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Exploring perceived learning effectiveness in virtual reality health communication through the lens of construal level theory

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Abstract

Background Virtual reality is increasingly being used for health communication. This study aimed to propose and test an integrated model of the determinants of perceived learning effectiveness in virtual reality (VR) within health communication. It proposes that psychological distance negatively affects immersion, flow, and presence, positively affecting perceived learning effectiveness.

Methods The Fuzzy Decision Making Trial and Evaluation Laboratory Method (F-DEMATEL) and structural equation modeling (SEM) were used to test the proposed model. Data for the F-DEMATEL study were collected from 20 participants, whereas data for the SEM study were collected from 1104 participants, with 775 included in the final analysis.

Results The results of the F-DEMATEL study revealed that the three dimensions of psychological distance, emotional distance, spatial distance, and social distance are causal factors. In contrast, temporal, technical, and hypothetical distance are effect factors. The SEM results confirmed the negative effects of psychological distance on flow and presence and the positive effects of immersion and presence on perceived learning effectiveness. In addition, the mediating role of presence was confirmed.

Conclusions The results suggest that interrelationships among the factors can enhance the perceived learning effectiveness of health communication from VR. The crucial role of ensuring low psychological distance and high engagement in VR communication is also confirmed, providing crucial implications for VR communication practitioners.

Keywords Virtual Reality (VR), Health Communication, Fuzzy Decision Making Trial and Evaluation Laboratory Method (F-DEMATEL), Structural Equation Modeling (SEM), Construal Level Theory, Psychological Distance, Engagement, Perceived Learning Effectiveness

Introduction

The rapid evolution of technology has ushered in innovative forms of communication, such as virtual reality (VR). VR refers to computer-generated simulations that enable individuals to interact with artificial sensory environments [1]. The global adoption of VR devices is increasing, with the VR market projected to increase from US$12.26 billion in 2022 to US$28.84 billion in 2026 [2]. Additionally, VR headset sales reached 16.44 million units in 2021 and are anticipated to increase to 34 million units by 2024 [2]. Due to its immersive and interactive nature, VR holds significant potential as an effective communication

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tool [3]. Consequently, it is being increasingly utilized as a communication medium across various sectors, including healthcare, where its value is forecasted to increase from US$2.33 billion in 2022 to US$25.22 billion in 2030, reflecting a 34.90% growth rate [4]. In healthcare, practitioners leverage computer-generated VR imagery to assist clients in visualizing specific medical conditions, comprehending the mechanisms of therapies, and better understanding their bodies and potential treatments [5, 6]. Given the increasing popularity of VR and its application in healthcare communication, it is important to understand how it can be effectively applied to health communication to ensure that it enhances the learning effectiveness of the communicated messages.

Research on human–computer interactions has emphasized the importance of psychological distance in technology-mediated communication. Anchored in construal level theory, psychological distance refers to the degree of abstraction in an individual's experience with immersive technology [7]. According to this theory, people interpret stimuli based on mental representations shaped by the perceived psychological distance in their interaction with these stimuli [8]. The construal level theory posits four subdimensions of psychological distance: temporal, social, spatial, and hypothetical [9]. Additional subdimensions, such as technical distance and emotional distance, have been proposed in other studies [10]. Mitigating psychological distance enhances users' relationships with computer devices and increases usage intentions [10]. In interpersonal contexts, experiences characterized by low psychological distance, indicative of healthy dyadic relationships, have been demonstrated to intensify engagement [11]. Numerous studies have applied the construal level theory to elucidate how psychological distance shapes outcomes in technological contexts such as social media, human–robot interaction, and human–computer interaction [12–14]. Despite the theory's significance in elucidating technology usage outcomes, its application in the VR domain remains underexplored, rendering the impact of psychological distance on engagement in VR contexts not to be fully understood.

VR has distinct affordance which necessitates developing an understanding of its applicability in the VR context. First, VR offers unparalleled immersive experiences which allow users to feel physically present in the virtual environment, which can significantly reduce psychological distances [15]. This immersion can make abstract health risks feel immediate and personal, thereby enhancing user engagement and motivation. Secondly, unlike traditional media, VR can create a sense of presence and embodiment and enable users to visualize and experience hypothetical health scenarios in a highly realistic manner [10, 12]. This ability to manipulate temporal, spatial, and social distances within a controlled virtual environment makes VR a powerful tool for health communication and allows messages to be framed in ways that resonate more deeply with users' perceptions and emotions. These distinct affordances of virtual reality necessitate the examination of its applicability in the health communication context. On the other hand, in the health communication context, the need for personalization and emotional engagement is paramount [14]. VR's immersive nature can facilitate empathy by placing users in scenarios that closely mimic real-life experiences, such as witnessing the progression of a disease or the benefits of a healthy lifestyle firsthand [16]. This immersive experience can make health risks and preventive measures more tangible and urgent [5]. Moreover, VR can simulate the impact of health behaviors over time, providing a vivid, experiential understanding that is difficult to achieve through other media [17]. Considering the distinctiveness of the VR and health communication contexts, this study applies the construal level theory to VR health communication to investigate the effect of psychological distance on engagement.

The existing body of research on technology-mediated communication underscores the pivotal role of engagement in influencing communication effectiveness in these contexts [18, 19]. When individuals are actively engaged in communication, they are more likely to internalize information effectively, as engagement captures attention, enhances comprehension, and facilitates information retention [20]. Research in interactive technology contexts has particularly emphasized the significance of flow, immersion, and presence as integral components of engagement [21]. Immersion allows users to interact with and manipulate objects naturally and intuitively [22]. Flow, achieved by maintaining a balance between the challenge of the virtual environment and the individual's skill level, ensures deep concentration and enjoyment [23]. Additionally, presence, facilitated through realistic sensory inputs such as graphics, spatial audio, and haptic feedback, creates a 'convincing illusion' of physical presence in the virtual world [3]. Despite the crucial role of engagement in technology-mediated communication, relatively few studies have empirically examined how engagement shapes communication effectiveness in VR [16, 24, 25]. Furthermore, scholars have advocated for additional empirical research to foster a deeper understanding of engagement in VR communication [16, 26]. In response to this gap in empirical evidence on the role of engagement in VR communication, this study proposes that psychological distance negatively impacts engagement, and that engagement positively affects perceived learning effectiveness.

This study thus addresses the following questions: (1) how does psychological distance affect engagement in health communication in the VR context? (2) does engagement enhance perceived learning effectiveness of health communication in the VR context? With two empirical studies, this research established that psychological distance and engagement enhance learning engagement in VR health communication. The results of the DEMATEL study showed that the three dimensions of psychological distance (i.e., emotional distance, spatial distance, and social distance) had causal effects on perceived learning effectiveness and that temporal distance, technical distance, and hypothetical distance were effect factors. The structural equation modeling study revealed that the dimensions of psychological distance had negative effects on flow and presence and that immersion and presence positively affected perceived learning effectiveness. The findings of this study also confirmed that presence mediated the effect of psychological distance on perceived learning effectiveness.

This study contributes to the field of VR communication research in several ways. First, applying the construal level theory sheds light on the psychological factors that shape the effectiveness of VR communication. Given the novelty of VR devices, existing research has focused predominantly on the determinants of their adoption rather than their effective usage [27, 28]. Second, the study underscores the crucial role of user engagement in VR communication. While engagement is recognized as a determinant of communication effectiveness in technology-mediated contexts [29, 30], its role in VR communication has yet to be explored in research. By demonstrating the mediating role of engagement, this study emphasizes that audience engagement is pivotal in shaping the effectiveness of VR-mediated learning. Furthermore, the study highlights the importance of psychological distance in enhancing VR communication, an aspect overlooked mainly by existing research. The concept has been examined to determine its effectiveness in contexts other than VR communication [11–14]. However, the differences in affordances across communication media necessitate the examination of the construct in VR communication. The findings also emphasize the need for reducing psychological distance and enhancing engagement in VR communication.

The rest of the paper is structured as follows: " Theoretical background, literature review, and hypothesis development" section discusses the literature review and hypothesis development, Sect. " Methodology" discusses the methodology, results and discussion of the results for both studies, " Results" section presents the theoretical implications, " Discussion" section discusses the practical implications, "Limitations and directions for future research" section presents the limitations and directions for future research.

