive journalism using immersive storytelling should be designed in accordance with the emotions expressed by the themes. In the case of videos that express a positive sentiment, VR devices are ideal tools to demonstrate the impact of human activity on the environment, with the possibility of showing images of beautiful natural scenery. Focusing on enhancing viewers' immersive experiences through the use of images, sounds, or other visualization methods can achieve better communication effectiveness. In contrast, viewers are more likely to empathize naturally with news that contain a negative sentiment, but the impact of technology on communication effectiveness may not be significant. Enhancing the credibility of news information and inducing empathy can give viewers the experience of "being there" and being immersed in a story. Today, VR is used in diverse cultural experiences. These findings are not limited to journalism. Sentiment analysis of the content presented, and storytelling designed to match different emotions will greatly enhance UX and the effectiveness of content communication in the context of cultural experiences.

6. Conclusions, Limitations, Implications, and Future Work

This research focused on VR storytelling to determine the best UX and the effectiveness of communication in immersive news. Two news were used as experimental material, and three immersive environments, 2D video, 360-degree video via mobile devices, and 360-degree video with a VR headset, were considered. Data collection was evaluated using a questionnaire that addressed presence, flow, understanding, empathy, credibility, and enjoyment. The results revealed better scores for the factors in immersive environments (360-degree video via mobile devices and 360-degree video with a VR headset) than in the 2D format. While immersive journalism has led to better UX and communication effectiveness, the sentiment analysis of news content still provides significant practical implications. In the case of both positive and negative news, understanding and credibility contribute significantly to enjoyment, which is consistent with the nature of news; users expect information and truth from news videos. However, the contribution of flow and empathy to enjoyment in the case of both positive and negative news varies considerably.

The findings highlight that VR offers greater utility by enhancing UX and communication effectiveness for positive stories than for negative ones.

This study had several limitations. First, a common problem with this type of research is the number of news story themes and a small sample size, which results in limited statistical power. The questionnaire, given the number of questions, was demanding for the participants. Completing the questionnaire within 10–15 min after watching a 10 min news story may have fatigued them, leading to possible errors (e.g., giving scores without reading each question carefully). Additional measurements would further extend the experiment time. Therefore, electrodermal measures and electroencephalogram (EEG) were not used in the data collection. Lastly, this study did not pay attention to a mutual influence between the variables. Further research is needed to identify the precise mechanisms underlying this effect, to distinguish sentiments across multiple themes, and to compare the UX of different immersive technologies and devices under different sentiments. Further investigation of the variables of UX with diverse themes and sentiments in the IVEs is required to deepen our understanding of the potential benefits and challenges presented by the practical application of VR technology. Age, occupation, educational background, and other differences between individuals (e.g., motion sickness and wearing glasses) may affect UX results. Therefore, in future studies, we will expand the sample size as much as possible to obtain more stable and accurate results and UX models. In addition to using questionnaires to collect UX data, researchers could incorporate deep learning-based facial expression recognition into the UX. Further, multiple-data collection using electrodermal measures and EEG can be carried out with a randomly selected subset of participants.

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Appendix C

Storytelling and User Experience in the Cultural Metaverse

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ABSTRACT

Enthusiasm for the metaverse is intensifying in academia and industries. The metaverse is a complex concept, combining many technologies to create many different types of user experiences (UX), depending on the intended use. The cultural metaverse was first introduced in this study.

This study is an initial attempt to fill the gaps in the practical research and storytelling research in the metaverse. Augmented reality (AR) technology is an applicative tool in cultural experience, which displays computer – generated virtual information on a real-world scene. AR displays digital information realistically, making it appear to be part of the actual environment, deepening or expanding the user's understanding of "reality". This study constructed a cultural metaverse using the innovative AR storytelling. The cultural metaverse is a new cultural ecology in which advanced information technologies are deeply integrated with cultural spaces and exhibits. It combines digital technologies and cultural industries, mixing virtual space and physical space to facilitate the UX in cultural experiences. In this study, the existing AR e-book and the innovative AR version were compared while measuring multiple aspects of UX, including presence, flow, enjoyment, education, and engagement.

By analyzing questionnaire data from two groups with a total of 368 participants, the results indicated that the innovative AR storytelling produced a better UX across all variables compared to the AR e-book application. Overall, innovative AR storytelling allows visitors to transition between real and virtual spaces, enriches their interactive experience, and improves user engagement with the metaverse exhibition of cultural experience. Therefore, practitioners can construct a primary cultural metaverse through innovative AR storytelling.

1. Introduction

The metaverse is currently one of the most talked about topics in the world. In 2021, the metaverse entered into users' field of view again. The word "metaverse" originally came from the American writer, Neal Stephenson's novel *Snow Crash* (1992). In the novel, the main character lives in a virtual world through digital virtual avatars. The virtual space is called the "metaverse" [1].

The metaverse does not yet have an accepted definition. As explained by Meta, the metaverse is the digital parallel universe that represents the evolution of social connection, which will allow us to socialize, learn, collaborate, and play in ways that surpass our imagination [2]. Some scholars argue that metaverse is an enduring virtual space where users can enjoy a variety of social, economic

Abbreviations: AR, augmented reality; AVE, average variance extracted; CR, composite reliability; IVE, immersive virtual environment; UX, user experience; VR, virtual reality; VIF, variance inflation factor.

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and leisure activities as an extension of their offline lives [3].

The metaverse is a complex web of integrated technologies, including 5G, block chain, AI, and immersive technologies [4]. The metaverse is immersive and has a strong sense of connection to the real – world objects, human lives and bodies [5]. Using diverse technologies, users can access and interact with immersive technologies, which are the foundation of the metaverse. Although there is no universally agreed definition of the metaverse. Much of the existing research has described visions of the future, no single example that can represent the metaverse has been provided so far. The application scenarios of the metaverse are still unclear. However, existing research and industry studies have reached a consensus that the metaverse can create new experiences in traditional industries as well as new business and marketing opportunities [6,7].

Microsoft put forward an industrial metaverse at the end of 2021 through its "industry + metaverse" model. Nishant Batra, the Chief strategy and technology officer at Nokia indicated that "The metaverse (of the future) is one where physical space, human and digital realities are conjoined" [8]. Instead of keeping the metaverse in our homes and offices, we may take it with us everywhere we go. This metaverse will be equally at home in the consumer, business, and industrial realms. Therefore, this paper proposes the concept of "cultural metaverse" for the first time. The cultural metaverse goes beyond the scope of the current digital museum and is the future form of the cultural industry in the cultural space.

Recently, Zuckerberg proposed a vision for the next stage in the digital age [9]. Although bold statements should be viewed with skepticism, augmented reality (AR) and the stimulation of the internal and external elements were the foundational axis in the metaverse [10]. Metaverse technology deals with maximum user interaction, which is supported by several emerging technologies such as immersive technologies, information and communication technologies, and human-computer interaction technologies [11]. The metaverse allows visitors to move freely between the virtual and real worlds and constitutes a hybrid world that enhances and expands visitors' user experience (UX) [12]. To solve the aforementioned limitations concerning space, AR was chosen as the tool in the study. AR has the characteristic ability to link the real world to the virtual world and enable interaction between the two [13]. In the current study, AR was used in the cultural venue where augmented objects are used to provide visitors with a UX in a cultural metaverse.

It is unclear how the metaverse, as a cutting-edge manifestation, influences cultural experience in the cultural venues. This study attempts to design an experimental metaverse with immersive technologies in cultural experience in order to promote user engagement. In this study, the use of AR in virtual storytelling embedded cultural venues to facilitate stimulating visitor experiences. We found that these experiences ultimately facilitate visitors' engagement. As a tool for transforming cultural knowledge into content that enhances visitors' experiences, immersive technologies fundamentally facilitate the formation of a cultural metaverse. AR can also be effectively implemented for virtual storytelling; for example, virtual scenes interacting with real scenes and realistic digital objects. As a visitors' engagement strategy, cultural experience with virtual storytelling can facilitate the connection of participants to the content of the visit and thus promote engagement. The current research contributes to the literature on cultural metaverse by examining the impact of AR interactions on UX, which in turn facilitates the improvisation of UX and cultural metaverse.

2. Literature review

The development of immersive technologies has allowed users to interact with a content environment through unique technical features and vivid presentations, such as virtual reality (VR) and AR. VR and AR have been widely used. Existing research has revealed that the use of VR and AR in cultural institutions has economic, social, experiential, cognitive, cultural, historical, and educational value [14].

Both VR and AR are already being used for cultural experiences in specific scenarios, showing their respective advantages. VR is defined as the digitally constructed representation of a natural or artificial environment [15–17]. AR is a technology that links the real and virtual worlds [18,19], enabling real-time interactions by combining computer-generated objects with the natural environment [20].

The use of VR in cultural experience reduces the distance barrier between the visitors and the exhibits in museums [21], through advanced and realistic virtual simulation, thus providing the visitors with a unique virtual experience by creating infinite possibilities in metaverse museum exhibitions. VR also provides a completely immersive virtual environment (IVE) where visitors can be fully immersed [22], thus enhancing their experience by facilitating interaction with the museum's exhibits [23,24]. VR has been heavily used to reconstruct historical environments, digital virtual museums, and galleries [25,26].

Some scholars emphasized the two sides of VR in cultural experiences. On the one hand, VR works as a tool to substitute for an in-person experience [27]; it offers the real-world exhibition space as a virtual space with detailed visuals for scenes in places that cannot be physically visited [28]. Thus, it enables visitors to feel as though they have visited the actual environments represented by the exhibitions [29]. On the other hand, VR makes sense only for virtual spaces that provide a limited form of experiential content.

Cultural venues are real spaces for displaying, appreciating, and learning about culture. Modern cultural venues are becoming integrated social learning spaces [13] by expanding into experiential spaces. AR has proved its potential to create an interactive and enjoyable cultural heritage experience [30]. Additionally, AR compensates for the limitations of VR—which changes or replaces one's real world—by augmenting the real world through information such as text, images, videos, among others. In cultural experiences, AR can facilitate visitors' collaborative participation and active learning. For example, one study compared the impact of different VR and AR devices in an immersive gallery experience at the National Gallery in London, by examining UX, which included enjoyment, presence, cognitive, emotional, and behavioral engagement [31]. The study confirmed that equipment characteristics produced differences in the measured UX variables. Although in the study, VR and two different AR groups had high UX, Verhulst et al. (2021) mainly discussed the variation in immersion between devices and did not focus much on the other factors that could have affected UX

[31]. Another study examined the impact of AR and VR experiences on museum services and users' satisfaction [32] at the Ara Pacis Museum in Rome. AR and VR tools was explored to enhance multi-experiential value in cultural heritage by integrating traditional cultural content with other experiences, such as socialization, entertainment, and learning, allowing visitors to engage in a new type of value co-creation. However, the study was hypothetical and conducted via questionnaire, and there have been no practical applications of AR and VR.

