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Enhancing safety education through empathic VR experiences: influences of first-person perspective and Victim's background story

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Introduction: Virtual reality (VR) offers immersive opportunities to enhance safety education, yet the mechanisms through which VR fosters empathy and safety motivation are underexplored. This study examines how perspective (first-person vs. third-person) and narrative context (with vs. without a victim's background story) influence empathy, safety motivation, and attitudes in a VR simulation of a fatal construction accident.

Methods: A 2 × 2 between-subjects experiment was conducted with 160 participants who experienced a VR accident scenario under one of four conditions: first- or third-person perspective, with or without the victim's background story. Participants completed validated and adapted measures of perceived closeness (IOS), state empathy (SES), embodiment, social presence, safety motivation, and attitudes toward construction safety. Direct, indirect, and serial mediation effects were analyzed using t-tests, ANOVA, and Hayes' PROCESS macro.

Results: The results showed that a victim's background story increased perceived closeness and marginally increased empathy, with an indirect effect on safety motivation. While perspective alone did not directly influence empathy, the first-person perspective enhanced participants' sense of embodiment, which in turn increased motivation and fostered social presence, resulting in more positive attitudes toward safety.

Discussion: The findings underscore the significance of emotionally resonant narratives and embodiment in VR training for cultivating empathy and a commitment to safety. The study's results provide insights to inform the design of VR-based safety training programs in the construction industry, highlighting the potential benefits of narrative-driven, immersive experiences in fostering empathy and improving safety education outcomes.

KEYWORDS
construction industry, empathy, safety training, virtual reality, workers' safety

1 Introduction

The construction industry is a high-risk work environment with a significant number of fatalities and injuries. Global statistics indicate that this sector has a disproportionately high rate of accidents and fatalities compared to others. For instance, data from 2019 show that approximately 20% of workplace fatalities in both Japan and the United Kingdom were attributable to the construction industry (Chellappa and Luximon, 2025). In Hong Kong, the construction sector is responsible for approximately 20% of all accidents and over 60% of workplace fatalities (Shafique and Rafiq, 2019). These elevated accident rates can lead to project delays, work disruptions, and substantial financial losses for those involved.

Research suggests that high accident rates are attributable to a lack of proactive measures, including risk identification, safety awareness, training, and education (Wong et al., 2016; Mésároš et al., 2023; Estudillo et al., 2024; Chellappa et al., 2024a). Several studies consistently show that safety education and training are crucial in reducing accidents by addressing these issues (Sacks et al., 2013; Gao et al., 2019; Eiris et al., 2020; Han et al., 2021; Chellappa, 2025). According to Wang et al. (2018), effective safety training helps individuals recognize potential risks in their trades and implement necessary precautions to mitigate them. As a result, researchers in the construction safety domain are increasingly focusing on virtual reality (VR) technology for worker training (Osti et al., 2020; Joshi et al., 2020; Seo et al., 2021; Shringi et al., 2022b; Zhang et al., 2022; Yoo et al., 2023). This shift is based on the argument that traditional training methods, such as hands-on sessions, handouts, toolbox talks, and lectures, are often ineffective in conveying safety knowledge and engaging workers (Chellappa et al., 2024b).

VR is a valuable tool for safety training programs because it effectively conveys safety knowledge and provides immersive, interactive, and visually engaging training experiences (Chellappa, 2025). VR technology enables the simulation of hazardous construction scenarios in a controlled environment, allowing trainees to experience and respond to potential dangers without real-world risks (Zhang et al., 2022). This approach has demonstrated significant advantages in improving hazard recognition, safety compliance, and decision-making skills (Gao et al., 2019; Han et al., 2021). In recent decades, the use of VR in safety training has garnered significant attention from the construction safety research community and numerous construction companies worldwide. For instance, Afzal and Shafiq (2021) evaluated the effectiveness of immersive VR safety training for multilingual construction crews in the UAE, demonstrating improved knowledge retention and behavioral change. Similarly, numerous studies have employed immersive VR to train individuals to recognize hazards and perform safe operations in various construction trades (Getuli et al., 2020; Osti et al., 2020; Seo et al., 2021). Recent meta-analyses confirm that VR training significantly enhances safety performance compared to traditional methods (Yoo et al., 2023), with particular effectiveness in fall-prevention and equipment-operation scenarios (Al-Khiami and Jaeger, 2023). Despite these advancements, current VR safety training often focuses primarily on procedural skills and hazard identification, with limited attention to the psychological and emotional dimensions of safety behavior (Shi et al., 2019; Bhandari et al., 2019). Despite its potential, VR safety training has several limitations that must be addressed. One significant limitation is its narrow focus on procedural skills, often neglecting the development of critical thinking and problem-solving skills (Lucas et al., 2008). For instance, many VR training programs primarily focus on teaching workers to identify hazards and respond to emergencies, but they do not adequately train them to analyze complex situations and make informed decisions (Lucas et al., 2008; Chellappa et al., 2024b). Additionally, current VR training scenarios often lack diversity and comprehensiveness, failing to cover all critical safety issues. For example, some VR training programs may focus primarily on common hazards such as falls and equipment operation, but neglect site-specific hazards and emergency response scenarios (Joshi et al., 2020; Zhang et al., 2022). Furthermore, current VR safety training often overlooks the critical role of emotional engagement and social factors in sustaining safety compliance (Han, 2012; Herrera and Bailenson, 2021). For instance, while immersive experiences can enhance technical skills, they may fail to adequately address the emotional and social aspects that contribute to a safety culture (Ho and Wong, 2026). Additionally, many existing VR programs may not fully account for individual differences in emotional responses, which can affect training effectiveness (Lucas et al., 2008). According to Ho and Ng (2022), safety training programs should not only focus on teaching workers what to do in emergencies but also on how to manage their emotions and behaviors in high-stress situations. The lack of robust narratives or psychological engagement can lead to superficial learning and diminished retention of safety principles (Ho and Ng, 2022; Al-Khiami and Jaeger, 2023). By neglecting these aspects, VR safety training may be less effective at promoting a safety-first culture. Therefore, VR safety training programs should prioritize the development of emotional intelligence and resilience alongside procedural skills.

Empathy is a critical component of effective safety training, enabling individuals to understand and connect with the emotional and physical consequences of unsafe practices. Empathetic experiences are situations or activities designed to evoke empathy, allowing individuals to connect emotionally with others' experiences (Brinck, 2017). In an industry where teamwork and communication are vital, empathy plays a crucial role in promoting a shared responsibility for safety among workers. In training contexts, these experiences can immerse participants in scenarios, fostering a deeper emotional connection to practices and encouraging more responsible actions (Hurissa et al., 2023). By immersing participants in realistic scenarios, these experiences encourage workers to internalize safety protocols and adopt more accountable behaviors (Herrera and Bailenson, 2021). This emotional engagement creates "safety ownership" - the psychological shift where workers transition from compliance to genuine commitment (Zohar and Polachek, 2014). Given this context, the study aims to investigate the use of VR to create an empathic experience, specifically through a VR-based simulation of witnessing an accident, and to examine its impact on enhancing construction safety education. The following objectives were created to achieve the aim of the study:

- To assess the impact of a victim's background story on perceived closeness and empathy in VR training.
- To evaluate the influence of perspective (first-person vs. third-person) on participants' sense of embodiment and safety motivation.
- To investigate how the interplay of narrative richness and perspective affects participants' safety attitudes.
- To explore the implications of VR training on emotional engagement and psychological dimensions in safety education.

By prioritizing empathy, this research aims to revolutionize safety training, fostering a culture that emphasizes emotional intelligence and behavioral transformation, thereby significantly reducing accidents and creating a safer work environment.

2 Literature review

2.1 Empathy

Empathy is widely recognized as the ability to understand and connect with others' emotional experiences (Wispé, 1986). It allows individuals to adopt another person's perspective, fostering a deep sense of connection by enabling them to see, feel, and share in that person's emotions and experiences. Eisenberg and Strayer (1987) and Kaukiainen et al. (1999) suggest a strong connection between empathy and prosocial behavior, indicating that individuals with higher empathy are more likely to engage in positive social actions. Conversely, those who lack empathy may struggle to relate to others, potentially leading to apathy, aggression, and antisocial behavior (Mayer et al., 2018).