Theoretical background, literature review, and hypothesis development

Construal level theory of psychological distance

According to construal level theory, individuals' preferences and evaluations of external stimuli are influenced by psychological distance [31]. Psychological distance refers to an individual's perception of whether something is close or far from the self [9]. When an object is perceived as distant from the self, it is represented at a higher construal level, as its mental representation requires greater abstraction. In contrast, if the object is perceived as close to the self, its mental representation requires a lower-level abstraction and is represented at a lower construal level [32]. The levels of abstraction differ for near and distant objects because it is easier to obtain extensive information for nearer objects [as compared to distant objects], reducing the cognitive effort required to form representations about an object [15].

Prior research indicates that psychological distance encompasses several interrelated subdimensions. The classical construal level theory literature suggests four dimensions of psychological distance: temporal, spatial, social, and hypothetical [9, 32]. Temporal distance pertains to individuals' perception of the interval between an object and future occurrences [10]. A higher temporal distance suggests an event will likely occur much later [33]. Spatial distance involves an individual's perception of the physical distance between himself or herself and the object they interact with within the virtual environment [9]. Objects perceived as being in the individual's vicinity [i.e., having low spatial distance] are construed at a lower construal level. Social distance is defined by the closeness of the relationship between the individual and the object [10]. Social connections help individuals develop close relationships with objects. A socially close object is construed at a lower level, whereas a socially distant object is construed at a higher level [32]. Hypothetical distance refers to an individual's belief in the reality of the object [9]. An object considered hypothetically near has a high probability of occurring, while one hypothetically distant object has a lower probability [34]. Objects that are hypothetically near have a high-level construal, whereas those that are hypothetically distant have a low-level construal.

Given that different media contexts have different affordances that shape users' perceptions of psychological distance, extant research has called for additional dimensions of psychological distance [9]. Recent research has proposed additional dimensions of psychological distance, more notably, technical and emotional distance [10]. A crucial factor in the use of technology is the efficacy of utilizing the technology effectively [35]. When individual efficacy is high, the use of technological devices becomes more accessible, allowing users to derive maximum benefits [36]. In VR, technical distance pertains to the ease users can navigate and use VR technology [10]. High technical distance occurs when an individual struggles to use VR technology comfortably, while low technical distance indicates that the individual can use VR technology with ease and efficiency. A low technical distance implies that the information communicated via the VR device can be understood at a low level because minimal cognitive effort is needed for device usage [10].

The emotional connection between the individual and the object of communication is also crucial in determining the success of communication. When individuals feel connected to a communication object, they are more likely to internalize the message effectively [37]. Recognizing the centrality of emotion in communication, emotional distance emerges as another dimension of psychological distance. Emotional distance refers to an individual's emotional affinity toward the subject being communicated through VR technology [38]. When an individual feels emotionally close to the object of communication, the emotional distance is low, and the message is processed with a low-level construal [39]. Conversely, if the individual feels emotionally disconnected from the object of communication, the emotional distance is high, and the message is processed with a high-level construal.

Engagement in VR

Engagement in VR is a multi-faceted concept that encompasses immersion, flow and presence [15]. These dimensions contribute to the overall user experience and effectiveness of VR communication. Immersion is the extent to which the VR system can deliver an inclusive, extensive, surrounding, and vivid illusion of reality [22]. It involves both the technical aspects of VR (such as graphical fidelity, audio quality, and haptic feedback) and the user's psychological involvement [40]. Immersion enables users to be deeply absorbed in the virtual environment and reduces their awareness of the real world [22]. It also enhances the believability of the virtual experience [41]. As a component of engagement, immersion enhances the intensity and quality of the VR experience [9]. Flow refers to the state of optimal experience characterized by complete absorption, enjoyment, and intrinsic motivation during VR use [42]. In the context of VR, flow is achieved when users are fully engaged in the virtual experience to the extent of losing track of time and external distractions [42]. The balance between challenge and skill is essential for achieving flow as it ensures that that users are neither bored nor overwhelmed [43]. Flow in VR has been linked to increased user satisfaction, prolonged engagement, and enhanced task performance [44]. Presence refers to the sense of being physically and spatially situated within a virtual environment [30]. It is the psychological state where users feel they are "inside" the VR world rather than merely observing it from an external perspective. Presence is crucial for enhancing the realism of VR experiences and fostering a deeper connection between users and the virtual environment [45].

Prior research has identified several antecedents of engagement in VR, including usability, interactivity, and content quality. Usability refers to the ease with which users can navigate and interact with the VR system, impacting their overall experience and satisfaction [46]. Interactivity, or the degree to which users can influence the virtual environment, has been shown to enhance engagement by providing a more dynamic and responsive experience [47]. Content quality, which encompasses the narrative, visuals, and overall coherence of the VR experience, also plays a crucial role in sustaining user interest and immersion [48]. However, there is a notable gap in the literature regarding the role of psychological distance as an antecedent of engagement in VR. Psychological distance has been established as a stimulant of active user behavior in contexts such as traditional media and social media [40, 49]. We apply the concept in the context of VR to examine its effects on engagement.

Furthermore, engagement in VR has been linked to various positive outcomes, including increased enjoyment, enhanced learning, and improved task performance. Users who are highly engaged in VR experiences tend to exhibit greater satisfaction and prolonged interaction with the system [30]. Engagement in VR can also lead to improved learning outcomes, as the immersive and interactive nature of VR facilitates deeper cognitive processing and retention of information [21, 29, 30]. This research examines perceived learning effectiveness as an outcome of engagement in VR health communication. Thus, the research provides insights into the efficacy of VR as a health communication tool and identifies the best practices for designing educational VR content that maximizes user engagement and learning.

VR, psychological distance, immersion, flow, and presence

VR technologies are engineered to teleport individuals from physical environments to virtual realms, delivering vivid and interactive immersive experiences [7]. Immersive media offer a rich sensory experience by providing viewers with a rich sensory experience environment [50]. Conversely, VR stimulates various senses at high resolution, intensifying the individual's perception and absorption into the virtual environment [51]. Through vividness and interactivity, VR can alter individuals' perceptions of time, space, and social interactions, helping users feel present in a specific place at a certain time and interacting with seemingly close but remote elements [10]. Moreover, VR enhances interactivity by allowing users to actively modify the form and content of the mediated environment in real time [28]. This is facilitated through hardware, software, and user elements [3]. VR systems incorporate display and audio systems for participants to engage with displayed content and tracking technologies for real-time monitoring of user movements and positioning, enabling accurate system responses [52]. These systems provide instant feedback to users, stimulating further user actions [53]. Thus, VR systems are meticulously designed to ensure interactivity, enhancing individuals' proximity and, consequently, psychological distance from the virtual environment.

Immersion encompasses physical, mental, and emotional involvement, significantly contributing to the overall quality of the VR experience [22, 41]. Unlike spatial distance, which measures the user's perceived physical distance from the virtual space, immersion focuses on the individual's mental and emotional perception of the virtual environment [9, 22]. When the gap between the virtual and real worlds is minimized, immersion is enhanced. Users who perceive the virtual environment as realistic are more likely to experience it as an alternate reality, fostering familiarity and recognition that encourage active engagement and deeper immersion [30, 53]. Low psychological distance, which implies increased realism, reduces users' disbelief in the virtual environment, thereby enhancing their sense of immersion [53]. Additionally, low psychological distance allows users to emotionally connect with both the VR device and the communicated health message, further enhancing immersion [43]. Therefore, it is expected that psychological distance has a negative relationship with immersion. When psychological distance is high, users may struggle to perceive the virtual environment as realistic and relevant, which may reduce their overall sense of immersion. Conversely, reducing psychological distance can create a more engaging and immersive VR experience. Hence, the following hypothesis is proposed:

> H1: Psychological distance has a negative relationship with immersion.