Cultural experiences have evolved in the metaverse system in cultural venues with two limitations. First, a clear boundary between the virtual and real worlds has been developed. Second, storytelling has not been well utilized in cultural experiences; instead, information is typically narrated, which is a one-way method of delivery. Therefore, cultural space should attain the meaning from the real-world space, with storytelling bridging the gap between virtual and real spaces.

Multi-sensory stimulation, realism, interactivity, and immersion have been extended by AR storytelling. AR enables an augmented experience by using the camera function on smartphones or wearable devices. It exists as a hybrid space that combines the characteristics of real and virtual spaces to structure an overlapping space. AR is increasingly used in museums, galleries, and other cultural venues. Specific themes for special exhibitions are explored using AR storytelling to enhance cultural learning. Users can encounter unique stimuli that affect their UX while using AR because of the range of manipulation between the virtual and real worlds [33]. AR could replace VR as a more suitable digital tool to serve museums, where users can continue being connected to a real context in the physical world. However, there have been no controlled studies that compare differences in AR storytelling. The existing research has compared the impact of VR and AR technologies on UX but has not discussed and investigated the role of AR storytelling. The artifacts, functions, and storytelling produce an AR cultural experience in a hybrid space. For example, an exhibition can provide different story guides and reward mechanisms when visitors enter the museum. When visitors reach each step in the museum, they can get a hint of the next step; when all the goals are reached, the visitors can get the final reward. Visitors can choose their own tour maps and receive rewards.

3. Theoretical background and hypotheses development

3.1. Experience economy theory

The most important function of a cultural venue is to provide visitors with cultural experiences. A cultural product is defined by three factors: satisfying consumers' intrinsic needs, eliciting good feelings, and engagement in the experience. Visitors in the cultural venues seek to create memorable images, arouse the senses, gain knowledge, and inspire thoughtful experiences [34]. Thus, the cultural metaverse can be thought of as a cultural experience product. Virtual tours, digital museums, and cultural experiences that integrate technology into physical space have all been attempted in the past. However, visitors now look for distinctive and unforgettable experiences and for high-quality experiential products and services.

Pine and Gilmore [35] delineated four dimensions of consumer experience, including education, entertainment, aesthetics, and escapism. These four characteristics are related to their level of engagement (passive versus active participation), as well as the connection that ties them to a certain performance or event (i.e., absorption and immersion).

Aesthetic experiences, in which users immerse themselves in a scene or event, are critical to creating a positive and memorable UX. In the experience economy, aesthetics are defined as consumers' perception of their immediate glamorous physical environment [36] and their complete and enjoyable engagement in real-world AR experience. Researchers have discovered that the aesthetic motive precedes the other three motives in the setting of immersive experiences [37]. Since immersive cultural metaverse experiences must first pull in clients in order to supply them with immersive cultural experiences that encourage feelings of entertainment, education, and escapism, aesthetics is an essential component of these encounters. Thus, aesthetics are associated with immersion, as participants immerse themselves in the allure of events or performances [35]. A research of Hosany and Witham examined data from 500 visitors to heritage/cultural attractions and discovered that the aesthetic features of such tourist attractions are essential factors influencing revisit and public praise intentions. In other words, when people are drawn to an immersive, aesthetically beautiful experience, other incentives follow. Consequently, aesthetics is critical in driving the experience economy [36].

The most fundamental requirement for an experience is entertainment. The previous study looked into the potential of AR to generate entertainment value [38,39]. The need for amusement was the primary motivation for using immersive technologies, which has been demonstrated to boost the perceived enjoyment of UX. Meanwhile, entertainment encourages a deeper engagement in AR [40,41]. Offerings for high-quality entertainment provide tourists with unforgettable memories [42].

People look for entertainment to escape reality and the business or monotony of everyday life, to find thrilling and interesting activities, to relax and to enrich the mental world in ways that go beyond entertainment. Escapism is therefore what enables individuals to forget reality by immersing themselves in the experience. Freud [43] believed that "intrusive foreign bodies" could result in "diverting emotional impulse" (p.105-117). In that vein, escapism is a defense mechanism against reality, driven by the desire to maximize the enjoyable experience. People are actively engaged in the experience rather than just being onlookers. Escapism is likely satisfied by the cultural metaverse experience.

Education in a cultural context refers to the desire to learn something new and to participate actively. Participants must have a subjective enthusiasm for an event and believe that participating in this experience will improve their knowledge and abilities. Participants absorb what they want to know and learn from the experience, and the outcome of a communication experience depends on the participants' attitudes. Compared to traditional communication, interaction and immersion lead to a higher level of engagement with digital content [44]. The desire to gain knowledge and skills as the primary educational motivation drives the participation in the experience [45].

The four dimensions of experience economy theory have already received widespread acceptance and validation from earlier investigations. This study, founded on experience economy theory, evaluates UX from the viewpoint of the cultural metaverse as an experienced good.

3.2. User experience in immersive environment

The metaverse is a two-dimensional to multi-dimensional extension of experiential communication [46], meant to appreciate, learn, entertain, and spread culture. By expanding into the space of experience, the modern technological scene is becoming an integrated socio-cultural communication space. The subject of experience is the "human" who enters the metaverse. Within the context of augmented technological, how is UX influenced?

Immersion has an impact on aesthetics and escapist experiences. The perception of being physically present in a virtual world is referred to as immersion, which is the central concept used to measure IVE. When people are completely immersed in an activity, they enter a state of complete isolation in the virtual world and have an immersive experience [47]. As technology advances and research expands, scientists are beginning to investigate the impact of UX in various contexts [48–50].

An existing study by Kim mentioned the immersion in AR as context immersion [51]; AR logically interacts with the user's real physical environment. A framework of context immersion that combines three dimensions was structured in IVEs of AR. Time and location-based context, object-based context, and user-based context represent mobility, relationship, and communication or interaction, respectively.

Presence and flow are main variables to measure the concept of immersion UX in an IVE [52]. Here, presence is a psychological state related to the human response to immersion [53]. In IVE, presence is defined as experiencing the virtual objects as real in either sensory or non-sensory ways [54,55]. In IVEs of AR, augmented technology provides valuable contextual information. A combination space of both virtual objects and real physical environment is structured in a metaverse space. Presence reflects a specific feeling whereby users experience "being there" and physically located in the metaverse space. In IVEs of AR, users can physically interact with the objects and environment. A study confirmed that presence had positive impact on theme park visitors' IVE [56]. Previous studies indicated that flow is also related to immersion and presence [57,58]. Flow is defined as the holistic sensation that people experience when they are engaged in action [59], which is something that most individuals have experienced, either through games, reading, watching movies, surfing the internet, visiting galleries, or even doing sports. The immersion in the metaverse is triggered and facilitated by stimuli in the IVEs of AR. AR E-book has been widely used in cultural experience, which is a mobile device application of AR as a one-way method of delivery. Users allows to experience visual and audible information on museum exhibits. AR technology can enhance UX through multi-sensory augmentation. An innovative AR that uses AR storytelling enabling two-way delivery, should boost more immersion and interaction than the existing E-book AR in IVEs complex, thereby leading to better UX.

Shernoff suggested that engagement may enhance through immersive technology [60]. Engagement is defined as the interaction between a person and an environment, and it includes participation, focus, and persistence within a task [61].

Enjoyment or entertainment is an effect of media. A sense of enjoyment comes from the continuous use of cultural and media sources. Previous studies have explored the value of immersive technologies to enhance UX [62–64]. For example, cultural venues support visitors seeking an enjoyable and entertaining experience in addition to information and learning [13]. In one study, people who watched 360-degree news videos in VR had a higher presence and enjoyment, and accepted the credibility of the news [65,66]. Similarly, in a study of shoppers, AR positively influenced flow, enjoyment, and other shopping experience outcomes [67].

A recent and comprehensive approach reconsidered the UX model by identifying the need to incorporate hedonistic and enjoyment attributes to explain how the attractiveness and aesthetics of technologies impact visitors [68]. Perceived enjoyment is one of the advantages of engaging with content via immersive technology. When compared to traditional cultural experiences, IVEs provide a higher level of enjoyment. This is supported by evidence that suggests interactivity is a key indicator of enjoyment [69]. In this study, virtual storytelling will be incorporated to improve interactivity. The enjoyment gained from interacting with AR technology has a positive impact on engagement. Thus, users who interact with AR content should have a higher level of enjoyment, which should lead to increased consumer engagement.

Therefore, the special exhibition of Shanghai Museum of Glass was chosen in this study. The theme was "It is the fate of glass to break." Taking this well-known proverb as its starting point, it explores how things shattered, fractured, and cracked can speak to heartbreak and hope, and everything in between. With glass as their core medium - a material whose inherent fragility renders it a potent and recurring metaphor in countless languages - as well as music, 21 installations explore the connotations, implications, and possibilities of brokenness. The informational content of the museum has no interactive storytelling to structure a cultural metaverse. Instead, the museum only uses AR to convey the information of the exhibits. Thus, this background provided a suitable opportunity to test a more innovative AR technique.

Two AR applications were used to run an experiment. An AR e-book application was used for the control group, which was similar to techniques being used by the museum, which allowed visitors to scan a QR code scan to view a brief overview of the exhibits. The second application was an innovative AR storytelling application. Depending on the map selected by the visitors, new hints were subsequently sent to them. The hints prompted the visitors to find the answer for each step of the game based on their understanding and guesses. Finally, a reward was provided upon completion of the entire exhibition. In this process, information and the overview of the exhibits were obtained in a game-like manner. This study examined the effects of AR storytelling on engagement through possible psychological and UX elements: presence, flow, education, information utility, and enjoyment to build a cultural metaverse.

This study aims to fill two gaps in the existing research. First, it aims to contribute towards the lack of research on cultural metaverse by AR storytelling in cultural experience. Second, it aims to contribute towards the lack of practical research on the real-world

study. The cultural metaverse is investigated through the effects of AR storytelling on UX in an augmented technology-supported cultural experience and metaverse environment.