Bodenhorn and Starkey (2005) emphasize two types of empathy in mental health: affective empathy and cognitive empathy. Cognitive empathy involves understanding another person's circumstances through rational thought and the ability to take their perspective (Goodhew and Edwards, 2021). It is developed through intentional reasoning and reflective engagement, allowing individuals to grasp the intellectual aspects of another's experience (Ho and Ng, 2022). Affective empathy, on the other hand, is based on emotional resonance. It involves instinctively feeling and sharing another person's emotions, facilitating a deeper, more intuitive connection with their emotional state (Thompson et al., 2021).

According to Sulzer et al. (2016), empathy is an adaptive process significantly influenced by situational factors, making it highly context-dependent. To enhance empathy, various interventions have been created that utilize tools such as role-playing exercises, videos, and images (Shea and Barney, 2015; Kral et al., 2018). These methods encourage individuals to imagine and understand others' emotions, helping them step into another's shoes. However, traditional methods may not fully engage individuals in others' emotional experiences (Khukalenko and Khanolainen, 2025). They often lack realism and fail to capture the complexities of real-life interactions (Jiang et al., 2024). Additionally, they can be resource-intensive, limiting their accessibility and scalability (Khukalenko and Khanolainen, 2025).

2.2 Empathy and virtual reality

VR interventions have been developed to promote empathy more effectively, overcoming the challenges and limitations of traditional methods (Guan et al., 2024). VR offers an immersive and interactive experience that can simulate real-life situations. It allows individuals to feel immersed in the environment and elicits stronger emotional responses. Herrera et al. (2018) found that VR intervention had a significantly higher mean score of empathy (5.29, 4.9, 4.87, 4.99) compared to traditional intervention (4.8, 4.57, 4.53, 4.43) over an 8-week period, suggesting that VR is a more effective tool for enhancing empathy than traditional methods. Presence and embodiment in VR have been shown to positively affect the development of empathy. Studies have found that presence, particularly co-presence, can increase cognitive and affective empathy (Cummings et al., 2021; Jiang et al., 2024). For example, Sundar et al. (2017) revealed that immersive storytelling through 360° video elicits a stronger sense of presence, greater credibility, and more profound emotional empathy than traditional text-based storytelling accompanied by images. Additionally, self-location and co-presence have been found to influence affective empathy, while co-presence impacts cognitive empathy (Jiang et al., 2024). In contrast, the illusions of embodiment, body ownership, and agency have been found to drive the development of empathy (Van Loon et al., 2018). Studies have demonstrated that interactive experiences can foster greater empathy development, highlighting the enhanced empathetic benefits of immersive and engaging experiences (Barbot and Kaufman, 2020; Bacca-Acosta et al., 2023). For instance, Rosenberg et al. (2013) found that VR embodiment experiences can increase empathy by allowing individuals to adopt different perspectives. Jiang et al. (2024) categorized three primary facets of VR's role in empathy training: immersive realism, personalized simulation, and interactive responsiveness. Based on these, several researchers from various domains have proposed the development of "empathy machines" that incorporate multiple components, such as meaningful interactions, high levels of presence, embodiment experiences, perspective-taking tasks, and intergroup contact to foster empathy (Rosenberg et al., 2013; Slater and Sanchez-Vives, 2016; Herrera et al., 2018; Tassinari et al., 2022; Ho and Ng, 2022).

2.3 Empathy and VR-based safety training in construction

The advent of cutting-edge technologies has made VR a valuable asset in the construction industry over the past few decades, particularly for safety training programs. Zhang et al. (2022) highlighted that a significant advantage of adopting VR for safety training is its capacity to replicate real-world scenarios, enabling trainees to experience and practice responding to high-risk situations safely. Along the same line, several studies have widely acknowledged the effectiveness of VR-based safety training programs in facilitating workers' safety knowledge, hazard identification skills, and safety awareness (Guo et al., 2016; Adami et al., 2022; Mésároš et al., 2023; Chellappa et al., 2024b). For instance, Rokooei et al. (2022) demonstrated the potential of VR to enhance safety training in the roofing industry. Their findings indicated that roofing professionals favored using VR technology for this purpose and suggested that VR could be a valuable complementary tool to boost safety awareness and engagement. Similarly, Shringi et al. (2022a) introduced a framework for context-aware safety training, aiming to enhance situational awareness among tower crane operators.

Nykänen et al. (2020) found that VR-based safety training had a greater impact on enhancing safety motivation and promoting self-reported safety behaviors than traditional lecture-based safety training. According to Burke et al. (2011), incorporating realistic hazardous scenarios into VR-based training programs can significantly enhance the effectiveness of engaging training methods. Burke et al. (2011) suggest that when workers experience an emotional response to potential threats, this response can serve as a powerful motivator, encouraging them to

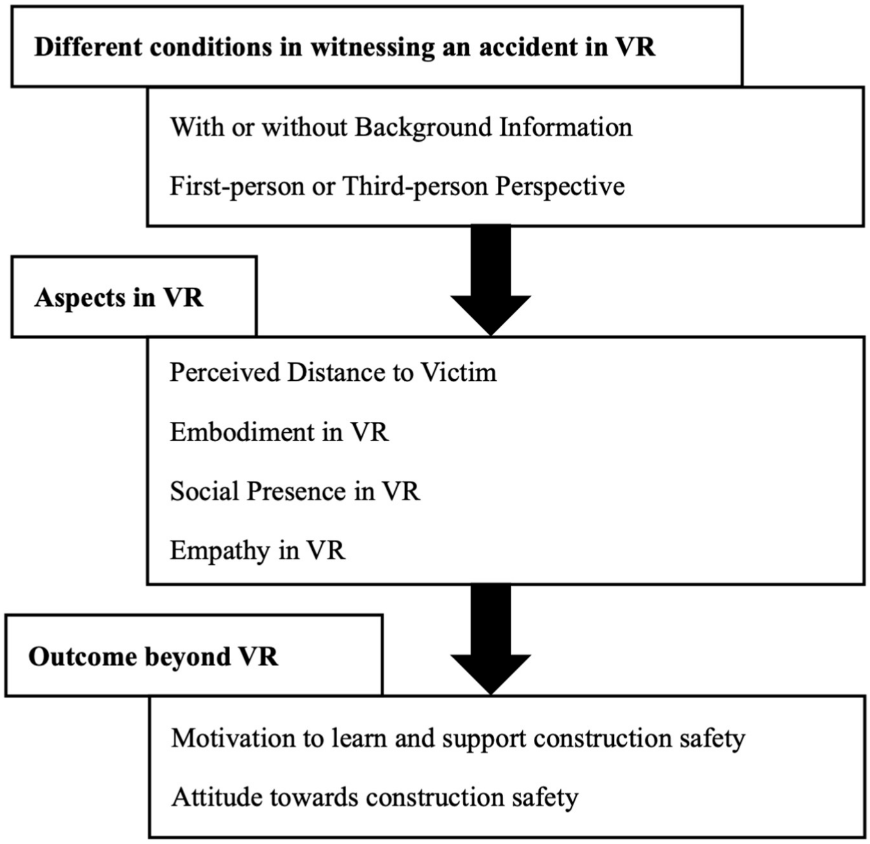

FIGURE 1
Theoretical model.

learn about hazards and develop avoidance strategies. Bhandari et al. (2019) found that naturalistic injury simulation (NIS), which involves the demonstration of realistic injuries, can elicit negative emotions and increase interest in safety information among young and novice construction workers. Shi et al. (2019) found that observing the negative consequences of others' risky behaviors through VR simulations can influence an individual's behavior when performing similar tasks, potentially due to the emotional impact of witnessing the consequences. While existing research has explored how emotions can motivate individuals to learn about safety, there is a gap in understanding how empathy, triggered by witnessing or experiencing an accident in VR, influences an individual's motivation to learn about safety. According to Han (2012), witnessing or experiencing a workplace accident can evoke strong emotional and psychological responses. However, processing these emotions through simulated experiences can foster empathy and potentially strengthen trainees' attitudes toward safety.