Flow is an optimal psychological experience whereby individuals become fully absorbed in an activity. For flow to occur, several preconditions must be met [42]. First, the individual must possess adequate skills to meet the demands of the activity. Second, the activity must have clear goals and provide timely, unambiguous feedback. Third, the individual must be considerably focused on the task, with a sense of control over it. During flow, the individual loses a degree of self-consciousness and experiences an autotelic experience and a distorted sense of time. Flow implies fun and interest while engaging in an activity, as the individual is focused entirely on the task [43]. Ultimately, this leads to positive behavioral outcomes such as continued usage intention and attachment to the activity [23]. In the context of VR, the conceptualization of flow as an affordance plays a pivotal role in enhancing the user experience and achieving a state of reduced psychological distance between the user and the virtual environment. This aligns with the concept of affordances that emphasizes the relationship between the characteristics of an environment and the actions individuals can perform within that environment [54]. Flow, characterized by deep engagement and optimal challenge–skill balance, closely aligns with VR by providing affordances that facilitate immersive and meaningful interactions [55]. Recent research substantiates that flow significantly contributes to positive outcomes in VR experiences [56–58]. A key goal in VR design is reducing psychological distance, aiming to minimize the perceived gap between the user and the virtual world [7]. When experiencing flow, users become fully absorbed in the VR environment, thereby blurring the boundary between reality and the virtual space. This reduced psychological distance is crucial for achieving a sense of presence and immersion, which is fundamental to successful VR experiences [7, 38]. The feeling of being present in the virtual world is closely tied to flow, which contributes to the overall sense of user satisfaction and engagement in VR applications [44].

When health messages in virtual environments feel distant, users must expend additional cognitive effort to bridge these gaps [59]. This can increase cognitive load and distracting them from the immersive experience [7]. High psychological distance can also dampen emotional engagement, which can make health messages feel less relevant or urgent and reduce users' emotional connection to the VR content [38]. This reduced emotional engagement can prevent users from becoming fully immersed, which is otherwise a necessary condition for achieving flow [42]. Furthermore, psychological distance can undermine presence by making it feel less real or immediate. Without a strong sense of presence, users may struggle to suspend disbelief and fully engage with the VR scenario [56, 57]. Additionally, psychological distance can interfere with intrinsic motivation, as health messages perceived as hypothetical or not immediately applicable may reduce users' motivation to deeply engage with the VR content [59]. As a result, psychological distance is likely to negatively affect flow in VR health communication by increasing cognitive load, reducing emotional engagement, undermining presence, and interfering with intrinsic motivation. The following hypothesis is proposed:

> H2: Psychological distance negatively affects flow.

Presence in VR refers to the feeling of being psychologically immersed in a virtual environment, even while physically situated elsewhere [30]. This immersive experience makes users perceive the virtual environment as genuine rather than a mere collection of computer images [60]. Presence in VR encompasses physical presence (feeling physically present in the virtual environment) and psychological presence (mental and emotional presence in the virtual environment). Achieving presence is a two-step process: first, individuals must perceive the virtual environment as a plausible and recognizable space, and second, they must perceive themselves as actively engaged within this environment [45]. Spatial presence is contingent upon the individual's active engagement and attention to the virtual environment [45].

When health messages or virtual environments feel temporally distant, such as future health risks that seem far off from the current period, users may find it challenging to perceive the information as immediate or urgent, thereby reducing their sense of presence in the VR health communication process [30, 61]. Similarly, spatial distance, where the virtual environment feels geographically remote, can make it harder for users to relate to the scenario as they may perceive it as less applicable to themselves [27]. This can, in turn, diminish their immersive experience and sense of presence in the VR communication process [18]. In addition, cases of high social distance, where the characters or scenarios in VR are perceived as socially or culturally distant, can hinder users' emotional and cognitive connection to the virtual environment and make it less engaging and realistic [60]. Finally, hypothetical distance, where the scenarios are perceived as unlikely or abstract, can further reduce the believability and immediacy of the VR experience [17]. Thus, when psychological distance is high, users struggle to suspend disbelief and fully immerse themselves in the virtual environment, thus negatively affecting their sense of presence. The following hypothesis is proposed:

> H3: Psychological distance has a negative relationship with presence.

Immersion, flow, presence and perceived learning effectiveness

Prior studies have focused on assessing communication effectiveness by measuring objective communication outcomes from the perspective of defined and targeted senders of information [20, 62]. However, recipients in the communication process form their own beliefs and judgments about the effectiveness of the learning process. These personal evaluations of communication effectiveness are crucial predictors of the behavioral outcomes related to communication [63]. Given that the primary goal of communication is often to persuade the audience to adopt or execute behaviors supportive of the communicated subject, it is crucial to understand the determinants of perceived learning effectiveness in communication.

Immersion entails profound engagement with the virtual environment, minimizing distractions from stimuli in the physical environment during the communication process [64]. The absence of external distractions enhances engagement and focus, improving information processing and retention [41]. Immersion is also linked to affective information processing, contributing to positive learning outcomes [65]. Therefore, immersion is expected to influence perceived learning positively. Effective learning requires individuals to be absorbed in the learning process, maintain focus, establish clear learning goals, maintain interest in the learning process, and possess sufficient skills to facilitate learning [66]. These characteristics align with the flow experience. Clear learning goals enable individuals to focus on achievement and make corrections when necessary. Adequate interest ensures sustained attention to the learning process, contributing to effective learning [45]. Additionally, possessing sufficient skills increases the likelihood of achieving learning goals [23].

In this study, presence refers to perceiving the virtual environment as interactive, emotional, and authentic [51]. Interactivity allows VR users to provide input during interactions, potentially aiding the internalization of communicated messages [67]. In addition, emotional engagement contributes to the consolidation and retrieval of learned content [44]. Furthermore, the realism of the learning process enhances the credibility of the learning output, attracting attention and consequently contributing to the internalization of communicated content [17, 45]. Therefore, it is expected that immersion, flow, and presence will positively impact perceived learning effectiveness, leading to the formulation of the following hypothesis:

> H4: [a] Immersion, [b] Flow, and [c] Presence positively affect perceived learning effectiveness.

Immersion, flow, and presence as mediators

Engagement is critical to learning in immersive contexts such as VR. Immersion, flow, and presence are key constructs that characterize engagement in VR [30], playing a vital role in the learning process within VR contexts. Specifically, immersion involves the individual being absorbed into the virtual environment with minimal external distractions, enabling undistracted focus on VR content [41, 49]. With explicit learning goals, personal interest, and skill adequacy, flow enhances attention and makes the learning experience interesting, potentially boosting learning effectiveness [23]. Additionally, presence entails perceiving the VR environment as authentic, making information from the VR context more believable [17, 45]. This perception increases interest in the learning process, contributing to effective learning.

The theoretical rationale presented in this paper posits that psychological distance positively influences immersion, flow, and presence. A lower disconnect between the individual and the virtual environment leads to individuals being more fully absorbed into the virtual environment [17, 56]. Consequently, psychological distance is expected to positively affect immersion, flow, and presence, ultimately influencing the perceived learning experience. Given the critical roles of immersion, flow, and presence in VR communication and their impact on the effectiveness of the communication process [21], this study proposes that immersion, flow, and presence mediate the effect of psychological distance on perceived learning effectiveness. Thus, hypothesis 5 is proposed.

> H5: (a) Immersion, (b) flow, and (c) presence mediate the relationship between psychological distance and perceived learning effectiveness.

Figure 1 illustrates the research framework for Study 2, which employs the SEM framework. This framework will guide the investigation of how psychological distance influences key engagement factors (immersion, flow, and presence) and how these factors subsequently impact the perceived effectiveness of learning in VR.

Methodology

This study applied the F-DEMATEL method and SEM to examine the relationships among the variables. The hypotheses could be validated through SEM; however, the F-DEMATEL method was also employed to provide a more comprehensive analysis. While SEM is effective for testing the relationships between constructs and validating the proposed model, F-DEMATEL offers additional insights into the causal relationships among variables. Specifically, F-DEMATEL helps to identify the direct and indirect effects and the strength of these relationships in a complex system. This dual-method approach allows for a deeper understanding of the dynamics within the model, ensuring a more robust and nuanced analysis of the data. Furthermore, the F-DEMATEL method was used to investigate the interrelationships among the predictor variables, whereas SEM was used to examine the research hypotheses proposed by the study. The two methods were employed to triangulate the sources of information in the communication process, which involves both senders and receivers of information. Thus, information was collected from experts in VR communication (i.e., senders) and analyzed using the F-DEMATEL method, and from end users of VR systems (i.e., receivers), and analyzed via SEM.