3.3. Research hypotheses

This study focuses on designing a primary cultural metaverse by innovative AR storytelling that is different from the existing AR applications. Existing AR applications in cultural venues consist mostly of AR-books. Users can view exhibits' audiovisual information in 3D [13]. E-book AR is a digital tour guidance, which has become increasingly popular in the museum and cultural heritage sector as it offers visitors a unique and engaging way to explore and interact with exhibits. It can notify users of content or autoplay audio through three basic method, tracking based on their physical location within the museum; inputting the code of exhibits; simply hitting the next button to see the multimedia content for each asset. While the basic functionalities of E-Book AR can provide useful information and enhance the visitors' experiences, it do not extend the UX beyond enhanced 3D information and multimedia messages. In contrast, innovative AR storytelling makes cultural content more informative, emotional, memorable, and attractive [31]. Innovative AR storytelling allows visitors to actively participate in the experience by interacting with virtual objects, exploring hidden layers of information. In a cultural metaverse, visitors can access a hybrid space that combines the virtual and real worlds, allowing for an even more immersive experience. Innovative AR storytelling enables visitors to explore exhibits in a more interactive and engaging way, creating a deeper understanding and appreciation of the cultural content. It can be used to tell the stories of underrepresented communities and cultures, fostering empathy and understanding among visitors, allowing visitors to connect with the cultural content

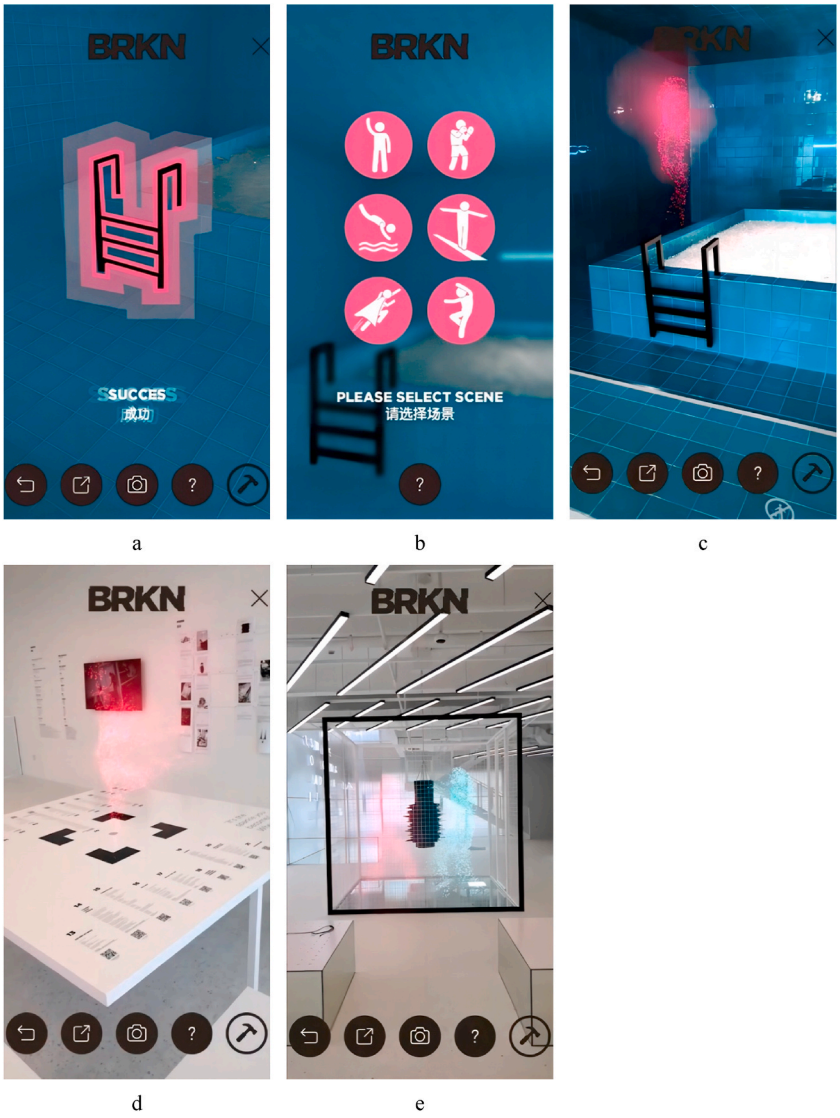

Fig. 1. (a–e). Screenshots of the main pages of the AR storytelling application.

in a meaningful way.

Therefore, a cultural experience results from a co-created activity between the visitor and the provider. The goal of the experience is to provide value to the visitor by facilitating interaction between the visitor, content, and space [31,70]. Based on the review of the existing literature, this study proposed the following hypothesis.

H1. The innovative AR storytelling application provides greater presence (H1a), flow (H1b), education (H1c), information utility (H1d), enjoyment (H1e), and engagement (H1f) than the AR e-book application.

Drawing on previous findings, combining presence, flow, engagement, and enjoyment, creates an integral UX that facilitates interaction between the visitor and an immersive environment that is enjoyable, informative, and educational [67]. Visitors' needs are met by the cultural metaverse, which allows them to quickly absorb new knowledge, foster positive emotions, create amazing memories, and engage in cultural experiences. Users can participate in an experience either actively or passively. Specifically, users engage in experience through active participation when they have an impact on the experience, as opposed to passive participation, when they do not have an impact on the experience [37,57]. Users can either immerse themselves in the event or absorb it in terms of connectedness. Based on this, the following hypothesis was proposed.

H2. Presence (H2a), flow (H2b), education (H2c), information utility (H2d) and enjoyment (H2e) influence engagement.

4. Materials and methods

4.1. Study design

This is a polit study. The Shanghai Museum of Glass is a young museum that opened in 2011 with a glass theme. The AR applications for the museum were created using unity engine. One of the AR applications was an AR e-book, which allowed participants to experience the guide of the exhibits in 3D view.

The other AR application, the AR storytelling application, incorporated a storyline that facilitated two-way communication between the participants and the exhibits. Participants were prompted on their smartphones to find six AR exhibit presentation panels in the museum's real space, each containing icons that would help them, trigger the appearance of "crystal fairies" in the real space of the museum using AR tools. The icon corresponding to the exhibit area where the participant was located could be selected from the menu bar of the mobile app. Next, the smartphone screen presented a positioning box and overlaid it with the corresponding object in real space. Finally, it triggered a crystal fairy. Each completed part provided clues for locating the next exhibit. The button on the smartphone screen performed additional interactive functions such as sharing, screenshotting, and smashing, as shown in Fig. 1 (a - e). Both the AR e-book and the AR storytelling application were based on local network departures. This app with embedded story clues adds to the object recognition. Overall, the use of AR storytelling application to enhance the museum experience for visitors, making it more interactive and engaging. By combining AR technology with storytelling, participants can explore the exhibits in a new and exciting way, with added features such as sharing and screenshotting to encourage social media engagement.

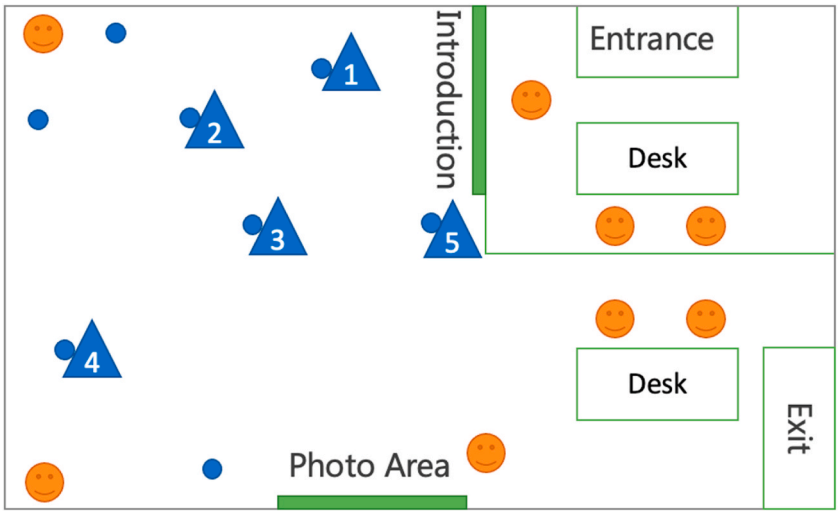

Fig. 2. Sketch map of the museum AR experience. The orange color dots represent the museum staff; the small blue dots represent clues; the blue triangles represent "cultural treasures"; the green rectangles indicate the introduction display area and photo area with the crystal fairies. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

4.2. Procedure

All visitors to Shanghai Museum of Glass were invited to participate in the AR cultural experience. However, participants could not choose if they wanted to be in the control group (i.e., using the AR e-book application) or the experimental group (i.e., using the AR storytelling application) because the different applications they were shown depended on when they visited the museum to eliminate bias in self-preference selection. They alternate between the AR e-book application and the AR storytelling application depending on the order of the visit. A staff member introduced the experiment to the participants before they entered the museum, and the participants voluntarily chose to participate by completing an anonymous questionnaire on our mobile devices at the end of their visit (Fig. 2).

The questionnaire was available in English and Chinese, and it did not request personal identifying information. No incentives or payments were provided to the participants in this study. The experiment was provided using 30 devices, which allowed for 30 participants to visit the museum simultaneously. During the entire experiment, the staff explained the purpose and procedures of the experiment to potential participants for approximately 10 min. The participants determined the amount of time spent visiting the museum, and the questionnaire, which took approximately 8–12 min to complete, was completed at the end of their visit (Fig. 3). This study did not include vulnerable minors or persons incapable of judgment, and informed consent to participate was obtained from all participants. The study was not ethically sensitive and conformed to the Ethics Committee's rules and guidelines.

4.3. Participants

The participants were randomly selected from the museum visitors. A total of 368 individuals were randomly divided into two groups to complete the experiment. Both female and male participants were 184 by chance. This study included a wide range of people of various ages, which reflects the characteristics of the museum visitors. Participants were at least 18 years old, which complied with the ethics committee's recommendations. The majority of participants held a bachelor's degree or higher. In addition, participants were briefly introduced on the methodology, purpose of the experiment, and the willingness to participate in the AR experiment. Participants were reasonably new to museum immersive technologies, with 87% indicating that they had never or only used an AR application in a cultural venue once or twice before.

5. Measures

The questions were divided into two main sections: user demographic variables and UX of the six aspects, presence, flow, education, information utility, enjoyment and engagement. In the first part, respondents were asked to give some general demographic information, including gender, age and level of education. The second part, variables were measured by having participants rate their overall experience using an 11-point Likert scale (0–10) [71]. The questionnaire design incorporated questionnaires that have been used in existing studies and drew on existing research on the reliability and validity measures of UX questionnaires in IVEs [72].