3 Current study

Despite advancements in VR applications for empathy and safety training, significant research gaps persist. The specific mechanisms by which factors such as narrative context and perspective affect empathy in construction settings remain underexplored. Moreover, previous studies often focus on general outcomes, neglecting to investigate how these elements influence empathy and motivation in safety training contexts. The existing literature also shows limited integration of emotional engagement with practical safety behaviors, and the pathway from empathy elicited by VR experiences to actual changes in safety behavior is poorly defined (Ho and Wong, 2026). Empathy, a critical component of effective safety training, is often neglected in traditional methods; however, VR has the potential to address this gap. By helping individuals understand and connect with the emotional and physical consequences of unsafe practices, empathy leads to more responsible behavior. Therefore, this study aims to explore the influence of witnessing an accident in VR, specifically examining how adopting a first-person perspective and exposure to the victim's background story affect individuals' motivation and attitudes toward construction safety. The theoretical model, illustrated in Figure 1, guides this investigation and seeks to address research gaps in the existing literature, including limited attention to the psychological and emotional dimensions of safety behavior, a narrow focus on individual immersion, and a lack of understanding of empathy in safety training.

In VR, individuals can witness accidents in at least two distinct ways: as a colleague (first-person perspective) or as an observer (third-person perspective). This distinction raises an intriguing question: how does witnessing an accident involving a coworker affect empathy compared with observing it from an outsider's perspective? According to empathy theory, individuals tend to feel more connected to and responsible for the victim when they can relate to the victim (Davis, 1983). As discussed earlier, empathy in VR refers to individuals' emotional and cognitive engagement with the narrative experience in VR (Ho and Ng, 2022). From a first-person perspective, the trainee assumes the role of the worker, making the victim a colleague. Conversely, the victim is perceived as a stranger when observed from a third-person perspective. This perspective-taking effect is supported by social presence theory, which suggests that users' sense of presence in a virtual environment influences their emotional and cognitive responses (Biocca et al., 2003). Therefore, the researchers hypothesize that:

- *H1: Trainees' empathy in a VR accident will be greater when witnessed from a first-person perspective than from a third-person perspective.*

The study also examined the importance of the victim's background. Traditional safety training videos often depict accidents involving strangers (Chellappa et al., 2024b); however, the impact is significantly greater when the victim is a close friend or coworker. However, it is challenging for trainees to form bonds with virtual characters. According to narrative transportation theory, a rich background story can increase empathy by creating a more immersive and engaging experience (Green and Appel, 2024). To address this, our study examines how providing a rich background story can illustrate close relationships between the victim and their co-workers. Background stories can offer valuable context, helping trainees better understand the victim. This narrative effect is supported by cognitive processing theory, which suggests that the narrative structure and content influence users' mental and emotional responses (Gerrig, 2018). Thus, it was proposed that:

- *H2: Trainees' empathy in a VR accident will be higher when exposed to the background story before the accident, compared to when they are not.*

Furthermore, the researchers hypothesize that the first-person perspective may enhance the effect of the background story on empathy. This interaction is theoretically supported by the concept of embodied simulation (Gallese, 2005), which posits that the combination of narrative immersion and embodied perspective maximizes emotional engagement. When trainees both "know" the victim (through a background story) and "stand in the shoes" of a colleague (through a first-person perspective), the mechanisms of empathy—such as perspective-taking, emotional contagion, and personal distress—are most strongly activated (Decety and Lamm, 2006). If the trainee witnesses the accident as a co-worker, the influence of the background story on empathy will be amplified:

- *H3: The impact of the background story on empathy will be greater when the accident is witnessed from a first-person perspective than from a third-person perspective.*

The researchers also expect that the effects of the background story and first-person perspective will extend beyond VR, influencing trainee motivation and attitudes toward construction safety. The link between empathy and motivation/attitude change is robustly supported by the Theory of Planned Behavior (Ajzen, 1991) and the Empathy-Altruism Hypothesis (Batson et al., 1991). When individuals experience empathy, they are more likely to develop prosocial attitudes and intentions, such as supporting safety initiatives or adopting safer behaviors. In safety training, emotional engagement with the consequences of unsafe acts (through empathy) increases perceived safety importance and motivation to act accordingly. Thus, both the background story and the first-person perspective are theorized to enhance motivation and attitudes by influencing empathy. Specifically:

- *H4a: The background story will positively affect trainees' motivation to learn about and support construction safety, with empathy serving as a mediator of this effect.*
- *H4b: The background story will positively affect trainees' attitudes toward construction safety, with empathy serving as a mediator of this effect.*
- *H5a: The first-person perspective will positively affect trainees' motivation to learn about and support construction safety compared to the third-person perspective, with empathy serving as a mediator of this effect.*
- *H5b: The first-person perspective will positively affect trainees' attitudes toward construction safety compared to the third-person perspective, with empathy serving as a mediator of this effect.*

Additionally, the researchers explored the mediating roles of psychological factors in VR: perceived distance to the virtual character (IOSVic), embodiment (Embod), and social presence (SoPre). First, the perceived distance to the victim was examined. IOSVic refers to the degree of social intimacy one feels with another person or character, rather than the physical distance between them (Ho and Wong, 2026). Understanding a co-worker's background and witnessing an accident may affect trainees' sense of connection to the victim, even when the victim is a virtual character. The Inclusion of Other in the Self (IOS) model explains that perceived closeness increases empathy and prosocial motivation (Aron et al., 1992). In VR, narrative context (background story) can reduce social distance, making the victim feel more like an "in-group" member, which has been shown to increase empathic concern and willingness to help (Cikara et al., 2011). This perceived distance could influence trainees' empathy and their motivation to support construction safety:

- *H6a: The background story will indirectly affect trainees' empathy by influencing their perceived distance to the victim.*
- *H6b: The background story will indirectly affect motivation to support and learn about construction safety through its effect on perceived distance and empathy.*

Next, embodiment refers to the sense of having a physical body within the VR environment, which increases identification with the avatar and the scenario, thereby enhancing emotional and motivational responses (Kilteni et al., 2012). The first-person perspective is particularly effective at inducing embodiment, leading to stronger internalization of the experience and its lessons (Slater and Sanchez-Vives, 2016). This aspect is relevant, as different perspectives during the accident simulation may influence how trainees embody their roles:

- *H7a: The first-person perspective will indirectly affect attitudes towards construction safety via its effect on trainees' embodiment in VR.*
- *H7b: The first-person perspective will indirectly influence motivation to learn and support construction safety through its effect on embodiment.*

Finally, social presence refers to the perception of being present in a social context, which leads to greater emotional engagement and behavioral intention (Ho and Wong, 2026). This concept is crucial, as trainees interact with multiple virtual characters in a simulated social scenario. According to Oh et al. (2018), a heightened sense of social presence in VR is associated with greater emotional engagement and behavioral intention. When trainees feel "present" with others in the virtual environment, primarily through embodiment and perspective-taking, they are more likely to adopt attitudes and motivations aligned with the training objectives. Thus:

- *H8a: The first-person perspective will indirectly affect attitudes toward construction safety through its influence on embodiment and social presence in VR.*
- *H8b: The first-person perspective will indirectly affect motivation to learn and support construction safety* via *its effect on embodiment and social presence in VR.*

This study presents a novel approach to safety training that highlights the critical role of empathy in promoting responsible behavior. Investigating the psychological and emotional dimensions of safety behavior offers a comprehensive understanding of the effectiveness of VR-based safety training. The study's focus on social presence and embodiment, and its exploration of the effects of narrative context and perspective on empathy and safety motivation, sets it apart from existing research. These novel aspects aim to inform the design of effective VR-based safety training programs that prioritize empathy, emotional engagement, and social presence, ultimately improving safety outcomes.

4 Methodology

This study examined the impact of witnessing a VR simulation of an accident involving a virtual colleague on trainees' motivation to engage in safety education and learning. The researchers followed a 5-step process to create a VR empathy experience. First, the researchers defined clear simulation goals and requirements in the concept phase to ensure alignment with desired outcomes. During the preparation phase, researchers assessed the capabilities and limitations of the VR hardware and software, weighing their pros and cons to inform the development process, which also involved creating virtual training scenarios. During the implementation phase, the researchers fine-tuned the simulation for optimal performance by adjusting visual elements, including shadows, lighting, and graphics settings. The researchers selected a suitable 3D engine framework (Unity) to enhance functionality and overall performance. The virtual environments were designed with a user-centric approach, emphasizing intuitive layouts, interactive features, and clear objectives to enhance usability and accessibility. An immersive ambiance was created to set the desired tone and facilitate realistic interactions with virtual objects. The researchers developed an intuitive interface with clear navigation, progress tracking, and audio cues to enhance immersion. Finally, in the evaluation phase, participants completed a pre- and post-training survey, enabling assessment of the training's effectiveness, as detailed in the subsequent sections.