Study 1: The F-DEMATEL method

Fuzzy DEMATEL, an integration of the Decision Making Trial and Evaluation Laboratory (DEMATEL) technique with fuzzy logic, is an advanced method for decision analysis that considers the inherent uncertainty and imprecision in real-world decision-making contexts [68]. The DEMATEL method examines cause-and-effect relationships among decision elements, offering insights into the interdependencies between these factors [69]. Fuzzy logic enhances this approach by accommodating qualitative data and imprecise information through the use of

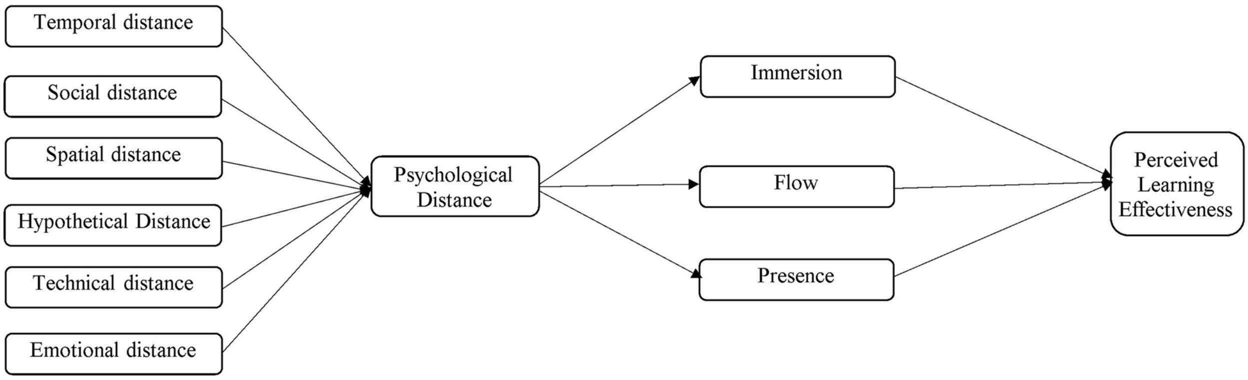

Fig. 1 The research framework for study 2 (SEM)

fuzzy sets [70]. The process involves constructing a fuzzy pairwise comparison matrix, where decision makers use fuzzy numbers to express the strength and direction of influence between elements [71]. This information is subsequently aggregated into a fuzzy total influence matrix and normalized for consistency and interpretation [71]. The outcome provides quantitative measures of influence and visual representations, empowering decision makers to prioritize factors and comprehend the intricate interactions within the decision model. Therefore, F-DEMATEL is a potent tool for helping decision makers navigate complex decision landscapes and offers a means to consider and integrate the uncertainties inherent in real-world scenarios [72]. The uncertainties inherent in communication, which are subject to influence by various external factors, make this a challenging endeavor. Applying fuzzy theory to DEMATEL helps mitigate subjectivity and ensures representative reliability [72]. Various studies have demonstrated the applicability of the F-DEMATEL model in diverse contexts, such as supply chain management [68] and health promotion [72]. Figure 2 illustrates the F-DEMATEL process framework, a systematic approach to analyzing and modeling complex causal relationships within a system.

The computational steps involved in F-DEMATEL are described below.

Step 1: Determination of the influencing factors in the system

A literature review was also conducted to determine the factors affecting the outcome variables. Table 1 below indicates the factors used in the study after the literature survey and the three M-Delphi rounds.

Step 2: Designing the fuzzy linguistic scale

The degrees of influence applied in the F-DEMATEL method typically consist of five levels: No Influence (N), Very Low Influence (VL), Low Influence (L), High Influence (H), and Very High Influence (VH). Participants used this semantic scale to rate causal relationships among factors within the system. The fuzzy linguistic scale in Table 2. was used to collect feedback from the experts.

Step 3: Computing the initial direct relation fuzzy matrix

Every respondent's initial direct relation matrix Z^k comprises ratings denoted by Z_{ij}^k. The direct relation matrix X_{ij}^k comprises three submatrices, L, M and U.

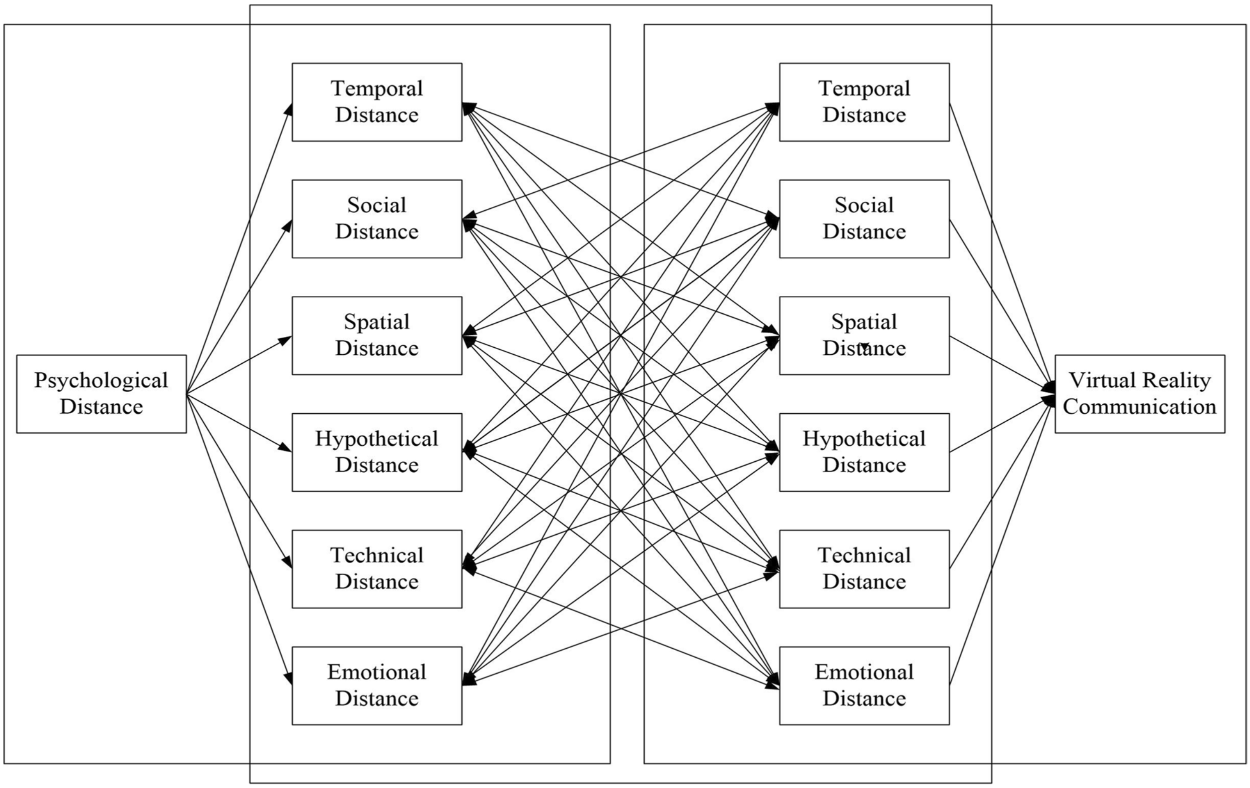

Fig. 2 The F-DEMATEL process framework

Table 1 The factors of psychological distance

Factor	Description
Temporal distance	The time during which an event is perceived to be likely to occur
Social distance	The closeness between the individual and others who influence their VR usage behaviour
Spatial distance	The likelihood of the topic of communication occurring in the individual's vicinity
Hypothetical distance	The individual's belief that the object being communicated is real or imaginary
Technical distance	Whether the VR technology can be used aptly by the user
Emotional distance	The individual's emotional affinity towards the subject being communicated

Table 2 The fuzzy linguistic scale for the respondents' evaluations

Linguistic terms	Triangular fuzzy numbers
No influence (N)	(0.000, 0.000, 0.250)
Very low influence (VL)	(0.000, 0.250, 0.500)
Low influence (L)	(0.250, 0.500, 0.750)
High influence (H)	(0.500, 0.750, 1.000)
Very high influence (VH)	(0.750, 1.000, 1.000)

$$Z^k = \begin{bmatrix} 0 & Z_{12}^k & \cdots & Z_{1n}^k \\ Z_{21}^k & 0 & \cdots & Z_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ Z_{n1}^k & Z_{n2}^k & \cdots & 0 \end{bmatrix}; k = 1, 2, \ldots, p \ldots \tag{1}$$

where $Z_{ij}^k = (L_{ij}^k, M_{ij}^k, U_{ij}^k)$, $\mathrm{n} = p$

The combined average direct relation matrix for all respondents is obtained as follows:

$$A = \frac{1}{p}\left(\sum\nolimits_{k=1}^{P} Z^k\right) k = 1, 2, \ldots, p \ldots \tag{2}$$

where $\sum_{k=1}^{P} Z^k = \sum_{k=1}^{P} L^k, \sum_{k=1}^{P} M^k, \sum_{k=1}^{P} U^k$.