The quality of the items and scales of the questionnaire was analyzed through reliability and validity to avoid the risk of misinterpreting the items' meaning and providing a stereotyped answer. The R package "semTools" was used to test the Cronbach's alpha coefficient, the composite reliability (CR), and the average variance extracted (AVE) [73]. To examine collinearity, the variance inflation factor (VIF) was tested using the R package "car". The *t*-test for independent samples and Levene's test for equality of variances were applied using the R package "car". The regression model was statistically examined when it was discovered via ANOVA that the regression coefficients of the independent variables were not equal to 0.

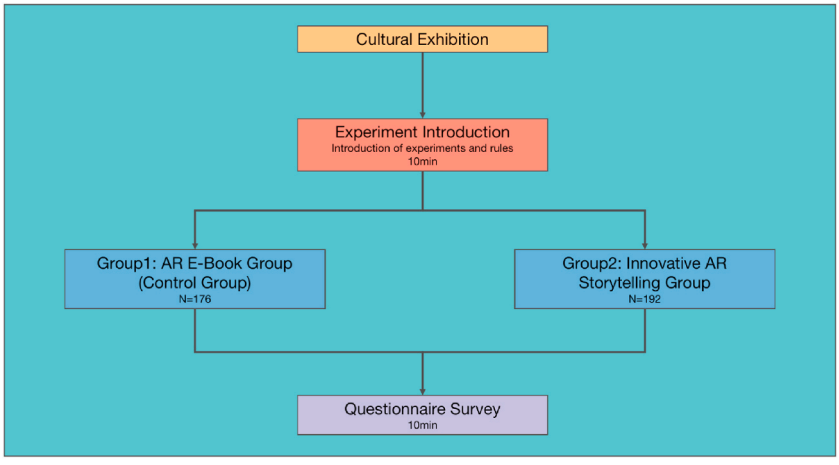

Fig. 3. Study's framework.

5.1. Presence

The variables were assessed using multi-item scales adapted from those validated in previous studies. Presence was measured using questionnaires based on the MEC Spatial Presence Questionnaire and other existing studies [74,75]. Some changes were made to accommodate the AR cultural experience scenario and to keep the questionnaire as concise as possible. The resulting scale included the following items, all of which were measured on an 11-point Likert scale ranging from 0 (strongly disagree) to 10 (strongly agree): "I felt like I was not only in the museum's physical space but also in the virtual space," "I had the feeling that I was in the middle of the action rather than merely observing," "It was as though my true location had shifted into the environment of not only the physical museum but also in the task," and "The boundaries between the physical and virtual spaces of the museum are increasingly blurred." This scale had the highest reliability (Cronbach's $\alpha = 0.946$) among all scales used in this study.

5.2. Flow

We constructed a measure of flow using the items proposed by Bachen et al. [76]. Four items were included in the scale: "I was deeply engrossed," "I was absorbed in the experience," "I felt that I was trying my best to understand the information," and "I felt as though I was moving through the task." The scale had good reliability (Cronbach's $\alpha = 0.864$).

5.3. Education

For the education scale, the items were taken from two existing studies [77,78], and included the following four items: "I learned something from the experience that I did not know before," "The experience made me more knowledgeable," "It stimulated my curiosity to learn new things," and "It was a real learning experience." These four items had comprehensive reliability (Cronbach's $\alpha = 0.848$).

5.4. Information utility

Information utility was measured using items based on a study that explored the influence of processes on information technology acceptance [79]. Four items were adopted to measure information utility in the context of AR application: "The AR provided was informative," "The information provided in AR was helpful," "The information provided in AR was valuable," and "The information provided during the AR application was persuasive." The reliability of these four items was comprehensive (Cronbach's $\alpha = 0.826$).

5.5. Enjoyment

Enjoyment was assessed using questions from scales originally proposed by Schmitt and Kleemans et al. [80,81]. The item descriptions were modified to make them suitable for the study of experimental environments. The three items adapted to the cultural experience were as follows: "I found the exhibition attractive," "I was so involved that I lost track of time," and "I would like to have this viewing experience again." The reliability of the enjoyment scale was high (Cronbach's $\alpha = 0.899$).

Table 1
Participants' characteristics.

Characteristics	Conditions				Significance Test
	Group1		Group2		
	Frequency	Percent	Frequency	Percent	
Gender					$x^2(1) = .011$, $p = .917$
Female	85	49.4	99	50.5	
Male	87	50.6	97	49.5	
Age					$x^2(5) = .863$, $p = .973$
18–20	8	4.7	12	6.1	
20–25	48	27.9	57	29.1	
26–30	69	40.1	74	37.8	
31–35	28	16.3	33	16.8	
36–40	11	6.4	11	5.6	
>40	8	4.7	9	4.6	
Education					$x^2(3) = 2.533$, $p = .469$
No Formal Qualification	24	14	27	13.8	
Undergraduate Degree	127	73.8	135	68.9	
Postgraduate Degree	14	8.1	26	13.3	
Doctoral Degree	7	4.1	8	4.1	
Total	172		196		368

Notes. Group1: AR e-book; Group 2: Innovative AR storytelling.

5.6. Engagement

To explore a reliable measure of engagement, items were included existing research were used [14,82]. The three items were as follows: "The experience has motivated me to find out more about the information of this cultural experience." "The experience has motivated me to find out more about this area of the exhibition"; "The experience has motivated me to participate in this area of the exhibition." The reliability of the engagement scale was comprehensive (Cronbach's $\alpha = 0.855$).

6. Results

6.1. Randomization check and preliminary analyses

Because the impact of technology and material stimuli on users' cognitive and emotional responses can be shaped by individual differences [83], differences in participant characteristics in the two experimental groups were investigated. Gender, age, and education were tested for significance, and most participant characteristics did not differ significantly between the two groups, as shown in Table 1 ($p > .05$). These results indicated that the randomization was successful.

A portion of the tested samples was analyzed for reliability and validity. After removing the items that failed the test, the results indicated that the reliability and validity of the questionnaire structure were high. After pre-testing, the final sample was used for data processing. The reliability assessed the consistency of a measure using the Cronbach's alpha coefficient, which was higher than 0.8 for all items. The values for CR were also higher than 0.8, indicating statistical significance. The AVE for all items was above 0.5, which was higher than all squared correlations between constructs, supporting discriminant validity. This evaluation provided strong support for reliability and validity, as each dimension variable had a higher variance than the observed items (Table 2). The R package "car" was used to examine the variance inflation factor (VIF) to avoid the influence of collinearity [84]. The results (presence = 3.0614, flow = 2.154; enjoyment = 3.485, education = 1.283, information utility = 1.393) indicated no collinearity in this model.

6.2. Results related to different groups

Levene's test for equality of variances and independent-samples *t*-test were performed. All the hypotheses are supported at relatively high levels of significance. The finding regarding the presence, flow, education, information utility, enjoyment and engagement of UX showed significant differences between the two groups. The mean and standard deviation results for all the factors of UX in the two groups were showed in Fig. 4. In accordance with H1a, participants in Group 2 reported more presence ($M = 6.041$; $SD = 2.464$; $t(366) = -7.699$) than participants in Group 1 ($M = 4.093$; $SD = 2.373$). Flow (H1b) had higher scores in Group 2 ($M = 6.383$; $SD = 1.699$; $t(366) = -7.452$) than in Group 1 ($M = 4.791$; $SD = 2.379$). The results showed that education (H1c) was higher in Group 2 ($M = 7.985$; $SD = 1.465$; $t(366) = -5.747$) than in Group 1 ($M = 7.076$; $SD = 1.567$). Information utility (H1d) was also higher in Group 2 ($M = 7.010$; $SD = 1.433$; $t(366) = -4.700$) than in Group 1 ($M = 6.194$; $SD = 1.890$). Participants in Group 2 felt more enjoyment (H1e) ($M = 5.492$; $SD = 2.403$; $t(366) = -6.953$) than participants in Group 1 ($M = 3.762$; $SD = 2.359$). Regarding H1f, engagement was reported to have higher scores in Group 2 ($M = 7.126$; $SD = 1.684$; $t(366) = -7.571$) than in Group 1 ($M = 5.651$; $SD = 2.010$). In other words, Group 2 scored significantly higher than Group 1 for all factors. Thus, H1a, H1b, H1c, H1d, H1e, and H1f are supported (Fig. 4).

6.3. Overall hypothesis testing

Multiple regression analysis was used to test H2. Among all the potential predictors, only presence was not significant ($p = .563$, 95%CI: [-0.056,102]). The predictors were examined through stepwise regression analyses, which were entered at the 0.05 significance level and removed at 0.01. An updated regression model was tested using four significant predictors: flow, education, information utility, and enjoyment. The results indicated that the regression relationship between all four independent variables (flow, education, information utility, and enjoyment) on engagement was relatively close ($R = .795$). The total variance in engagement was 63.3% ($R^2 = 0.633$), which was explained by four independent variables in the model. The corrected coefficient of determination, R^2, increased, and the remaining standard deviation decreased, indicating an increasingly good fit. The change in R^2 with new variables was also statistically significant. Using ANOVA, the regression coefficients of the independent variables were found to not be 0, and the regression model was considered statistically significant. There was no collinearity among flow (VIF = 1.922), education (VIF =

Table 2
Convergent validity and internal consistency reliability.

Variables	Cronbach's α	CR	AVE
Presence	0.946	0.949	0.785
Flow	0.864	0.858	0.616
Enjoyment	0.899	0.902	0.664
Education	0.848	0.839	0.581
Information	0.826	0.828	0.612
Engagement	0.855	0.822	0.577

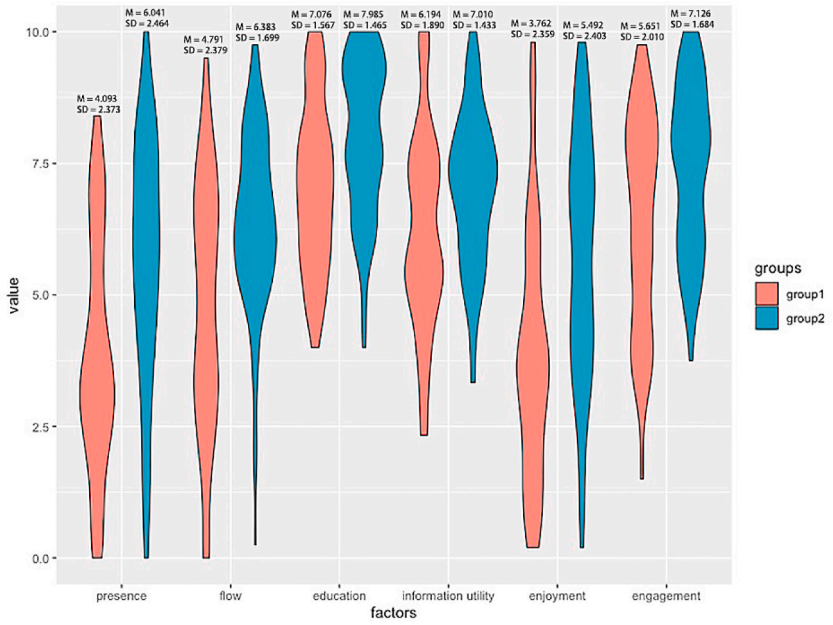

Fig. 4. The score distribution for presence, flow, education, information utility, enjoyment and engagement in Groups 1 and 2.