4.1 Participants

The study participants were recruited from a public university in Hong Kong through a mass email invitation. This choice was made because university students are at a critical stage in their education, during which safety concepts can significantly influence their future professional behavior. The controlled academic environment also facilitates manageable recruitment and logistics. Additionally, students can offer insights into integrating VR interventions into construction safety curricula. While this sample may not fully represent the broader workforce, it serves as a crucial preliminary step in evaluating the efficacy of VR in safety training. To participate in the study, individuals had to meet the following inclusion criteria: (1) they must be native Cantonese speakers; (2) they must be able to read Traditional Chinese; and (3) they must be aged between 18 and 60. This was necessary because the VR application's audio content was in Cantonese, a prevalent language in Hong Kong. Additionally, the text was displayed in Traditional Chinese, which is another of the region's official languages. The participants comprised students across all academic levels, from undergraduate to doctoral programs, as well as staff members. This inclusive approach was deliberately designed to enhance the diversity of perspectives within the sample, thereby facilitating a more comprehensive understanding of the VR experience and its effects on empathy, motivation, and attitudes toward safety. Furthermore, prior VR experience was not a criterion for eligibility, allowing for a broad range of participants to be included. Two participation exclusion criteria were implemented: first, participants with a history of dizziness during VR gaming or viewing VR videos were excluded. Secondly, individuals who had been involved in a construction accident or had a close family member involved in one were also excluded. This second criterion was implemented to avoid reminding participants of their traumatic experiences and causing potential emotional distress, thereby minimizing biases and emotional influences in the study. Upon completion of the experimental procedure, each participant received supermarket coupons valued at 100 Hong Kong dollars (approximately $12.88 USD) as an incentive. The study procedure was reviewed and approved by the Human Subjects Ethics Sub-Committee of the Hong Kong Polytechnic University (reference code: HSEARS20200115004).

4.2 Materials

The VR session began with an introductory training segment to familiarize participants with the VR controllers. Background music was played throughout the session to facilitate sound checks. Participants were presented with a notice board displaying essential instructions. They were instructed to pick up three objects from the table in front of them and place them in the

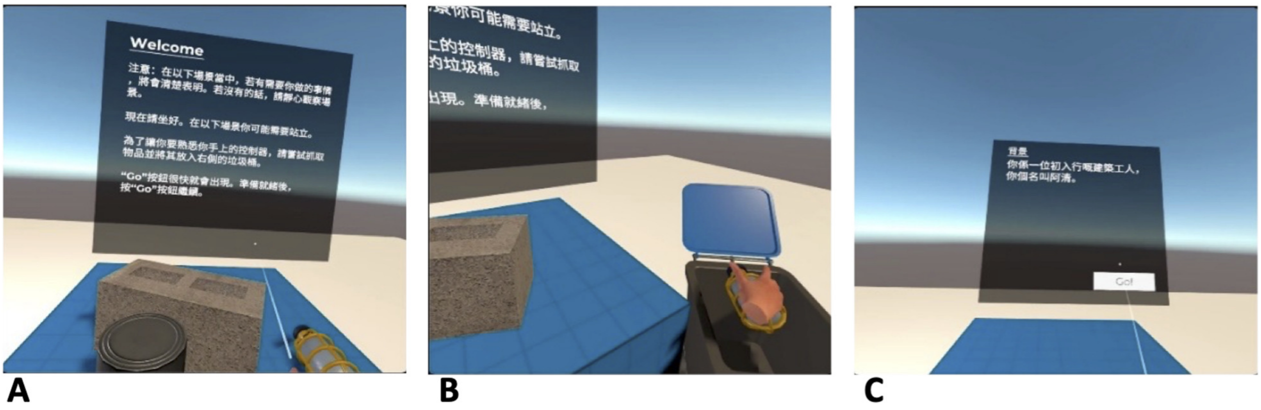

FIGURE 2
Screenshots of the VR introduction training session. **(A)** The welcome message and the training scene; **(B)** the participants had to place the objects into the garbage bin; **(C)** the story background was shown to the participants. For conditions C1 and C3, the story background told the participants they would see the story of a new worker Ah Ching in the following scenes. For conditions C2 and C4, the story background told the participants that they would become Ah Ching.

rubbish bin on their right to proceed. Subsequently, participants were shown a notice outlining the background of the VR experience, including the story context and their roles. The VR scenario consisted of three scenes featuring Ah Wah, Ah Ching, and the Master. Figure 2 presents screenshots from the VR introduction training session.

Scene 1 - The first scene features three construction workers having lunch together in a restaurant on a construction site's ground floor. Ah Wah is seated to the left of Ah Ching, while the Master is to the right. A table in the center holds lunch boxes and beverage cups that participants in conditions C2 and C4 can interact with. To the left of Ah Ching, a radio plays the news. In the scene, the Master casually converses with Ah Wah, inquiring about his son's studies and demonstrating genuine care. Ah Wah comments to Ah Ching that the Master is a rare and wonderful mentor who looks after his juniors. After finishing their meal, Ah Wah and the Master stand up, preparing to begin their work. At this point, Ah Ching stood up for conditions C1 and C3. For conditions C2 and C4, an instruction prompts the participants (as Ah Ching) to stand up and prepare for work. Participants in different conditions were exposed to the scenario with corresponding settings throughout the scene. In conditions C1 and C2 (provided with background story), participants can hear the conversation between Ah Wah and the Master, which provides essential background information about their relationship and Ah Wah's family. In contrast, participants in conditions C3 and C4 (who were not provided with a background story) only heard the radio and missed the conversation. In conditions C1 and C3 (third-person perspective), the participants observed the entire scene, with all three characters interacting with each other, from a third-person perspective, and without interacting with any objects or characters. In conditions C2 and C4 (first-person perspective), the participants could interact with the objects on the table and had to stand up to proceed to the next scene. Figure 3 displays screenshots from VR Scene 1.

Scene 2 - In the second scene, the three construction workers are portrayed working on a higher floor of the building under construction, standing near an elevator with its door open. The Master instructs Ah Ching to press the red button to close the elevator door. In conditions C2 and C4, a panel appeared to teach the participant to press the red button. In conditions C1 and C3, the participants observed the character Ah Ching press the red button. After the door was closed, Ah Wah received a phone call from his wife, who informed him that his father-in-law had been admitted to the hospital. This news compels Ah Wah to finish his work quickly so he can pick up his son from school. In conditions C1 and C2, participants can hear Ah Wah's phone conversation, which reveals the details of this urgent family matter. However, in conditions C3 and C4, participants only hear the radio, leaving them unaware of Ah Wah's pressing situation. In conditions C1 and C3 (third-person perspective), the participants observed the whole scene as all three characters interacted. In conditions C2 and C4 (first-person perspective), the participants adopted Ah Ching's perspective, as viewed by Ah Wah and Master when speaking (Figures 4, 5 show screenshots from VR Scene 2).