Step 4: Normalize the direct-relation fuzzy matrix.

To normalize the direct relation matrix, the most significant values element in the initial direct relation matrix is obtained

$$\mathrm{as} r^k = \max_{1 \le i \le n}\left(\sum\nolimits_{j=1}^{n} u_{ij}^k\right) k = 1, 2, \ldots, p \ldots \tag{3}$$

Thereafter, the normalized direct relation fuzzy matrix X^k is obtained by dividing each element of the average direct relation matrix by the highest value of the sum of the matrix's rows and columns (r^k). Thus, the normalized direct relation matrix is obtained as follows.

$$X^K = \begin{bmatrix} X_{11}^K & X_{12}^k & \cdots & X_{1n}^k \\ X_{21}^k & X_{22}^k & \cdots & X_{2n}^k \\ \vdots & \vdots & \ddots & \vdots \\ X_{n1}^k & X_{n2}^k & \cdots & X_{nn}^k \end{bmatrix} k = 1, 2, \ldots, p \ldots \tag{4}$$

$$\mathrm{where} X_{ij}^k = \left(L_{ij}^k, M_{ij}^k, U_{ij}^k\right) = \left(\frac{Z_{ij}^k}{r^k}\right) = \left(\frac{L_{ij}^k}{r^k}, \frac{M_{ij}^k}{r^k}, \frac{U_{ij}^k}{r^k}\right).$$

Step 5: Obtaining the fuzzy total relation matrix

To compute the fuzzy total relation matrix, $\lim\limits_{w \to \infty} X^w$ must first be obtained. X^w represents the triangular fuzzy matrix, which can be expressed as:

$$X^w = \begin{bmatrix} 0 & x_{12}^w & \cdots & x_{1n}^w \\ x_{21}^w & 0 & \cdots & x_{2n}^w \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1}^w & x_{n2}^w & \cdots & 0 \end{bmatrix}, \text{ where } x_{ij}^w = \left(L_{ij}^w, M_{ij}^w, U_{ij}^w\right)$$

and.

$$L_{ij}^w = \begin{bmatrix} 0 & L_{12}^w & \cdots & L_{1n}^w \\ L_{21}^w & 0 & \cdots & L_{2n}^w \\ \vdots & \vdots & \ddots & \vdots \\ L_{n1}^w & L_{n2}^w & \cdots & 0 \end{bmatrix}, M_{ij}^w = \begin{bmatrix} 0 & M_{12}^w & \cdots & M_{1n}^w \\ M_{21}^w & 0 & \cdots & M_{2n}^w \\ \vdots & \vdots & \ddots & \vdots \\ M_{n1}^w & M_{n2}^w & \cdots & 0 \end{bmatrix} \text{ and}$$

$$U_{ij}^w = \begin{bmatrix} 0 & U_{12}^w & \cdots & U_{1n}^w \\ U_{21}^w & 0 & \cdots & U_{2n}^w \\ \vdots & \vdots & \ddots & \vdots \\ U_{n1}^w & U_{n2}^w & \cdots & 0 \end{bmatrix}$$

These three matrices can be ordered as$L_{ij}^w = X_L^w, M_{ij}^w = X_M^w, U_U^w = X_U^w$. If $\lim\limits_{w \to \infty} X^w = 0$ and $\lim\limits_{w \to \infty} (1 + X + X^2 + \cdots + X^k) = (1 - X)^{-1}$, where 0 is the zero matrix and I is the identity matrix, the total relation matrix can be expressed as $\mathrm{T} = \lim\limits_{w \to \infty} (X + X^2 + \cdots + X^k) = (1 - X)^{-1}$. Because the X^w matrix comprises matrices$L_{ij}^w, M_{ij}^w, U_{ij}^w$, the fuzzy total relation matrix for the three submatrices can be obtained as follows:

$$T^L = [T^L] = \lim_{c \to \infty} (L + L^2 + \cdots + L^k) = L(1 - L)^{-1} \ldots \tag{5}$$

$$T^M = [T^M] = \lim_{c \to \infty} (M + M^2 + \cdots + M^k) = M(1 - M)^{-1} \ldots \tag{6}$$

$$T^U = [T^U] = \lim_{c\to\infty}(U + U^2 + \cdots + U^k) = U(1-U)^{-1}\ldots \quad (7)$$

Step 6: Obtaining the sum of rows and columns

The sums of the rows and columns are plotted as vectors D_i and R_i. Prominence, the horizontal axis vector $(D_i + R_i)$, is obtained by summing the rows and columns for each factor at the three levels. $D_i - R_i$), the vertical axis vector, is obtained by subtracting the columns from the rows for each factor. The D_i and R_i values have three levels (D_i^L, D_i^M, D_i^U and R_i^L, R_i^M and R_i^U).

$$D_i^* = \sum_{x=1}^{n} T_{ix'} = \left[D_i^L, D_i^M, D_i^U\right]\ldots \quad (8)$$

$$R_i^* = \sum_{y=1}^{n} T_{yj'} = \left[R_i^L, R_i^M, R_i^U\right]\ldots \quad (9)$$

To obtain single values from triangular values, the mean of the triangular values is obtained as follows:

$$D_i + R_i = Mean(D_i^* - R_i^*)\ldots \quad (10)$$

$$D_i - R_i = Mean(D_i^* - R_i^*)\ldots \quad (11)$$

The criteria are then classified into cause-and-effect groups. Factors with positive $D_i + R_i$ values are categorized as causal factors, and those with negative $D_i + R_i$ values are categorized as effect factors. The causal model is obtained by graphing the values of $D_i + R_i$ and $D_i - R_i$.

Sampling

This study recruited experts in VR communication from the Tzu Chi Foundation, an international humanitarian organization founded in 1966 by Dharma Master Cheng Yen. The foundation, dedicated to charitable services, humanitarian values, and community well-being, operates under principles of compassion, relief, and respect for all life. Its activities include disaster relief, medical aid, environmental conservation, and educational initiatives. With a global network of volunteers, Tzu Chi provides aid regardless of ethnicity, nationality, or religion, aiming to alleviate suffering and promote sustainable living.

To participate in the study, individuals needed over ten years of experience in VR communication and a managerial position. Twenty participants met these criteria. All data elements were present, and ratings were within the provided scale, so all collected samples were included in the final analysis.

Results

F-DEMATEL results

The detailed computational procedure of the F-DEMATEL study is shown in the supplementary file. Table 3 indicates the causal effects established by the study. The results indicate that the factors have a similar degree of importance. Emotional distance was the most significant causal factor ($D_i - R_i = 0.9007$), followed by spatial distance ($D_i - R_i = 0.2359$) and social distance ($D_i - R_i =$ 0.0265). Among the effect factors, temporal distance has the highest $D_i - R_i$ value (0.7675), followed by technical distance ($D_i - R_i =$ -0.3587) and hypothetical distance ($D_i - R_i =$ -0.7675).

Figure 3 is the scatter plot of the causal relationship diagram of each factor. The Causal relationship diagrams are essential for visually representing and analyzing interactions within a system, offering several key benefits. They clarify complex systems by illustrating how different factors influence each other, identify key drivers for targeted interventions, and provide insights for prioritizing actions based on causal impacts.