1.250), information utility (VIF = 1.354), and enjoyment (VIF = 1.855). Therefore, there was sufficient evidence to support H2b ($\beta = 0.388$, $p < .0001$), H2c ($\beta = 0.324$, $p < .0001$), H2d ($\beta = 0.149$, $p < .0001$), H2e ($\beta = 0.144$, $p < .001$), and to reject H2a ($\beta = 0.031$, $p = .563$).

Regarding the measurement of other experimental data, 142 (72.5%) of the visitors in Group 2 completed the tasks prompted in the AR. Moreover, at the end of the experiment, researchers approached visitors at the exit and asked if they were willing to register for other special exhibitions. Group 2 registered 23% more people for special exhibitions than Group 1. Furthermore, participants in Group 2 were willing to help their friends register for special exhibitions 37% more than those in Group 1.

7. Discussion

Major findings are described in this section, with their theoretical and practical contributions and implications for further research, while also taking into account the limitations of this study. The primary contributions of this study's exploration are summarized, which demonstrate how AR storytelling can increase visitor engagement, and design concepts and foundational frameworks for practitioners of the cultural metaverse are discussed.

This study contributed to the literature of AR storytelling in cultural experiences and explored the psychological, behavioral, and technological effects of AR storytelling on participants in AR cultural experiences, and shows a pilot project of cultural metaverse. This is one of the few explorations of AR storytelling that discusses the relationship between different UX factors and different influences on engagement; thus, it represents a new extension of previous work in the field. Despite the differences in the results between the two applications, the items generally scored high, which supports earlier studies that found that AR produced greater immersion and UX than the average immersion obtained when AR was not employed [20,24], suggesting that AR technology creates an overall positive UX in cultural experiences. This is consistent with earlier findings [85]. On top of that, through the data analysis of the pilot experiment, the study supported that AR is a worth promoting as an effective immersive storytelling tool in cultural metaverse. The study revealed that the cultural metaverse creates new opportunities for innovative and personalized services, allowing users to interact with the digital and physical worlds in new and meaningful ways.

One of the key challenges that arise with the emergence of the metaverse is the need to develop new storytelling design. Unlike traditional media formats, the metaverse offers users a highly interactive and customizable experience, which demands a different kind of storytelling. The creators must explore new methods of storytelling that are optimized for two -way interactive communication in IVEs. This includes exploring the potential for user-generated content, real-time storytelling, and dynamic environments hat respond to user input.

Overall, the emergence of the metaverse introduces new and interaction between the virtual and physical worlds, resulting in new opportunities and potential models in cultural experiences and beyond. To fully realize the potential, more research is needed to research and explore new methods and means to actively contribute to storytelling design in cultural metaverse, exploring our understanding and optimization of two-way interactive communication content for UX in IVEs, in order to create truly compelling and engaging cultural content.

7.1. Theoretical contributions

This study contributes to AR storytelling in cultural experience and to the construction of cultural metaverse literature by exploring visitors' UX in cultural venues. The results of our two AR applications show that highly interactive AR applications can lead to increased visitor engagement and thus, positive behavioral intentions in technologically enhanced cultural experiences. As expected, innovative AR storytelling can improve visitors' high-level presence, flow, enjoyment, education, information utility, and engagement. This is consistent with previous studies of UX in IVEs based on the experience economy theory [37,78].

The results demonstrated the importance of AR storytelling, suggesting that it offers absorption, entertainment, challenges, and rewards to receive a heightened state of flow, thus obtaining high engagement in UX. The study design was based on prior research that found that flow was the main factor contributing to engagement. In addition, the design is supported by, who proposed that "perceived skills and challenges," "a clear goal," and "immediate feedback" are significant flow triggers, which were the main reasons why the innovative AR storytelling application had higher flow than the AR e-book [67].

Furthermore, the findings demonstrated that AR storytelling mostly depends on flow and instruction to improve engagement outcomes in cultural experiences. The flow is influenced by a highly immersive and interactive environment [86]. In the present study, an AR e-book group was chosen to control the technology effects, instead of a physical visiting group that controlled different immersive technologies to influence the elements' changes. Therefore, the impact of outcomes mainly came from different AR storytelling. The UX and engagement processes are reflected in the UX regression model.

Education is another important factor that influences engagement. This study's results provide empirical support for past research on UX [87,88] and experience economy theory studies in IVEs [42]. The results confirmed that cultural experiences have a strong educational attribute, which is the primary purpose of visiting a museum [89].

In addition, this study found that presence is a critical factor in the cultural metaverse experience. However, that was not significant in the regression model. There are two probable reasons for this result. First, both experimental groups visited the museum, which is a real physical space, and thus, there was little difference in the experience of actually "being there." Second, the results of the part and partial correlations were somewhat different, suggesting that the correlation between the variables may be the primary reason for this result. Under the same technical environment, future research should explore the influence of presence and other variables by designing different interaction contents.

This study appears to open up new opportunities for the use of AR, particularly storytelling in cultural metaverse. Consistent with our expectations, the AR applications with embedded story clues resulted cultural metaverse a great experience for museum visitors. This study was an attempt at a cultural metaverse. By allowing the visitors to choose their own tour route and providing them with diverse stories, a two-way interactive AR storytelling and an experimental cultural metaverse could be realized.

7.2. Practical contributions

Practitioners are developing applied technology strategies to address the advent of the age of metaverse cultural experiences. This study provides much needed guidance for practitioners working on the cultural metaverse by revealing how the implementation of AR technology solutions can facilitate UX. Furthermore, this study highlights important points for practitioners planning to implement immersive technology applications for cultural experiences to improve UX and engagement.

7.3. Limitations and future research direction

While this study provides valuable insights into the impact of AR technology on cultural metaverse, this study has several limitations related to the population sample that need to be addressed in future research to ensure the validity and generalizability of the results.

Firstly, the museum exhibition focused on technology and digitization; therefore, visitors tended to be highly educated people who were interested in digital culture and technology, limiting the generalizability of the findings to other visitor profiles. This has the potential to lead to high overall results for the questionnaire. Owing to the geographical limitations of this venue, the population was relatively homogeneous in terms of cultural background, which may not be representative of other cultural institutions or events. It is essential to replicate the study in other cultural venues to confirm the results. Future research should explore cultural experiences that display different types of cultural venues to gain a more comprehensive understanding.

Furthermore, the pilot study discusses the differences between the AR E-book group and the AR storytelling group. While these groups were found to be significantly different in terms of UX, there may be other groups that were not studied that could yield important insights. Due to the small sample size and less-than-rich demographics, the relationship between the factors was not discussed in this study.

Finally, the study also acknowledges that the creation and selection of measurement instruments were also influenced by the sample size. Future studies should extend the population to include cultural metaverse users from other cultural backgrounds to obtain more accurate and generalizable results.

8. Conclusions

The cultural metaverse can be thought of as a multiple experience. Combining the cultural experience of physical space with the experience of computer – generated information allows for education, entertainment, aesthetics, and escapism, with varying levels of

visitor engagement improves the process of interaction between users and cultural spaces by activating opportunities for facilitating the emergence of new experiential forms.

The study reveals that AR is a suitable tool for constructing a primary cultural metaverse. Interactive AR storytelling can provide immersive experiences that effectively boost visitors' engagement. Together, flow, education, information utility, and enjoyment influence user engagement. In the cultural experience, flow and education are the two influential factors that contribute most to engagement. This study contributes to AR storytelling in cultural experience and to the construction of cultural metaverse literature. It demonstrates how the use of AR technology solutions can improve UX, offering much-needed direction for practitioners on the cultural metaverse.

The industrial metaverse opens up avenues for personalized and immersive UX and influences user behavior in a variety of ways. Practitioners can apply the metaverse's own strengths to make the UX more immersive, enjoyable, learner-friendly, and knowledge-enhancing, thereby increasing user engagement with the experience. It is, therefore, recommended that practitioners consider investing in AR storytelling to promote interactive user engagement and provide more exciting cultural experiences for a cultural metaverse with real value.

Author contribution statement

Shuran Yang: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

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Appendix D

Media Reports of the COVID-19 Pandemic: A Computational Text Analysis of English Reports in China, the UK, and the US

Shuran Yang, Zhao Yuan, and Wenxiang Zhang

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Media Reports of the COVID-19 Pandemic: A Computational Text Analysis of English Reports in China, the UK, and the US

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Abstract

This study explored how news outlets, China Daily (CD), Cable News Network (CNN), and Daily Mail (DM) have reported the COVID-19 pandemic. Mainstream media is a credible communication path to guide public attention on COVID-19. Computational text analysis contributes to understanding media activities about the pandemic and promotes health information communication. The word frequency statistics and lexical diversity highlighted how pandemic reports changed in the early outbreak. A cluster analysis illustrated the frequency and semantic relationship between the highly frequent words from CD, CNN, and DM reports. Sentiment analysis was based on natural language processing when analyzing the sentiment of all headlines and the sentiment of the different words in the headlines. This study also discussed similarities and differences in the coverage by the three different media outlets at various stages of the outbreak. Three media reported comprehensive coverage of the pandemic. Since they are based in different countries, their focus and the numbers of reports are different at different stages. The richness of the vocabulary and the degree of emotion are related to their media attributes. These results can help health departments exchange information, guide accurate public awareness, and eliminate public fears regarding misconceptions about the pandemic.

Keywords

Computational Text Analysis, COVID-19, Cluster Analysis, Sentiment Analysis, Media Studies

1. Introduction

Worldwide, the media's reports on significant events have greatly influenced the public's perception, most recently evidenced by the daily coverage of the COVID-19 pandemic. Since late December 2019, multiple cases with symptoms of unexplained viral pneumonia occurred in Wuhan, China. By February 2020, the localized outbreak in China had evolved into a global outbreak.