Scene 3 - The final scene shows three construction workers working on another floor. Ah Ching stands before a workbench cluttered with various tools and items. Meanwhile, Ah Wah is outside the railing, moving heavy objects. The Master instructs Ah Ching to tidy up the mess on the workbench and place everything inside a wooden box to the left. In conditions C1 and C3, the participants observed Ah Ching tidy up the mess. In conditions C2 and C4, a panel instructed participants to place the items in the wooden box located next to the workbench. After they did so, the scene continued. The Master expresses concern to Ah Ching about the potential danger of Ah Wah crossing over the railing to work and decides to approach Ah Wah directly to address the issue. Tragically, as the Master gets closer to caution Ah Wah, a large cement object falls from above, striking Ah Wah and causing him to collapse on the ground. The VR experiment concludes after the accident, and a notification appears, prompting participants to remove their headsets. In conditions C1 and C3 (third-person perspective), the participants observed the whole scene as the characters interacted. In conditions C2 and C4 (first-person perspective), the participants adopted the

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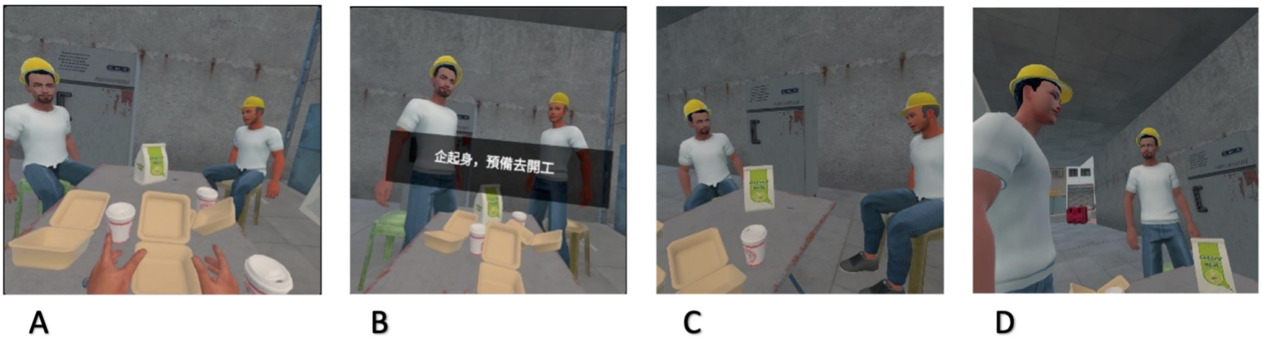

FIGURE 3
Screenshots of the VR scene 1. **(A)** For conditions C2 and C4: the participants embodied Ah Ching, facing Ah Wah and the Master from a first-person; **(B)** a message appeared near the end of the scene instructing the participants to stand up to prepare for work; **(C)** For conditions C1 and C3: the participants observed the scene from a third-person perspective; **(D)** For conditions C1 and C3: near the end of the scene, the participants could see Ah Ching stood up to prepare for work, from a third-person perspective.

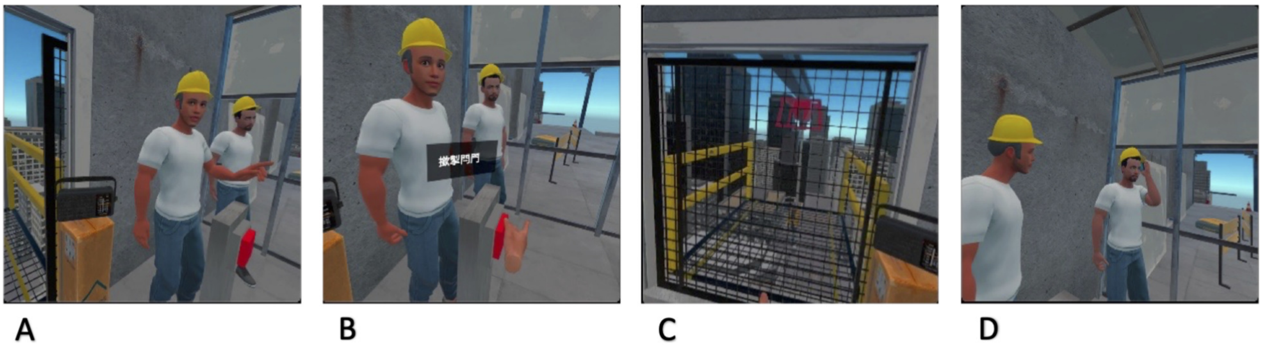

FIGURE 4
Screenshots of the VR scene 2, for first-person perspective conditions, C2 and C4. **(A)** The participants stood next to an elevator with an open door from a first-person perspective, as Ah Ching; **(B)** a message appeared instructing the participants to press the red button to shut the elevator door; **(C)** the elevator door was closed; **(D)** Ah Wah was talking on the phone.

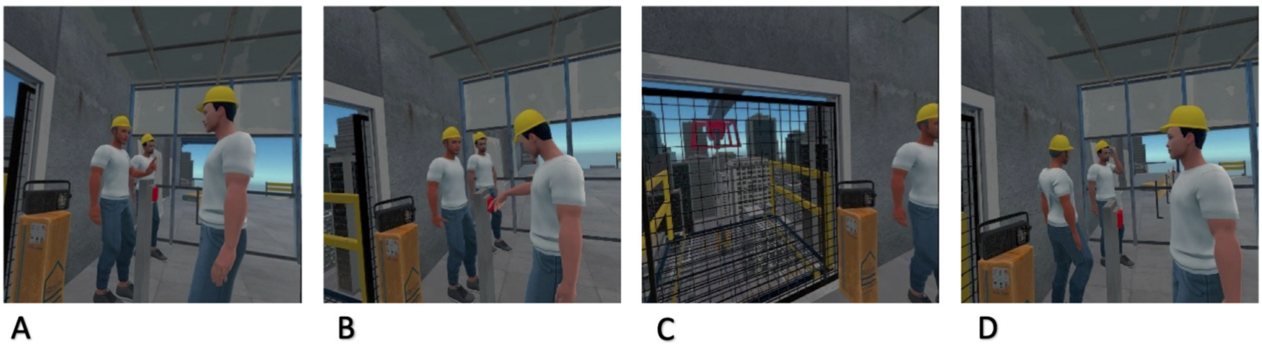

FIGURE 5
Screenshots of VR scene 2, for third-person perspective conditions, C1 and C3. **(A)** The participants stood next to an elevator with an open door from a third-person perspective, as an observer; **(B)** the participants observed Ah Ching listen to the Master's instruction and press the red button; **(C)** the elevator door was closed; **(D)** Ah Wah was talking on the phone.

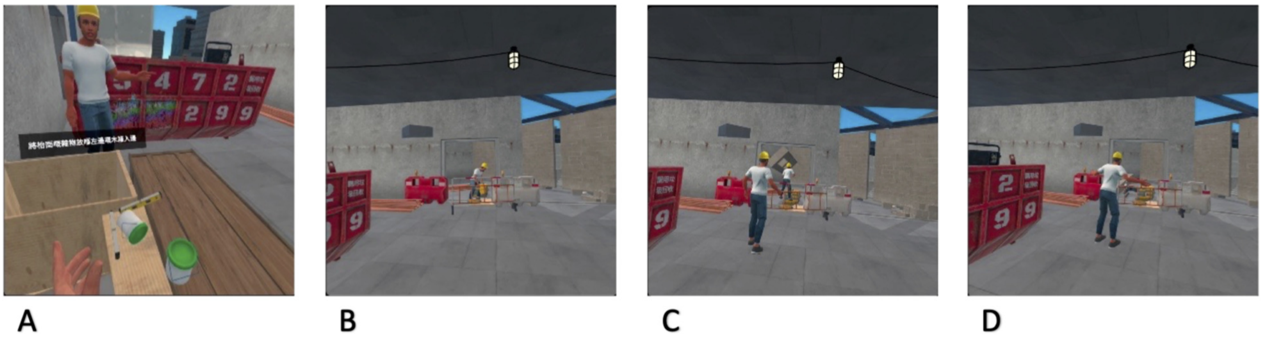

FIGURE 6
Screenshots of the VR scene 3, for first-person perspective conditions, C2, and C4. **(A)** a message appeared instructing the participants to put the objects in the wooden box; **(B)** Ah Wah was moving heavy objects outside the railing; **(C)** the cement object struck Ah Wah when the Master was approaching him; **(D)** Ah Wah collapsed on the ground.

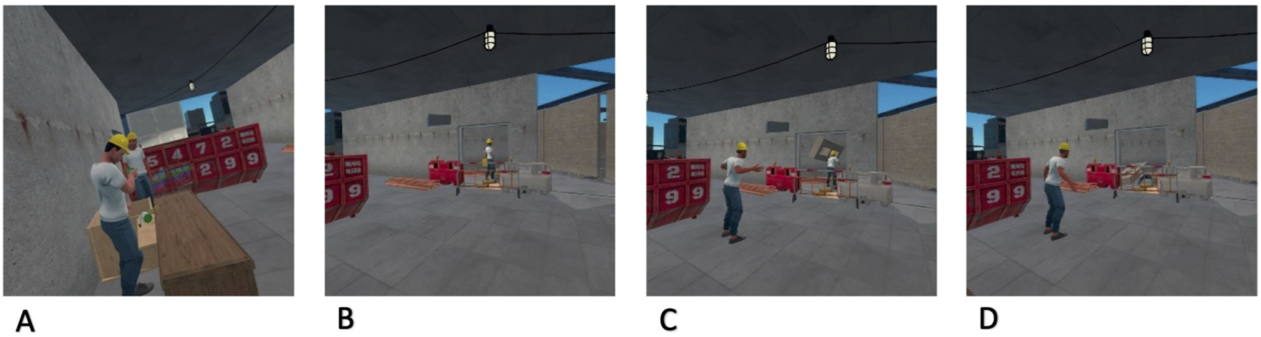

FIGURE 7
Screenshots of the VR scene 3, for third-person perspective conditions, C1 and C3. **(A)** The participants could see Ah Ching listen to the Master and clear the objects on the workbench; **(B)** Ah Wah was moving heavy objects outside the railing; **(C)** the cement object struck Ah Wah when the Master was approaching him; **(D)** Ah Wah collapsed on the ground.

perspective of Ah Ching, whom the Master looked at when speaking—Figures 6, 7 show screenshots from VR Scene 3.