Discussion of the F-DEMATEL results

The results showed that emotional distance is a significant causal factor, aligning with the conclusions drawn by prior research regarding the critical role of emotional distance in VR communication [38]. Messages designed to reduce emotional distance exhibit increased retention by recipients, consistent with findings from previous research emphasizing the internalization of emotionally resonant information [17, 37, 49]. Moreover, the study revealed that maintaining low emotional distance contributes to achieving temporal, virtual, and technical distance. The

Table 3 Prominence and cause and effect

	Di			Ri			Di + Ri	Di-Ri
TmD	0.684	2.257	15.536	0.936	2.748	17.095	13.085	-0.768
SoD	0.916	2.710	17.007	0.915	2.708	16.931	13.729	0.027
SpD	0.942	2.758	17.352	0.898	2.669	16.777	13.799	0.236
HD	0.924	2.717	16.703	0.893	2.668	16.893	13.600	-0.037
TeD	0.749	2.401	16.170	0.905	2.672	16.819	13.239	-0.359
EmD	1.049	2.956	17.561	0.717	2.334	15.813	13.476	0.901

TmD Temporal distance, *SoD* Social distance, *SpD* Spatial distance, *HD* Hypothetical distance, *TeD* Technical distance, *EmD* Emotional distance

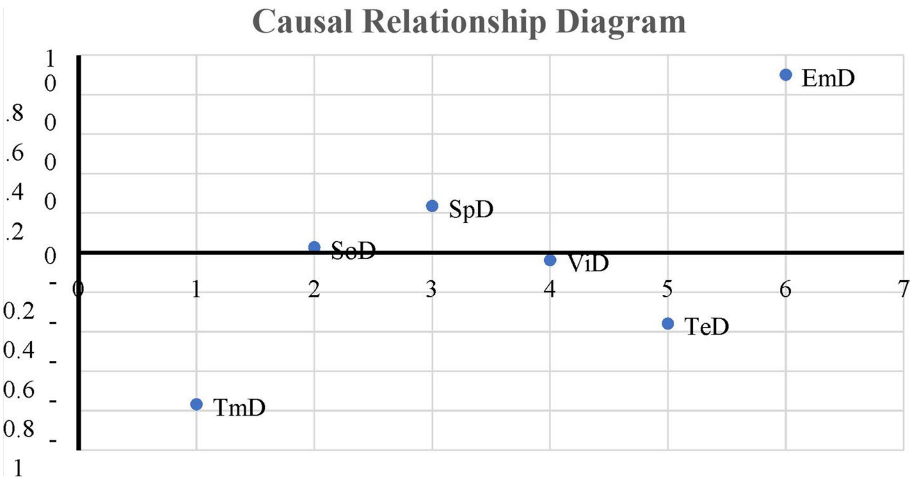

Fig. 3 F-DEMATEL Scatter plot of causal relationship diagram. Note: TmD = Temporal Distance, SoD = Social Distance, SpD = Spatial Distance, HD = Hypothetical Distance, TeD = Technical Distance, EmD = Emotional Distance

results further indicate that addressing spatial distance is crucial for learning effectiveness. This finding concurs with prior research suggesting that individuals are more likely to retain stimuli perceived as likely to occur, emphasizing the importance of ensuring that the message remains connected to the individual's immediate environment [9, 32]. The findings also show that spatial distance has causal effects on temporal, social, visual, and technical distance, indicating that spatial distance can enhance learning effectiveness by ensuring the attainment of these factors. The findings also confirm that social distance is another influential causal factor in the model, indicating that messages fostering a sense of closeness between the individual and the subject of communication enhance learning. This observation aligns with earlier research underscoring the role of social distance in promoting information retention [10]. In addition, the results confirm that social distance enhances learning effectiveness by ensuring the attainment of temporal distance, spatial distance, visual distance, and technical distance.

Furthermore, the results underscore temporal distance as the most significant factor. When health communication successfully reduces emotional, spatial, and social distancing, the audience perceives the issue as requiring urgent attention, enhancing learning effectiveness. Additionally, technical distance and hypothetical distance are identified as noteworthy effect factors. This shows that the technical barriers associated with VR system usage become more navigable when messages effectively minimize emotional, social, and spatial distance. Moreover, when VR health communication messages consider emotional, spatial, and social distance, individuals are more inclined to believe that the communicated subject is likely to experience such communication.

Study 2: Structural equation modeling study

Measurement and sampling

The measurement instruments for the constructs in this study were adapted from existing studies. Specifically, items for measuring temporal distance, spatial distance, and technical distance were sourced from Kim and Lee [10]. Social distance was assessed using items adapted from Cui et al. [73]. Items used to measure hypothetical distance were drawn from Blauza et al. [74], and emotional distance was measured using a scale adapted from Wu et al. [38]. Immersion, flow, and presence were measured utilizing a scale adopted from Shin [30], while perceived learning effectiveness was assessed with items adapted from Kirk-Johnson et al. [75].

The study collected data from individuals in Taiwan who had experience using VR devices for health communication. Back-translation was employed to translate the items into Mandarin Chinese, and a pretest involving 50 participants in ten rounds of five participants each was conducted to validate the translation. The questionnaire underwent modifications based on participant feedback until no further issues were encountered. Subsequently, a pilot study involving 120 participants was carried out to refine the specified model, with 95% of the initial 120 participants included in the final analysis, indicating a 79.17% effectiveness rate. The collected data were subjected to SmartPLS analysis and passed all validity and reliability tests, confirming the readiness of the items for use in the formal study.

The formal survey, conducted among 1104 Taiwanese individuals with experience learning about health issues through VR devices, resulted in 775 responses deemed suitable for final analysis, reflecting a 70.20% validity rate. The demographic distribution of the respondents included 405 males, 656 in the 18–25 age range, 710 with a bachelor's degree, and 106 employed individuals. The demographic data are shown in Table 4.

Data analysis

Common Method Bias (CMB)

To avoid CMB, the measurement items were randomized, and the identities of the respondents were concealed [76]. The study also used Harman's single-factor test with exploratory factor analysis. The variance explained by the first factor was 22.875%, which is less than the recommended threshold of 50% [76]. Furthermore, a multicollinearity test based on the variance inflation factors (VIFs) was conducted in SmartPLS 3.0. The VIFs were below the 3.3 threshold [77]. Thus, CMB was not an issue in this study.

Measurement model

SmartPLS 3.0 was used to perform the confirmatory factor analysis. Convergent validity was assessed by checking the factor loadings, squared multiple correlations (SMCs), and average variance extracted (AVE). The loadings, SMC, and AVE values exceeded the thresholds of 0.5, 0.2, and 0.5, respectively, confirming convergent validity. The Cronbach's alpha for all the constructs was greater than 0.7, confirming reliability. The correlation between every pair of constructs was lower than the square root of the AVE of either of those constructs. Furthermore, all the constructs had HTMT ratios lower than 0.9. These results (see Tables 5 and 6) indicate that discriminant validity was achieved. In addition, all the constructs had composite reliability values higher than 0.7, indicating that the constructs had internal consistency.

SEM results

A two-step analytical approach was utilized because psychological distance was conceptualized as a second-order formative construct based on prior research [77]. While the six distances are conventionally treated as reflective indicators, this study classifies them as formative indicators. This classification is justified because these distances collectively define and construct the latent variable of psychological distance within the context of VR health communication [78]. Each distance contributes uniquely to the construct, and variations in any of the distances can affect the overall perception of psychological distance. Treating these indicators as formative allows for a more nuanced representation of how the distances collectively influence the construct of psychological distance in this specific context.

First, a preliminary factor analysis was conducted to examine the reliability and validity of the model. Thereafter, the latent scores of the subconstructs for psychological distance were used to create the formative psychological distance construct, which was used for hypothesis testing. The coefficients of emotional distance, hypothetical distance, social distance, spatial distance, technical distance, and temporal distance were significant (0.690, 0.234, 0.186, 0.316, 0.150, and 0.247, respectively; $p < 0.001$). The R^2 values for immersion, flow, presence, and perceived learning effectiveness were greater than 0.1 (0.134, 0.258, and 0.785, respectively). However, the R^2 value for presence was 0.002. The Q^2 values for the outcome variables were also higher than the threshold of 0 (immersion = 0.114, flow = 0.127, presence = 0.002, perceived learning effectiveness = 0.612). In addition, the model had a standardized root mean squared residual (SRMR) of 0.038, which is lower than the recommended threshold of 0.08.