People can quickly obtain an unprecedented amount of content from online platforms beyond their inner social networks. Since everyone can communicate their opinion on social media platforms, these sites become burdened with misinformation, including the spread of rumors and "fake news", which are often difficult to verify (Bode & Vraga, 2018; van der Meer & Jin, 2020). Users tend to obtain information that adheres to their views of the world and ignores opposing information, establishing what is known as an "echo chamber" (Mocanu, Rossi, Zhang, Karsai, & Quattrociocchi, 2015). Algorithms mediate and promote content according to users' preferences and attitudes, thereby facilitating information exchange (Kulshrestha et al., 2017). It profoundly impacts the construction of social concepts and narrative frameworks. The spread of uncertain information and concepts can cause group differentiation and negatively affect user emotions (Bakshy, Messing, & Adamic, 2015). Thus, the spread of misinformation in mainstream media is dangerous, perhaps even fatal.

Communication researchers have found that respondents who tend to obtain information from mainstream media are more aware of the disease's lethality and how to protect themselves (Ball & Maxmen, 2020). In the middle of March, Fox News reported that hydroxychloroquine was robust against COVID-19. In response to the Fox News report, Stanford University clarified that the author was not a consultant, and the university was not involved. Although correcting the misinformation, it has widely spread on social media platforms to the extent that it covered up accurate information. This misinformation communication has caused medication shortages, poisoning, and death (Donovan, 2020). The spread of misinformation in mainstream media is dangerous and can even turn out deadly.

According to the media dependency theory (Ball-Rokeach, 1998; Ball-Rokeach, 1985), people mainly depend on the media to acquire the information needed in hazardous conditions (Jang & Baek, 2019; Seo, 2019). The mainstream media's impact is evident; the information they release should be as accurate as possible (McCombs & Shaw, 2016). Therefore, examining the differences in the reporting habits of distinct media outlets is important. This includes whether cultural, regional, and media differences have affected the development of the pandemic and people's perception of the pandemic in each country; whether the media outlets disseminate credible information; and whether their reporting promoted panic.

Media from China, the UK, and the US were chosen as research objects. The goal of the study was to understand the patterns in informing the public by three major media outlets in each country. Computational text analysis was performed

for mining the data, and visual data analysis was applied to visualize the patterns of the COVID-19 pandemic (DiMaggio, 2015). This study discusses similarities and differences in the way the media from these three countries reported on the COVID-19 pandemic. The following research questions (RQs) were asked: What are the news reports trends concerning the pandemic (RQ1)? What did these media outlets report at different stages (RQ2)? Was the sentiment expressed in the headlines of their coverage positive or negative (RQ3)?

This study contributes to clearing up national or regional media discourses on the pandemic. Besides, it develops a valuable model for hot news reports, public opinion research, and media effects research in the future.

2. Computational Text Analysis

Content analysis of text-based data is generally accepted as a popular method in social sciences (Grimmer & Stewart, 2013). Various computational techniques have been developed in computer science, bioinformatics, psychology, linguistics, and communication (e.g. computational communication research) (Nelson, 2017). Artificial intelligence knowledge, such as natural language processing (NLP), deep learning, and data mining, suggests implicit connections between data and how entities express, infer, predict, and visualize relationships between texts and concepts (Socher et al., 2013). The content analysis framework for health communication is explored in research on new methods suitable for combining computational research and humanities (Medford, Saleh, Sumarsono, Perl, & Lehmann, 2020).

The application of algorithms and mathematical models to text-based data has injected new vitality into content analysis through interdisciplinary collaboration (Agerri, Artola, Beloki, Rigau, & Soroa, 2015; Alm, Roth, & Sproat, 2005). NLP and other machine learning methods provide support and analyses of text data to construct newer and faster computing methods, especially for big data research (Agerri et al., 2015; DiMaggio, 2015; Scharkow, 2013). Additional software packages have been developed to bundle algorithms and simplify their application in conventional text analysis projects (Oh et al., 2020) (i.e. Stanford NLP used in my research).

Many researchers are still skeptical about the role of computers in processing content 21. Human behavior is the core content of this type of research, which is not easy to elucidate using simple data-based methods (Hancock, Landrigan, & Silver, 2007). This article provides a hybrid approach for developing language and text analysis, which offers a comprehensive interpretation of the texts and incorporates the rigorous, reliable, and repeatable computational text analysis method.

3. Methods

3.1. Data Collection

In this research, Python version 3.7 was used for data processing and analysis (C.

Luthra and D. Mittal, 2010). This study employed a computational text analysis approach of coverage between 9 January 2020 (the first report about the pandemic) and 31 March 2020. At the beginning of the outbreak, the pandemic erupted in China and spread to Europe and America. This particular period is essential for examining media reactions related to the early COVID-19 outbreak.

3.2. Lexical Diversity (LD)

LD is used for content analysis of vocabulary richness (McCarthy & Jarvis, 2010; Yu, 2010). LD is a measure of the number of different words used in a text (Johansson, 2009). One of the most common methods for measuring LD is to use the ratio of unique lexical items divided by the ratio of the total number of words in text samples; i.e. the type-token ratio (TTR) (Bates et al., 1988; Fergadiotis, G., Wright, H. H., & West, 2013). This study examined the lexical semantics between the different media outlets.

3.3. Cluster Analysis

This study used keywords such as "COVID-19", "pandemic", etc. to capture the media's coverage. Word frequency analysis was performed and high-frequency words were discussed. Using VOSviewer, a cluster analysis was performed (van Eck & Waltman, 2010, 2013). Focusing on the frequencies of single words in the coverage and visualizing these frequencies through cluster analysis to view the most common topics is critical.

3.4. Sentiment Analysis

Sentiment analysis is an NLP method that classifies sentiment towards news report headlines. This study used two methods for sentiment analysis. First, keywords that appeared in headlines were analyzed. Positive, neutral, and negative words were tallied, based on the study by Pang and Li (Pang & Lee, 2005). Second, based on a new type of recurrent neural network (RNN) (Socher et al., 2013), the Stanford Sentiment Treebank was built on a grammatical structure which is a deep recursive model of semantic composition on a sentiment tree. The semantic space might be handy; however, the meaning of longer phrases cannot be expressed in a principled way. It primarily relied on the sentence structure to construct the representation of the entire sentence and measure the sentiment according to the meaning of longer phrases.

4. Results

4.1. News Coverage Trend of COVID-19

From the perspective of global information dissemination, English is still the most widespread language. Therefore, this study chose these three media as research objects. China Daily (CD) is a representative of English-language media in China. Cable News Network (CNN) and Daily Mail (DM) are both mainstream English media with a universal influence worldwide. The first report on

COVID-19 was published on CNN, DM, and CD on 9 January 2020. Therefore, all related reports published from 9 January 2020 to 31 March 2020 were included in the dataset. A total of 16,705 reports on COVID-19 were obtained, including 7400 articles from CD, 2204 articles from CNN, and 7101 articles from DM. CD has paid attention to the pandemic since 9 January 2020. CNN and DM have not reported many reports in the previous period, but they both have kept a constant focus. The number of reports has a cycle of seven days a week. On the weekends, the number has decreased significantly, owing to fewer editorial staff on the weekends. Depending on the occurrence and development of the pandemic outbreak, time was divided into two parts: the localized outbreak in China (9 January 2020 to 21 February 2020) and the global pandemic stage (22 February 2020 and 31 March 2020) Figure 1 illustrates the pattern of increased reports from individual peaks. In Stage 1, the number of CD reports positively correlated with the number of new cases in China, and the number of reports by CNN and DM positively correlated with their own country's new cases in Stage 2. The number of CD reports did not change with the number of new global cases.

These results indicate the intensity of covering COVID-19. Concerning temporal distribution, the reports of CD showed a marked increase from 9 January to 2 February whereas the number of reports from 3 February to 31 March was steady. DM's reports showed an apparent increase from 22 January onward, climbing again on 23 February. The number of reports gradually increased. CNN's reports did not change significantly in Stage 1; although, there were considerable increases in the number of reports posted on 29 January 04 February and 10 February. The overall trend was comparatively similar to that of DM. Table 1 shows the changes in the number of reports of the three media at different stages.

4.2. Word Frequency Statistics and LD

In the word frequency, high-frequency words were sorted from high to low (Figure 2). From 9 January to 31 March, 26,735, different words were used 568,582 times by CNN; 4,807,762 words were used 57,382 times by DM, and 39,455 words were used in 1,636,758 instances by CD. Articles, prepositions, conjunctions, and other words that were not specific to the topic were beyond the statistical scope of this study.

Table 1. Number, proportion, and mean reports by CD, CNN, and DM in the two different stages.

	Stage 1			Stage 2		
	Number	Proportion	Mean	Number	Proportion	Mean
CD	3078	41.59%	69.96	4322	58.41%	110.82
CNN	287	13.02%	18.41	1917	86.98	287
DM	810	11.41%	161.31	6291	88.59%	1917

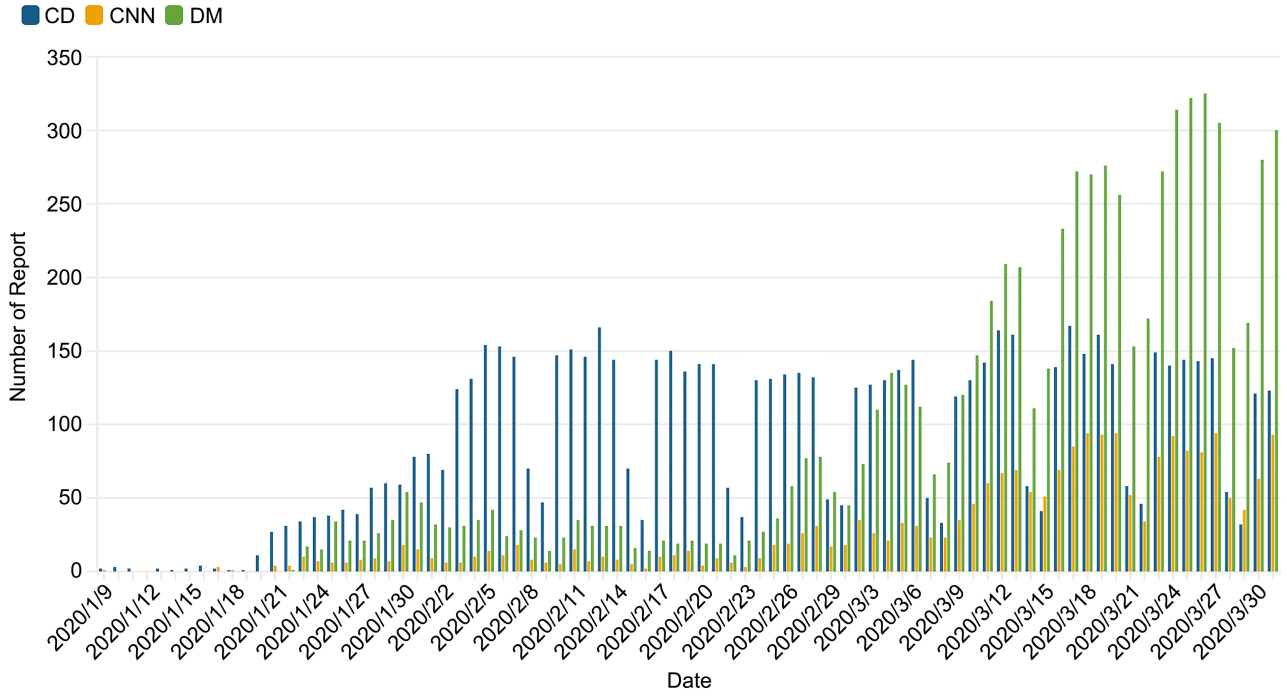

Figure 1. Number of reports by day on CNN, DM, and CD from 9 January 2020 to 31 March 2020.