4.3 Experimental design

This study employed a 2 × 2 between-subjects factorial design, featuring two independent variables: FirstPer (comparing First-Person Perspective to Third-Person Perspective) and BgInfo (comparing conditions with background information about the victim to those without such information). Participants were randomly assigned to one of four experimental conditions: condition 1 (C1): the victim's background story provided; participants observed scenarios passively as an observer from a third-person perspective; condition 2 (C2): the victim's background story provided; participants embodied the character Ah Ching and participated in the virtual scenarios from a first-person perspective, condition 3 (C3): no background story; participants observed scenarios as an observer from a third-person perspective, and condition 4 (C4): no background story; participants embodied the character Ah Ching and participated in the scenarios from a first-person perspective. The VR application was designed and developed to immerse participants in relevant VR scenarios.

4.4 Measurements

The measurement employed a comprehensive questionnaire that included self-reported questions to assess participants' perceptions and cognitive responses. The questionnaire was divided into two sections: Part 1 and Part 2. Part 1 focused on gathering background information, including participants' gender, age, education level, prior VR experience, and involvement in the construction industry. Part 2 measured participants' responses to the VR stimulus. It included questions assessing their perceived sense of presence, emotional state, empathy, and feelings of responsibility regarding the accident. To evaluate the perceived closeness between the participant and the virtual victim (Ah Wah), a modified version of the Inclusion of Other in the Self (IOS) scale (Aron et al., 1992) was used. This involved presenting participants with seven illustrations, each depicting two overlapping circles labeled "self" and "Ah Wah." The illustrations varied in the degree of overlap, from the first, which showed completely separate circles, to the seventh, which showed them almost entirely overlapping. Participants selected the illustration that best represented their perceived closeness to the Master. Participants' answers were recorded as a single value ranging from 1 to 7, corresponding to the seven illustrations. This item was referred to as IOSVic in the analysis.

SoPre in the virtual environment and Embod were assessed using three and two questionnaire items, respectively, adapted from measures developed by Gonzalez-Liencres et al. (2020) for the main virtual character, Ah Ching. Empathy was conceptualized as participants' emotional and cognitive engagement with the narrative experience presented in the VR scenario. To measure this, the researchers used the State Empathy Scale (SES; Shen, 2010), originally developed to assess empathy elicited during message processing, particularly in media contexts. The SES is well-suited to VR-based research because it focuses on emotional responses to immersive narratives (Ho and Ng, 2022). The adaptation process involved a thorough review of all 12 items from the original SES. After careful consideration, three items (4, 8, and 12) were excluded because they were deemed not applicable to the first-person perspective conditions examined in this study. For the remaining nine items, the team identified that 7 included the phrase "the character" in their wording. However, directly adopting these items as is could have introduced ambiguity for participants, given that the VR scenarios presented multiple characters. To address this, the researchers replaced the generic "the character" phrase with a specific reference to the witness character, "Ah Ching," who was the central figure observing the construction accident and served as the primary narrative anchor throughout the VR experience. By anchoring the empathy-related items to the witness character, Ah Ching, the researchers maintained consistency in the measurement approach. They ensured that participants' responses reflected a transparent and emotionally salient figure within the narrative.

The motivation toward safety learning and education (Mot) and attitude towards construction safety (AttBI) were measured using self-developed questions. These self-developed items were designed to assess participants' motivation and attitudes toward construction safety, as existing standardized scales did not align directly with our research objectives. The motivation items were designed to capture participants' willingness to learn and engage with safety practices. In contrast, the attitude item assessed their behavioral intention to support construction safety. Participants responded to the measurement items using a 5-point Likert scale, indicating their level of agreement or the intensity of their feelings. Two attention-check questions were included to assess participants' attention and comprehension of the scenarios, to ensure active engagement during the VR experiment, and to confirm awareness that an accident had occurred in the virtual scenario. Furthermore, participants were asked to imagine donating a portion of the 100 HKD supermarket coupon incentive they would receive to support construction safety. They were then asked to specify the amount they would be willing to donate, ranging from 0 HKD to 100 HKD. Participants completed each part of the questionnaire at different stages throughout the session, with each section carefully aligned with the procedural sequence to capture relevant data at specific points in the study. The measurement items used in Part 2 of the questionnaire are provided in the Supplementary material for reference.

4.5 Procedure

The experimental procedure was designed to be structured and systematic, with clearly defined stages that minimized variability and ensured consistency throughout the process. Upon arriving at the experimental venue, each participant received a standardized briefing before the experiment began. This briefing provided a uniform introduction to the study's procedures, ensuring all participants understood what to expect. After the briefing, participants provided their written informed consent and completed Part 1 of a questionnaire. Next, participants were seated and instructed in the use of the VR equipment. They donned the VR headset and initiated the VR experience, which began with a training scene designed to familiarize them with the VR controllers and ensure their comfort with the device. The leading VR scenario consisted of three distinct scenes featuring the same three characters, presented sequentially and in an immersive manner. After completing the VR experience, participants filled out Part 2 of the questionnaire. Afterward, the participants were debriefed and given the supermarket coupons as an incentive. Each participant's entire session lasted approximately 45–60 min.

4.6 Data analysis

The study started with 185 participants. Nineteen participants were excluded due to attentional issues, including incorrect responses to attention-check questions, which compromised data integrity and validity. Furthermore, an additional 6 participants were excluded from the study due to unforeseen disruptions during the experimental procedure. These disruptions were attributed to technical issues with the VR equipment or to unanticipated participant behavior, thereby compromising data quality. Ultimately, the study sample comprised 160 participants (mean age = 29.24 years, SD = 9.55 years), of whom 63.1% were female, 36.3% were male, and 0.6% were unspecified or "prefer not to say", distributed evenly across four experimental conditions: C1 with a mean age of 27.65 years (60% females, 40% males), C2 with a mean age of 26.63 years (65% females, 35% males), C3 with a mean age of 30.18 years (60% females, 37.5% males, 2.5% unspecified or "prefer not to say"), and C4 with a mean age of 32.50 years (67.5% females, 32.5% males).

Inferential statistics, including t-tests and ANOVA, were conducted using IBM SPSS v29 to test the hypotheses. Mediation analyses (indirect effect analyses) were performed using Hayes' PROCESS Macro for SPSS v4.2 (Hayes, 2015). The dependent variables, measured using single-item scales, were IOSVic and AttiBI. In contrast, the dependent variables measured with multiple-item scales included Embod, SoPre, SES, and Mot. Before conducting the statistical tests, the reliability of the multi-item scales was evaluated. The Cronbach's alphas for Embod, SoPre, SES, and Mot were 0.89, 0.64, 0.91, and 0.85, respectively, indicating acceptable reliability levels (Hair et al., 2019; Cheung et al., 2023).

5 Results

The results highlighted complex relationships among background stories, perspective-taking, and psychological

TABLE 1 Results of the main effects of IVs on SES.

Hypothesis	Condition comparison	Mean (M) of SES	Standard deviation (SD) of SES	t-value	p-value	Result
H1	Third-person	3.26	0.87	−1.29	0.20	Not supported
	First-person	3.43	0.79			
H2	Without background story	3.22	0.89	−1.94	0.055	Marginally supported
	With background story	3.47	0.76			

TABLE 2 Results of the 2 × 2 factorial ANOVA testing hypothesis H3.