The results (Fig. 4, Tables 7 and 8) showed that psychological distance has a negative effect on immersion (β = 0.367, $p < 0.001$, CI = (-0.388, -0.430)), supporting hypothesis 1. The relationship between psychological distance and flow was also significant (β = -0.511, $p < 0.001$,

Table 4 Demographic information

Measures	Groups	Frequency	Percentage (%)	Cumulative %
Gender	Male	405	52.3	52.3
	Female	370	47.3	100.0
Age	18–25	656	84.6	84.6
	26–40	76	9.8	94.5
	41–55	8	1.0	95.5
	56 or more	35	4.5	100.0
Education	Bachelor's degree	710	91.6	91.6
	Postgraduate	65	8.4	100.0
Employment Status	Employed	106	13.7	13.7
	Self-employed	113	14.6	28.3
	Student	556	71.7	100.0

Table 5 Measurement items, loading scores and construct validity

Construct	Item	Factor Loading	Error term	SMC	AVE	CR	α
Temporal distance	TD1	0.930	0.865	0.135	0.898	0.691	0.849
	TD2	0.913	0.834	0.166			
	TD3	0.704	0.496	0.504			
	TD4	0.753	0.567	0.433			
	TD5	*Item removed*					
Social distance	SD1	0.956	0.914	0.086	0.896	0.743	0.824
	SD2	0.872	0.760	0.240			
	SD3	0.745	0.555	0.445			
Spatial distance	*SPD1*	*Item removed*					
	SPD2	0.624	0.389	0.611	0.843	0.647	0.720
	SPD3	0.858	0.736	0.264			
	SPD4	0.903	0.815	0.185			
Hypothetical distance	HD1	0.918	0.843	0.157	0.893	0.738	0.838
	HD2	0.703	0.494	0.506			
	HD3	0.937	0.878	0.122			
Technical distance	TCD1	0.903	0.815	0.185	0.878	0.707	0.792
	TCD2	0.794	0.630	0.370			
	TCD3	*Item removed*					
	TCD4	*Item removed*					
	TCD5	0.822	0.676	0.324			
Emotional distance	ED1	0.903	0.815	0.185	0.883	0.655	0.822
	ED2	0.802	0.643	0.357			
	ED3	0.753	0.567	0.433			
	ED4	0.770	0.593	0.407			
Immersion	IM1	0.915	0.837	0.163	0.949	0.861	0.919
	IM2	0.968	0.937	0.063			
	IM3	0.900	0.810	0.190			
Flow	FL1	0.936	0.876	0.124	0.817	0.608	0.701
	FL2	0.785	0.616	0.384			
	FL3	0.575	0.331	0.669			
Presence	PR1	0.913	0.834	0.166	0.957	0.883	0.932
	PR2	0.912	0.832	0.168			
	PR3	0.991	0.982	0.018			
Perceived learning effectiveness	PLE1	0.777	0.604	0.396	0.937	0.789	0.909
	PLE2	0.877	0.769	0.231			
	PLE3	0.950	0.903	0.098			
	PLE4	0.938	0.880	0.120			

SMC Squared Multiple Correlation, *AVE* Average Variance Extracted, *CR* Composite Reliability

CI = (-0.525, -0.592)), supporting hypothesis 2. However, the relationship between psychological distance and telepresence was nonsignificant (β = -0.053, $p = 0.370$; CI = (-0.044, -0.140)), refuting hypothesis 3. Immersion had a significant and positive effect on perceived learning effectiveness (β = 0.163, $p < 0.001$; CI = (0.110, 0.225)), and presence had a positive and significant effect on perceived learning effectiveness (β = 0.813, $p < 0.001$; CI = (0.754, 0.863)). However, flow did not significantly affect perceived learning effectiveness (β = 0.013, $p = 0.429$, CI = (-0.019, 0.048)). Thus, hypothesis 4a and hypothesis 4c were supported, but hypothesis 4b was not supported. The mediating effect of immersion was also significant (β = 0.-0.060, $p < 0.000$, CI = (-0.077, -0.088)), providing support for hypothesis 5a. However, the mediating effects of flow (β = -0.007, $p < 0.441$; CI = (-0.009, 0.025)) and presence (β = -0.043, $p < 0.369$; CI = (-0.061, 0.113)) were not significant. Thus, hypotheses 5a and 5b were not supported.

Table 6 Correlations of constructs and HTMT ratios

	TD	SD	SPD	HD	TCD	ED	IM	FL	PR	PLE
TD	**0.809**	0.374	0.652	0.623	0.153	0.517	0.097	0.224	0.134	0.173
SD	-0.624	**0.78**	0.405	0.376	0.121	0.12	0.113	0.166	0.161	0.153
SPD	0.319	-0.123	**0.859**	0.74	0.164	0.422	0.091	0.205	0.212	0.212
HD	-0.136	0.417	-0.018	**0.928**	0.069	0.397	0.09	0.206	0.15	0.162
TCD	-0.057	0.165	-0.16	0.459	**0.888**	0.65	0.437	0.185	0.153	0.198
ED	-0.077	0.121	-0.139	0.357	0.572	**0.939**	0.165	0.837	0.096	0.104
IM	0.008	0.114	0.051	-0.062	-0.127	-0.151	**0.862**	0.54	0.384	0.509
FL	0.295	-0.137	0.632	-0.008	-0.178	-0.171	-0.015	**0.804**	0.278	0.278
PR	-0.525	0.318	-0.052	0.371	0.154	0.081	0.025	-0.111	**0.841**	0.937
PLE	-0.437	0.174	-0.521	-0.028	0.166	0.128	-0.097	-0.711	0.128	**0.831**

[a] *TD* Temporal distance, *SD* Social distance, *SPD* Spatial distance, *HD* Hypothetical distance, *TCD* Technical distance, *ED* Emotional distance, *IM* Immersion, *FL* Flow, *PR* Presence, *PLE* Perceived learning effectiveness

[b] Pearson correlations are shown below the diagonal

[c] HTMT ratios are shown above the diagonal

[d] The diagonal indicates the square roots of the AVEs

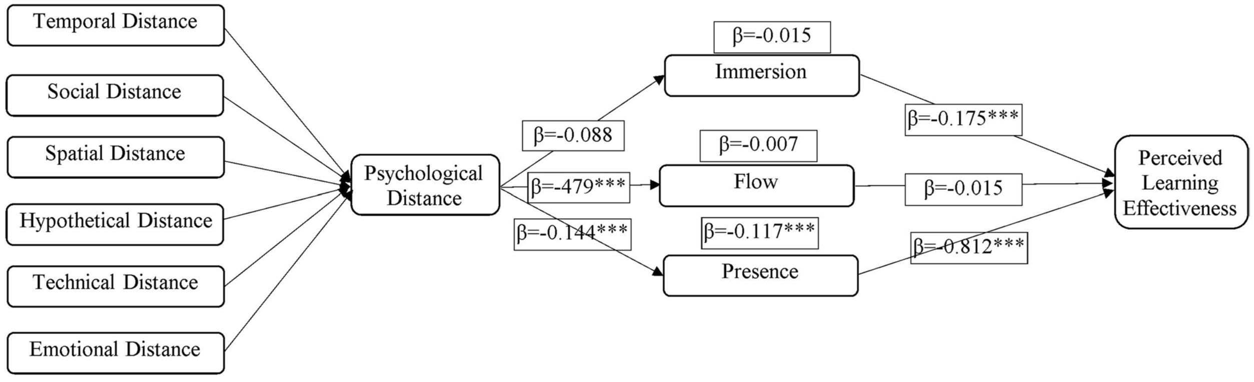

Fig. 4 Path estimates is SEM Model

Table 7 Standardised structural estimates and tests of hypotheses

Hypothesis	Paths	β	T	Result
H1	Psychological distance ➔ Immersion	-0.088	1.653	Not supported
H2	Psychological distance ➔ Flow	-0.479***	16.653	Supported
H3	Psychological distance ➔ Presence	-0.144**	3.366	Supported
H4a	Immersion ➔ Perceived learning effectiveness	0.175***	6.559	Supported
H4b	Flow ➔ Perceived learning effectiveness	0.015	0.629	Not supported
H4c	Presence ➔ Perceived learning effectiveness	0.812***	28.102	Supported

**: $p < 0.01$

***: $p < 0.001$

Discussion

The findings of Study 2 align with our theoretical framework, suggesting that psychological distance has adverse effects on immersion and flow in VR communication, consistent with previous research emphasizing the need to minimize psychological distance in this context [7, 43, 65]. Low psychological distance enhances the realism of virtual environments, immersing users more effectively. Conversely, high psychological distance impedes the attainment and maintenance of flow experiences, as disconnection

Table 8 Mediation results

IV	M	DV	IV → M	M → DV	Indirect	95% CI	Result
PD	IM	PLE	-0.088	0.175***	-0.015	(-0.012, 0.022)	Not supported
PD	FL	PLE	-0.479***	0.015	-0.007	(-0.012, 0.022)	Not supported
PD	PR	PLE	-0.144***	0.812***	-0.117	(-0.012, -0.052)	Supported

PD Psychological Distance, *IM* Immersion, *FL* Flow, *PR* Presence, *PLE* Perceived learning effectiveness

***: $p < 0.001$

from the virtual environment leads to disinterest and a lack of cognitive or behavioral engagement. This underscores the importance of designing VR experiences that reduce the psychological distance to foster deeper immersion and sustained flow, as this can enhance user engagement and the overall effectiveness of VR communication. Interestingly, the study revealed a nonsignificant effect of psychological distance on immersion, inconsistent with the findings of prior research which suggested a positive effect of psychological distance on immersion [66]. This could be attributed to VR technology's ability to create a strong sense of presence and realism. The immersive nature of VR involves multiple sensory modalities and interactivity [65]. This can make distant or hypothetical scenarios feel immediate and engaging, potentially mitigating the effects of psychological distance [60]. Additionally, well-crafted narratives and contextual framing in VR experiences can make users feel connected to the content regardless of its perceived distance [53]. As users become more familiar with VR technology, their ability to immerse themselves in virtual environments improves [52]. This can further reduce the effect of psychological distance, as individuals become more engrossed in the experience regardless of their perceived distance from the virtual world.