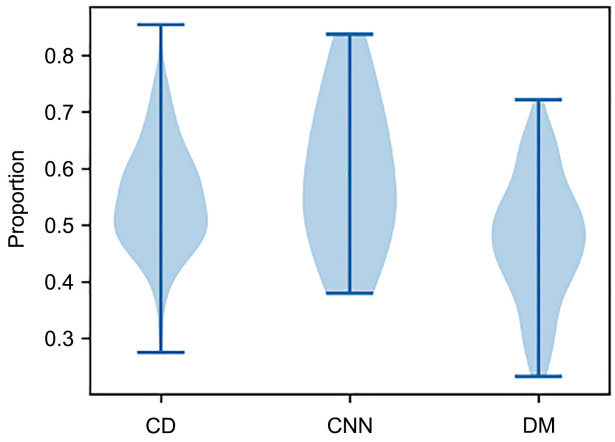

Figure 2. Measures of lexical diversity using the TTR.

The LD was calculated based on the number of articles, the word count, and the unique word count published over this period (Tweedie & Baayen, 1998). Compared with CD and CNN, each DM report used the most words; however, the TTR was the lowest for DM as compared to the other two. The TTR results of CNN and CD were similar; however, CNN's TTR was more concentrated than CDs. It is worth noting that Hong Kong ranked evenly in the DM and CD reports for historical and political reasons. Before 1997, Hong Kong was a British colony. The Chinese government resumed the exercise of sovereignty over Hong Kong on July 1, 1997. Owing to Australia's membership in the Commonwealth, the British media pay attention to Australia. Australia ranks very high in the DM report than others.

After deleting prepositions, conjunctions, and other words in these news reports that were not topic-specific, the top 30 high-frequency words were selected for subsequent analysis. The results show that different media were all focused on similar topics about this global pandemic. All media paid attention to the changes in the outbreak in different countries, the number of cases, and the respective government's responses. Owing to geographical reasons, the frequency of both "China" and "Daily" was high in CD. CNN repeatedly featured "the US" and "CNN". "UK" appeared in DM for the same reason. "Trump" and "president" appeared more often on CNN than others, suggesting that the President of the United States plays a dominant role in the public sphere. Moreover, Trump keenly expressed his opinions on social media platforms, prominently Twitter: every time he posted a social media statement, he received considerable attention (Lee & Xu, 2018).

According to the content analysis, CNN and DM preferred to use "tell" to quote other people's statements, while CD opted for an objective narrative; thus, "photo(s)" appeared more often. Interestingly, the frequency of "Australian" was very high in DM's reporting.

4.3. Cluster Analysis

A cluster analysis was conducted on the high-frequency keywords in the reports between 9 January and 31 March 2020. Through the empirical judgment method, 23 high-frequency keywords with strong descriptiveness and contribution to the topic were selected from CNN, DM, and CD. This highlights the differences between different media concerning frequency and variation (**Figures 3-5**).

From the cluster analysis, news reports on the pandemic mainly revolved around four themes: 1) the pandemic situation and confirmed cases of COVID-19, 2) how to control the disease, 3) travel concerns, and 4) health and medical treatment concerns.

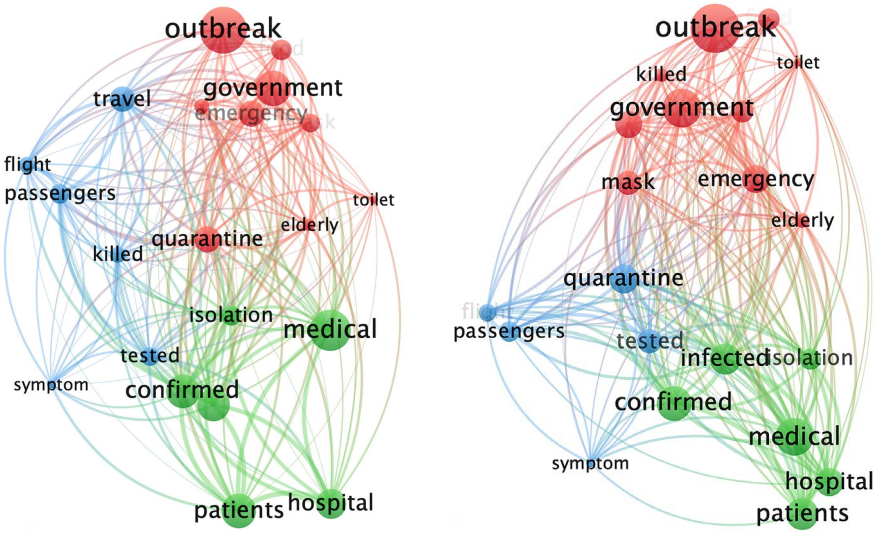

Figure 3. Cluster analysis of CD in stage 1 and 2.

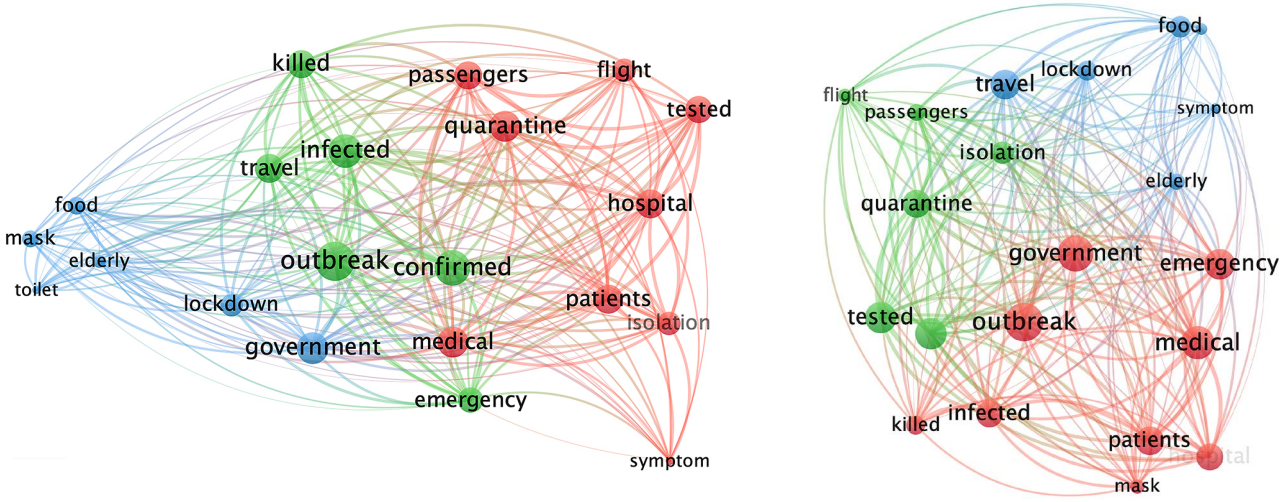

Figure 4. Cluster analysis of CNN in stage 1 and 2.

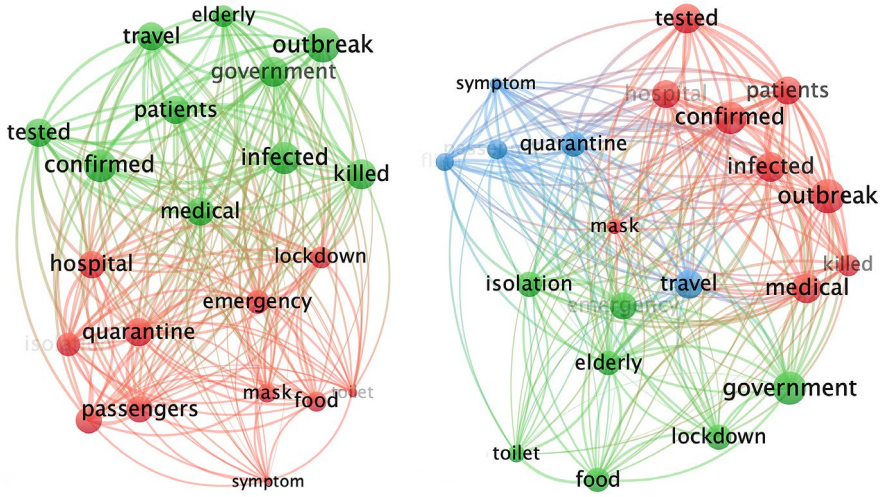

Figure 5. Cluster analysis of DM in stage 1 and 2.

In Stage 1, these mainstream media mainly reported on localized outbreaks in China. CNN's reports mainly focused on Themes 1 and 2 and tended to follow-up on the pandemic outbreak. DM reported "outbreaks" related to Theme 1 and Theme 4 formed a set. Theme 3 and Theme 4 constituted the other group. At this stage, both CD and DM were intensely concerned with Theme 4.

In Stage 2, the outbreak developed into a global pandemic. The focus of the reports shifted from China to global developments and the situation in the respective countries. The coverage was still closely related to these four themes. The "outbreak" in CD's coverage was still strongly related to "government". CNN's "outbreak" began to connect to "government" and "medical". In DM, "outbreak" was also strongly related to "medical". During this time, CNN and DM discussed their own countries' medical conditions.

Figure 4 shows that in DM and CNN, the word "killed" was the high frequency in Stage 1, during the outbreak in China. This term decreased in frequency during

Stage 2. In CD, this term's frequency was comparatively lower during both stages.