Hypothesis	Factor 1	Factor 2	F-value	df	p-value	Result
H3	FirstPer	BgInfo	0.05	1, 156	0.83	Not supported

TABLE 3 Results of mediation analysis.

Hypothesis	Model	Predictor	Mediator(s)	Predicted variable	Indirect effect (b)	95% CI	Result
H4a	4	BgInfo	SES	Mot	0.09	[0.0021, 0.2030]	Supported
H4b	4	BgInfo	SES	AttBI	Not sig	[-0.48, 4.31]	Not supported
H5a	4	FirstPer	SES	Mot	Not sig	[-0.03, 0.18]	Not supported
H5b	4	FirstPer	SES	AttBI	Not sig	[-0.71, 3.49]	Not supported
H6a	4	BgInfo	IOSVic	SES	0.10	[0.03, 0.19]	Supported
H6b	6	BgInfo	IOSVic, SES	Mot	0.04	[0.0077, 0.0826]	Supported
H7a	4	FirstPer	Embod	AttBI	Not sig	[−4.09, 8.76]	Not supported
H7b	4	FirstPer	Embod	Mot	0.2	[0.07, 0.37]	Supported
H8a	6	FirstPer	Embod, SoPre	AttBI	2.95	[0.14, 7.31]	Supported
H8b	6	FirstPer	Embod, SoPre	Mot	0.11	[0.03, 0.22]	Supported

mediators. The analysis revealed varied support for the hypotheses, and the results are depicted in Tables 1–3.

5.1 Direct effects

Independent-samples t-tests were conducted to compare the means of SES for Hypotheses H1 and H2. In H1, the means for participants in the third-person perspective (M = 3.26) and those in the first-person perspective (M = 3.43) were compared. The results indicated no significant difference between the two groups ($p = 0.20$), suggesting that H1 was not supported. In H2, the means for conditions with a background story (M = 3.47) and without one (M = 3.22) were compared. This analysis revealed a marginally significant difference ($p = 0.055$), indicating that H2 was marginally supported. Table 1 shows the results of the main effects of IVs on SES. Additionally, H3 was examined using a two-by-two factorial ANOVA to investigate the interaction effect of the FirstPer and BgInfo on the SES. The results revealed a non-significant interaction ($p = 0.83$), indicating that H3 was not supported (see Table 2).

5.2 Indirect effects

H4a examined the indirect effect of BgInfo on Mot via SES. The analysis revealed a marginally significant effect of BgInfo on SES (b = 0.25, p = 0.054), along with a substantial effect of SES on Mot (b = 0.37, p < 0.001). A significant indirect effect was identified (b = 0.09, 95% CI: [0.0021, 0.2030]), thus supporting H4a (see Table 3). In contrast, H4b, which examined the indirect effect of BgInfo on AttBI through SES, found no significant indirect effect (95% CI: [-0.48, 4.31]), thereby failing to support H4b. Similarly, Hypotheses H5a and H5b examined the indirect effects of FirstPer on Mot and AttBI through SES, respectively. The results indicated no significant indirect effects for either hypothesis (H5a: 95% CI: [-0.03, 0.18]; H5b: 95% CI: [-0.71, 3.49]), leading to the conclusion that neither hypothesis was supported (see Table 3).

In H6a, a mediation analysis assessed the indirect effect of BgInfo on SES through IOSVic. The results indicated that BgInfo significantly affected IOSVic (b = 0.81, SE = 0.20, t (158) = 4.02, p < 0.001), and IOSVic significantly impacted SES (b = 0.12, SE = 0.05, t (157) = 2.41, p < 0.05). A significant indirect effect was found (b =

0.10, 95% CI: [0.03, 0.19]) and the direct effect of BgInfo on SES was not significant ($p = 0.26$), thus supporting H6a. Similarly, in H6b, a mediation analysis examined the indirect effect of BgInfo on Mot through IOSVic and SES. The results indicated significant effects for both IOSVic and SES, with an indirect effect of BgInfo on Mot found ($b = 0.04$, 95% CI: [0.0077, 0.0826]). Therefore, Hypothesis H6b was supported.

5.3 Effects of perspective and embodiment

The hypothesis H7 (a,b) focused on the effects of FirstPer on AttBI and Mot through Embod. The results indicated no significant indirect effect on AttBI (95% CI [-4.09, 8.76]), thus not supporting H7a. Conversely, FirstPer was found to have a significant effect of on Embod ($b = 1.08$, $SE = 0.16$, $t(158) = 6.53$, $p < 0.001$) and Embod was found to have a positive effect on Mot ($b = 0.19$, $SE = 0.06$, $t(157) = 3.01$, $p < 0.005$). The significant indirect effect of FirstPer on Mot via Embod was ($b = 0.20$, 95% CI [0.07, 0.37]), supporting H7b.

5.4 Serial mediation effects

Finally, H8 (a,b) examined the serial mediation of FirstPer on AttBI and Mot through Embod and SoPre. The results shows that FirstPer positively affected Embod ($b = 1.08$, $SE = 0.16$, $t(158) = 6.53$, $p < 0.001$), which significantly affected SoPre ($b = 0.39$, $SE = 0.06$, $t(157) = 6.34$, $p < 0.001$). SoPre had a marginally significant effect on AttBI ($b = 6.99$, $SE = 3.67$, $t(156) = 1.90$, $p = 0.06$), leading to a significant indirect effect of FirstPer on AttBI ($b = 2.95$, 95% CI: [0.14, 7.31]), thus supporting H8a. Similarly, H8b was supported, as the mediation analysis indicated that FirstPer had a significant indirect effect on Mot via Embod and SoPre ($b = 0.11$, 95% CI: [0.03, 0.22]).

6 Discussions

This study investigated the impact of an empathy-focused VR intervention simulating a construction accident, presented either in first-person (as a colleague) or third-person (as an observer) perspective, with or without exposure to the victim's background story, on empathy, safety motivation, and safety attitudes. The results reveal distinct pathways through which specific VR design elements influence these outcomes, providing valuable insights for the theory and practice of construction safety training.

The results showed that witnessing the accident from a first-person perspective did not elicit significantly greater empathy than from a third-person perspective (H1). This suggests that occupying the role of a colleague at the accident scene alone is insufficient to elicit greater empathy in this simulated context. The results underscore the necessity for a rich narrative context and personal relevance to elicit effective empathetic engagement. While the first-person perspective is often assumed to enhance emotional engagement, the current study suggests that these effects depend fundamentally on the depth and richness of the narrative and contextual information provided. The absence of significant support for H1 raises critical questions about the underlying assumptions regarding perspective-taking in VR. It implies that immersive experiences alone may be insufficient to foster empathy without a compelling, meaningful narrative framework. However, providing the victim's background story (H2) demonstrated a marginally significant positive effect on empathy ($p = 0.055$). This finding should not be overinterpreted as a definitive effect, but rather as a suggestive trend that warrants further investigation. This aligns with the understanding that empathy is context-dependent (Sulzer et al., 2016) and underscores the fundamental importance of narrative and contextual information in fostering emotional and cognitive connections with virtual characters. Knowledge of Ah Wah's circumstances provided participants with crucial context for understanding his potential motivations and the accident's tragic consequences, thereby enhancing empathetic responses. This finding is consistent with Narrative Transportation Theory (Green and Appel, 2024), which posits that individuals become more emotionally involved and empathetic when immersed in a compelling narrative. The results support the idea that narrative context, rather than perspective alone, is a key driver of empathy in VR, as predicted by the theoretical model.

The mediation analysis (H6a) clarifies this mechanism: the background story significantly increased IOSVic participants' feelings towards Ah Wah. This heightened sense of social intimacy significantly boosted empathy, supporting the notion that establishing a perceived relationship, even with a virtual character, is vital for eliciting empathy (Ho and Ng, 2022). It indicates that VR's potential to induce empathy in safety training depends significantly on its ability to deliver a rich narrative context that bridges the social distance between the trainee and the virtual victim. This finding directly supports the IOS model, which suggests that perceived closeness increases empathy and prosocial motivation (Aron et al., 1992). The results demonstrate that reducing social distance through narrative context effectively activates empathy, as hypothesized. The absence of a significant interaction effect (H3) between perspective and background story further underscores that the background story's positive impact on empathy was evident regardless of the visual perspective adopted during the accident. This suggests that, contrary to predictions from embodied simulation theory (Gallese, 2005), the combination of perspective-taking and narrative context does not necessarily yield additive effects in this setting. Instead, narrative context appears to be the dominant factor, which refines our understanding of how these theoretical mechanisms operate in VR safety training. Future research could examine whether specific narrative structures or character backgrounds enhance the effectiveness of different perspectives in eliciting empathetic responses.