Consistent with earlier studies [21, 30, 64], this research affirms the positive effect of immersion on perceived learning effectiveness. Immersing users in lifelike scenarios enhances comprehension by minimizing external distractions and fostering user engagement and focus during learning. By creating a realistic and engaging environment, immersion helps individuals concentrate better on the content. This can lead to improved understanding and retention of information, ensuring effective learning outcomes. The study also establishes a positive impact of presence on perceived learning effectiveness, echoing previous findings that link presence to positive learning outcomes [51, 53, 60]. When users feel a strong sense of "being there" in the virtual environment, their behavioral engagement facilitates effective learning. Nevertheless, the results did not confirm the expected positive effect of flow on perceived learning effectiveness, challenging prior research suggesting a beneficial role of flow in achieving learning outcomes in immersive environments [23, 29]. This finding could be due to the engaging nature of the flow. The intense focus and enjoyment associated with the flow may lead users to become so absorbed in the experience that they need to remember educational content [43]. As such, instead of actively processing and retaining information, users might prioritize the entertaining aspects of the VR experience [43, 51]. Furthermore, VR's novelty and entertainment value can sometimes overshadow educational objectives [23]. When users are highly engaged and enjoy the VR environment, they may focus more on the immersive experience rather than on learning [21, 51].

In addition, the study confirms the mediating role of immersion in the relationship between psychological distance and perceived learning effectiveness. Reduced psychological distance leads to effective learning outcomes by enhancing immersion, as individuals who perceive a low psychological distance become fully engaged in the virtual environment and pay undistracted attention to the content. This engagement and focused attention foster better comprehension and retention of information, further highlighting the critical importance of minimizing psychological distance to optimize learning effectiveness in VR environments. Conversely, the mediating effects of flow and telepresence were nonsignificant, highlighting the intricate nature of the VR learning process. Flow and presence may only sometimes enhance learning, especially if the challenge posed by flow exceeds the individual's skill level or if the VR environment closely mirrors the real environment, potentially triggering suspicions of uncanniness among users [79]. This suggests that while immersion plays a crucial role in enhancing perceived learning effectiveness, the impact of flow and telepresence can vary based on the user's experience and the design of the VR environment. This indicates the need for careful calibration of VR experiences to balance engagement and realism without overwhelming users.

Theoretical implications

This study contributes significantly to the literature on VR communication in several key aspects. First, this study advances our understanding of the psychological factors influencing the effectiveness of VR communication.

While prior studies have focused primarily on the adoption of VR by users [27, 28, 80], the current research addresses the critical need to comprehend how VR devices can be effectively utilized for communication initiatives, particularly in health communication. The findings highlight the pivotal role of psychological distance, demonstrating that emotional, spatial, and social distances are causal factors leading to the effectiveness of VR communication. Moreover, addressing these factors ensures the achievement of effect factors, such as temporal, technical, and hypothetical distances, ultimately contributing to the effectiveness of VR-mediated learning. The structural equation modeling results underscore the importance of low psychological distance, with immersion and presence emerging as key factors in facilitating effective VR-mediated learning.

Second, this study underscores the essential role of user engagement with immersive technologies in facilitating effective learning. Extending findings from other technological contexts, the research establishes that immersion and presence [81, 82], as outcomes of low psychological distance, are instrumental in fostering effective learning in VR. The mediating effect of immersion further emphasizes the centrality of engagement in the VR learning context. However, the findings of this study did not confirm the positive effects of flow on perceived learning effectiveness or the mediating effects of flow and presence. This finding suggested that not all dimensions of engagement necessarily lead to effective learning in VR, in contrast to the findings of studies in other technological contexts that suggest that all three dimensions have a positive influence on communication effectiveness.

Furthermore, this study demonstrated the suitability of the F-DEMATEL method for communication research. Given that communication is shaped by many uncertainties, this method is adaptable and capable of providing insights. The method's strength is handling imprecision and subjectivity, which are common in communication. By combining the structured approach of DEMATEL with fuzzy logic, researchers can use this methodology to quantify the strength and direction of relationships, prioritize influencing factors, and provide a quantitative measure of their impact on communication outcomes. The application of the F-DEMATEL in this study reveals the causal effects of psychological distance elements on various dimensions, demonstrating the effect of psychological distance in shaping learning effectiveness and how these factors interact in shaping VR learning effectiveness. Researchers exploring the complexities of communication dynamics and prioritizing influential factors may find F-DEMATEL a valuable tool.

Practical implications

The findings of this study hold several implications for VR communication practitioners. First, the results underscore the imperative of diminishing psychological distance in virtual communication to enhance effectiveness. Users' perception of the immersive environment as realistic and user friendly is pivotal. Communicators should strive to employ scenarios that are not only realistic but also emotionally compelling, fostering relevance for individuals. This approach and user-friendly VR technologies can effectively reduce psychological distance, optimizing VR-mediated learning.

Another managerial insight is the important role of engagement, particularly immersion and presence, in shaping learning effectiveness. Immersion and presence positively affect perceived learning effectiveness. Managers must consider strategies that enhance immersion and presence to enhance the learning experience. Although this study demonstrated that psychological distance is one way of achieving engagement, other means for boosting engagement, such as focused interactivity of VR systems and individuals' perceived control of their actions during the learning process, could be used to increase immersion and presence. By increasing immersion and presence through these mechanisms, effective learning of health communication messages results.

The nonsignificant effect of flow on perceived learning effectiveness also has important managerial implications. Managers must ensure that the VR learning experience is simple for audiences, which can hinder learning effectiveness. Complex learning processes may not match the skills and abilities of individual users. As a result, users may become frustrated with the learning process, as they may perceive the process to be beyond their ability to keep up with and the content beyond their ability to comprehend. Thus, VR learning practitioners must ensure that the learning process is as simple as possible to ensure that users go through it smoothly with fewer learning hiccups.

Limitations and directions for future research

This study has several limitations that future research could address. First, data were collected at a single time point, so the learning process of users was not monitored over time. Investigating the effects of psychological distance and engagement could offer deeper insights into how individuals retain information from VR over extended periods. Future studies should explore how these factors influence VR learning over time. Second, the study relied on data from Taiwan, where VR usage dynamics may differ due to cultural factors [83].

Future research could apply the study's model in different cultural contexts to better understand cross-cultural differences.

Examining possible moderators in the variables could also help provide a deeper understanding of the antecedents of health communication in VR. As extant research indicates that technology readiness and social influence are among the determinants of technology usage outcomes [52], future research could examine these and other similar constructs as boundary conditions that shape the VR learning process. In addition, given the dynamic nature of VR technologies, the learning outcomes may also vary over time as the technologies improve over time. Changes in technology media used for learning tend to shape users' internalization of information in the usage process. As such, future research could examine the dynamics of VR-learning experiences vis-à-vis continuous changes in VR technologies. Finally, examining moderating variables such as cognitive load, task relevance, and cultural factors could further elucidate the relationships among the constructs in this model [84].

Supplementary Information

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Supplementary Material 1.

Authors' contributions

CHL confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

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Availability of data and materials

All data generated or analyzed in this study have been incorporated into both the published article and the supplementary files.

Declarations

Ethics approval and consent to participate

The requirement for ethical approval was waived by the Ethics Committee of Tzu Chi University because of the retrospective nature of the study.
The informed consent was obtained from all the expert participants.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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