4.4. Sentiment Analysis

In the news report, the headline is critical (Blom & Hansen, 2015). It helps the audience decide whether to continue reading. Therefore, sentiment analysis was used for all headlines in the dataset (Rameshbhai & Paulose, 2019). Two sentiment analysis methods were employed. This set of values indicates the attitudes and opinions of each medium regarding the outbreak. One is to analyze every word in the headline. Sematic vector spaces have been extensively used as features for single words (Turney & Pantel, 2010). The more significant the proportion of positive and negative words in the headline, the more exaggerated it is. According to the results (**Table 2**), the proportion of positive and negative words was the highest in DM as compared to CNN and CD. This indicates that this newspaper preferred to use exaggerated expressions to attract readers. CD had the lowest percentage of positive and negative words as compared to CNN and DM. Its headline expression was closer to the objective narrative. Throughout Stages 1 and 2, the format of news headlines in the dataset did not change much, and the style was relatively consistent.

The other is to analyze the entire headline. According to the RNN model results for sentiment analysis (Oh et al., 2020) (**Table 3**), each headline was mainly negative about the pandemic. During Stage 1, the negative sentiments of the three media were relatively consistent. In Stage 2, the Chinese situation took a better turn; thus, CD reduced their negative sentiment. Interestingly, in the global pandemic stage, CNN's negative sentiment was much lower as compared to CD. CNN's reports were relatively optimistic. When some of the headlines were extracted for content analysis, the results showed that CNN did not fully support Trump's points of view and instead questioned his policies. Among these positive headlines, some indicated that China's outbreak was controlled and efficient. Overall, CNN's attitude at the time of reporting was relatively positive and did not rely too much on the expression or evocation of emotions. During Stage 1, the negative emotions expressed or evoked by DM were of the highest degree using exaggerated emotional vocabulary; during the pandemic phase, they slightly decreased but still remained at a high level.

Table 2. Results of sentiment analysis for each word of the headlines in CD, CNN, and DM.

	CD		CNN		DM	
1	Positive	Negative	Positive	Negative	Positive	Negative
Stage 1	41.88%	14.13%	49.06%	22.50%	58.48%	64.91%
Stage 2	41.59%	16.10%	49.48%	21.47%	65.93%	61.26%
Total	41.71%	15.29%	49.42%	21.60%	65.11%	61.67%

Table 3. Results of the recurrent neural network model analysis for each headline in CD, CNN, and DM.

	CD		CNN		DM	
2	Positive	Negative	Positive	Negative	Positive	Negative
Stage 1	12.53%	51.40%	4.06%	61.30%	3.16%	78.13%
Stage 2	8.31%	29.91%	3.65%	24.31%	4.55%	67.56%
Total	8.40%	32.28%	3.37%	24.16%	4.36%	67.94%

5. Discussion

In a global health crisis, misinformation does not lead people, such as people starting to take untested medication, ignoring public health advice, and even boycotting a prospective vaccination. Misinformation provides a hotbed for the pandemic to attack anywhere. It is impossible to stop the spread of misinformation, even if social media platforms already stepped up their efforts to remove misinformation and lead people to reliable sources (Ball & Maxmen, 2020). Mainstream media plays a decisive role in guiding people and conveying reliable information.

The mainstream media in each country (the United Kingdom, the United States of America, and the PR China) are the main channels for public information about the pandemic. Online news in the mainstream media also took full advantage of the network to be time-sensitive. The three selected mainstream media outlets have the standard features of fast communication, a sufficient number of reports, high reporting density, representative samples, and international perspective in each country. However, their attributes are different: CD is an official newspaper operated by the Chinese government; CNN is a commercial news broadcast operated by a corporation, the Warner Media group; and DM is a known representative of the so-called "yellow press" (Örnebring & Jönsson, 2004).

CNN and DM similarly constructed reports in Stage 1. They had the same curve of change in the volume of articles, and both focused on all four themes. However, the emphasis was different. In Stage 1, the content of CD's reports mainly consisted of descriptions of the pandemic, government measures, knowledge and science, news about medical workers, information about help and donations, dispelling misinformation, and some media reviews on the outbreak. The content of CNN's reports mainly focused on the condition of the pandemic, Chinese government measures, and media reviews of measures taken in China The coverage was relatively objective and comprehensive; but it also lacked awareness of the crisis and warning. Compared to the others, DM has more "attitude". It followed the development of the pandemic in China and the Chinese government's measures and doubts about the pandemic and the measures taken. In Stage 2, the changes in the volume of manuscripts issued by the three media were nearly identical. They jointly paid attention to the pandemic's international

issues and the changes, measures, and available medical treatment in the respective countries.

All three media reports revolved around three words: "outbreak", "government", and "medical". These were the most used terms in the four main themes in both stages. The strong correlation with "government" was mainly related to government measures. The words are closely associated with the development of the pandemic and government decisions. The proportion of socially active words such as "travel" and "flight" in Theme 3 increased in the second stage and were related.

CD paid more attention to "masks" than the other media. The difference in the frequency of the word "masks" depended on whether different countries required people to wear masks to guide public health measures. Perhaps CD mentioned masks more often because China emphasized that wearing a mask is the most effective protective measure. At this stage, the United Kingdom and the United States believed that masks were only necessary for sick people. However, in Stage 2, British and American media reported more on masks, which significantly impacted the audience's decision to wear masks.

Rumors triggered by emergencies all have an inevitable life cycle, and the development of rumors will gradually disappear from inception, followed by the birth of new rumors (Shibutani, 1966). As a special kind of unexpected event, the pandemic has a prolonged impact cycle; therefore, the rumors triggered by the pandemic have a long emergence period. The public and media have consistently maintained high-level attention. In Stage 1, the number of new cases per day in China was positively correlated with the daily reports in CD. The number of new cases per day positively affected the number of daily reports. The correlation between the number of new cases per day and the number of daily reports was not significant in the second half of Stages 1 and 2. Changes in the number of new cases per day did not directly affect the number of daily reports. In Stage 2, CNN and DM presented the same situation as the CD in Stage 1.

In the first half of each country's pandemic, the spread of the pandemic directly affected the increase in the number of reports. As the pandemic stabilizes in increments, the measures taken by different governments were widely accepted. Public opinion slowed until it reached a relatively stable state. During this stage, the rumors continued to change; but the cycle of change slowed. Changes in the pandemic would no longer directly affect the number of pandemic-related reports. However, the government introduced relevant guidance and regulations that would break this stable situation. For example, on 23 January 2020, Wuhan, China locked down, and on 9 March Italy proposed a lockdown from 10 March onward. These sparked another wave of public opinion and rumors. The number of reports increased dramatically. Each time the government made pandemic-related announcements, it should anticipate the subsequent actions triggered by public opinions following the media release, such as lockdown regulations, wearing masks in public places, and other related regula-

tions. The information released was followed by demonstrations that resulted in mass gatherings, which results in infection. Media attitudes and opinions should be used to promote or control the occurrence and development of these behaviors.

CNN had the highest overall vocabulary richness. The DM's vocabulary richness was slightly lower than that of the CD. However, CNN and DM both used English as their mother tongue. As the so-called yellow press, DM uses simplified language and exaggerated headlines. According to the sentiment analysis, the proportion of positive and negative words in CD was smaller than in the other two. It preferred neutral words. In Stage 1, the negative words were even higher than the positive words, indicating that DM has a particular negative emotion for China's localized outbreak. In Stage 2, although positive words were slightly higher than negative words, both had a large proportion. The DM headlines were the most exaggerated to garner attention. Regarding overall sentiment analysis, CNN's and DM's reports focused heavily on the Chinese outbreak under review and were very negative overall. Once the disease had engulfed the whole world, CNN's negative headlines reduced significantly. When the outbreak was more severe in each respective country, negative sentiment was reported less. CD had the smallest before-and-after change in positive and negative sentiment of all three media outlets. In Stage 2, when the outbreak in China was already under control, and the world outbreak was trending, the negative sentiment of CD increased by almost 2% from Stage 1. The negative sentiment was mainly related to the widespread knowledge of the pandemic and the current situation. In Stage 1, the negative sentiment reported by CNN and DM focused on China's pandemic. In Stage 2, CD's negative sentiment focused on its own respective pandemic situation, the spread of protection knowledge, and the pandemic situation in other countries.

The sentiment analysis and LD correlated with the media attributes: CNN targeted the more educated public; the state officially operates the CD. The positive and negative words were not rich, mainly based on the objective narrative and strict attitude. The news sources were well-founded. DM relied heavily on exaggerated headlines to arouse potential readers' interest in reading and tempting them to invest in the media. The average literacy level of the audience was lower than that of others, meaning that the words were simple to read 39. However, the number of extremely positive and negative two extremes was high. Headlines with more positive and negative words were more stimulating and have their attitudes. However, news content published during outbreaks is likely to spread quickly and generate public opinions. If the media target an audience with a low overall literacy level, such news is more likely to promote the spreading of rumors.

Individuals' need for pandemic-related information rises rapidly based on their safety and rights. If the information cannot be obtained from the authoritative official channels, the public will blindly adopt the information from other

channels, which leaves considerable room for rumors to survive. Internet rumors spread with high efficiency. If rumors are spread unchecked, individuals' sense of uncertainty and insecurity will gradually deepen, and public opinions and rumors will get out of control and even threaten people's lives. Mainstream media, as the leading voice channel for public affairs communication, should assume corresponding responsibility. Through objective and truthful reporting of emergencies, media outlets should reasonably help the public vent dissatisfaction and express opinions, thereby alleviating or eliminating public dissatisfaction and insecurity, maintaining stable social relationships.

Researchers were trying to use interdisciplinary methods for text analysis. Researchers express, infer, predict, and visualize the relationship between text and concepts through computational text analysis. According to people-oriented communication studies, researchers find new ways to combine computational research and humanism within the content analysis framework in health communication.

6. Implications

This study had some limitations. First, the length of the articles varied greatly, which may have affected data analysis. Analyzing articles of a similar length from the same date on the same topic would yield more accurate results. Second, as data were mined only from CNN, DM, and CD, there was still much room for optimizing data volume and data dimensions. Data mining on the same timeline on social media networks is necessary and combines data with media report data (Demszky et al., 2019; Ordun, Purushotham, & Raff, 2020) The final step is to formulate a practical management and prediction model through machine learning. For instance, understanding users' engagement in the related COVID-19 tags on social media platforms and understanding users' sentimental dynamics behind the COVID-19 pandemic could help explore mainstream media's effect in a crisis and design more efficient social behavior models for efficiently solving misinformation communication. Lastly, sentiment analysis is not a magic wand. It depends heavily on the psychological theories behind it; for example, whether a sentiment analysis is based on discrete emotions (Ekman & Friesen, 1971) or valence and arousal (Kim & Klinger, 2018).

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Author Contributions

Conceptualization, formal analysis, investigation, visualization, data curation, writing—original draft preparation, Shuran Yang.; methodology, Shuran Yang and Zhao Yuan.; resources, Zhao Yuan and Wenxiang Zhang.; All authors have

read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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