While the first-person perspective did not directly enhance empathy, it had a substantial impact on Embod (H7b). Participants embodying Ah Ching (FirstPer) reported a stronger sense of physical presence and agency in the virtual environment than passive observers. This increased embodiment directly translated into greater motivation to learn about and support construction safety. This suggests that, although empathy may not have been directly influenced, the immersive experience of the first-person perspective fosters a more profound connection, thereby enhancing motivational outcomes. Furthermore, the effect of the background story on safety motivation was mediated by a pathway involving IOSVic, whereby increased empathy, in turn, positively influenced motivation. This highlights empathy as a key affective mechanism that transforms narrative context into a personal drive for safety engagement. Witnessing an accident involving someone they felt closer to and for whom they felt greater empathy motivated participants to engage more strongly with safety. This finding demonstrates the importance of emotional engagement in safety training. When trainees feel empathy for the victim, they are more likely to adopt safer behaviors and support safety initiatives.

A more complex pathway involved the use of a first-person perspective. It significantly increased Embod, which subsequently enhanced the sense of SoPre–the feeling of being socially present with the other virtual characters (Ah Wah, Master) within the environment. This sequential mediation (FirstPer → Embod → SoPre) subsequently led to increased safety motivation and more positive attitudes toward construction safety, as indicated by increased willingness to donate. This highlights the crucial importance of the social dimension of the VR experience facilitated by embodiment. The absence of stronger correlations between empathy and attitudes suggests that while embodiment and social presence play significant roles, other factors—such as individual differences or external contextual variables—could also influence these relationships. Being embodied within the scene alongside other characters and experiencing their social presence amplified the impact of the accident and its context, driving both motivation and a behavioral intention to support safety. This pathway suggests that VR interventions should not only focus on individual immersion but also on fostering social presence and interaction within the virtual environment. Social presence enhances the scenario's realism and emotional impact, making the safety message more compelling and actionable.

The measure of attitudes exhibited less consistent direct and indirect effects compared to motivation. While the serial mediation through embodiment and social presence (H8a) was significant, the direct path from empathy to attitude (H4b) and the mediation solely through embodiment (H7a) were not significant. This inconsistency may suggest that the donation-based measure, while capturing a form of behavioral intention, could be influenced by factors beyond empathy or embodiment alone. Specifically, the findings for H4b indicate that although empathy may influence motivation, it does not necessarily translate into favorable attitudes toward safety. This complexity of attitude change implies that more than empathetic engagement may be required to influence behavioral intention. Furthermore, it suggests that contextual factors—such as participants' prior experiences or ingrained perceptions of safety—may significantly shape attitudes, independent of their empathetic feelings toward the virtual victim. Future investigation is warranted to explore alternative measures more directly aligned with safety attitudes, such as self-reported likelihood of adhering to safety protocols or observable behavioral changes in real-world settings. The significant effect observed only along the entire pathway (Embod → SoPre → AttBI) supports the conclusion that social realism and connection in the scenario were particularly influential for this specific behavioral intention measure. This finding indicates that attitudes toward safety, as measured by willingness to donate, may be shaped by social, emotional, and contextual factors rather than by empathy or embodiment alone. Future research could explore alternative or complementary measures of safety attitudes and behavioral intentions, such as self-reported likelihood of adhering to safety protocols or observed behavioral changes in real-world settings. Future research could explore alternative or complementary measures of safety attitudes and behavioral intentions.

7 Implications

This research makes significant contributions to understanding how VR design elements influence empathy and safety outcomes. Theoretically, it demonstrates that while VR's perspective-taking capability is valuable, a rich background story that fosters perceived closeness to virtual characters is more critical for inducing empathy regarding safety consequences than the visual perspective alone. This challenges assumptions that first-person viewing inherently guarantees a greater emotional connection. Furthermore, the study establishes embodiment (enabled by first-person perspective) as a foundational driver that not only directly increases safety motivation but also facilitates social presence—the feeling of being with virtual co-workers. Notably, this social presence pathway emerged as a potent mediator for both safety motivation and behavioral intentions, underscoring the importance of social realism in VR training beyond visual fidelity. These findings validate and extend concepts of VR as an "empathy machine," emphasizing the synergistic roles of narrative, embodiment, and social interaction.

Practically, the implications of this study are significant for the development of construction safety training programs. It suggests that incorporating VR interventions that emphasize narrative context and immersive experiences can effectively foster greater empathy and motivation among trainees. By designing VR scenarios that incorporate rich background stories and enable trainees to witness accidents from multiple perspectives, training can become more relatable and impactful. Furthermore, emphasizing embodiment and social interaction in these VR experiences can enhance trainees' feelings of social connection, ultimately increasing motivation to prioritize safety. Organizations should also consider integrating comprehensive measures to evaluate both motivation and attitudes toward safety when assessing the effectiveness of VR training. This understanding can help refine training approaches and improve safety outcomes in the construction industry. Lastly, the study opens avenues for future research, suggesting the exploration of alternative measures for attitudes and behavioral intentions in safety contexts, as well as the impact of demographic factors or repeated exposure to VR training.

8 Limitations

Despite the study's significance, several limitations should be acknowledged. First, the sample was drawn from a single university, which may not fully represent the broader construction workforce. This limitation could limit the generalizability of the results, as university students may differ significantly from seasoned professionals in experience, risk perception, and safety attitudes. Such differences could influence emotional and cognitive responses to the VR intervention. For instance, experienced workers might have established safety protocols that vary from those of students new to the field, potentially affecting empathy and motivation to adopt safety practices. Additionally, contextual factors unique to the university environment may not capture the complexities faced by construction workers in diverse settings. Second, the study relied on self-reported measures, which may introduce bias in participants' responses. Third, the absence of long-term follow-up to assess the lasting impact of the VR training on safety behaviors, as it remains unclear whether the observed effects will translate into sustained changes in real-world safety practices. Fourth, questionnaire items used in this study were entirely self-developed, and the researchers acknowledge that this approach may limit the validity and reliability of our findings. Finally, this study primarily measured empathy as the key emotional outcome, which may introduce measurement bias. While the design intentionally incorporated different perspectives and a background story to evoke empathy, relying solely on empathy may overlook other significant emotional factors, such as fear, anxiety, or personal relevance. Measuring a broader range of emotional responses could provide a more comprehensive understanding of how VR interventions affect trainees' overall emotional engagement and safety-related motivations. Therefore, future research should address these limitations by including diverse participant samples, utilizing objective measures of safety behavior, validating the measures, assessing the long-term efficacy of VR training interventions, and incorporating additional emotional metrics to capture the complexity of participants' experiences.

9 Conclusion

To conclude, this study illustrates the significant potential of empathy-focused VR interventions to enhance construction safety training. The study findings demonstrate that the effectiveness of these interventions is influenced by two key factors: perspective-taking and narrative context richness. It is evident that how trainees perceive and engage with the virtual environment can markedly affect their empathetic responses. The results underscore the importance of immersive experiences that cultivate emotional connections with virtual characters. Specifically, the integration of rich background stories enables participants to relate more personally to the scenarios, thereby enhancing their empathetic engagement. This suggests that a well-crafted narrative not only facilitates emotional resonance but also motivates trainees to adopt safer behaviors and attitudes toward safety protocols. By highlighting these dynamics, this research advocates for a more narrative-driven approach in VR safety training programs. Future implementations should prioritize designing immersive environments that not only present realistic situations but also enrich them with compelling storylines. Such a strategy may significantly enhance the effectiveness of safety initiatives in the construction industry, ultimately leading to safer work environments and improved outcomes.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Human Subjects Ethics Sub-Committee of the Hong Kong Polytechnic University (reference code: HSEARS20200115004). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

VC: Visualization, Writing – original draft, Writing – review and editing. JH: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. YL: Supervision, Writing – review and editing.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The author(s) declared that generative AI was used in the creation of this manuscript. Generative AI tools including Copilot and Grammarly were used to improve the language of the manuscript.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2026.1728897/full#supplementary-material

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