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# VR training program for fire escape: Learning progress predicted by the perception of fire presence, VR operational frustration, and gameplay self-efficacy

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ABSTRACT

Most VR fire escape training programs only task learners to observe the procedure of fire escape in different simulated fire scenes. To improve the effectiveness of such training programs for everyone, we tested a "fire escape virtual reality training program" which takes advantage of the feedback on the action to help individuals to learn the necessary and correct steps of fire escape. The virtual program emulates a real fire scene by providing realistic visual and auditory stimuli. A single-group quasi-experimental study was carried out to measure the effectiveness of the program, and a total of 173 seventh- and eighth-grade students from a high school in New Taipei City participated. The results of structural equation modeling showed that 1) gameplay self-efficacy was negatively predicted by frustration, 2) fire presence positively predicted gameplay self-efficacy, and 3) gameplay self-efficacy positively predicted learning progress. The findings suggested that critical life-saving skills such as fire escape skills can be readily acquired and trained through individual virtual reality training programs.

## 1. Introduction

The stimulus–organism–response (S–O–R) model posits that environmental stimuli trigger individuals to subsequently respond (Mehrabian & Russell, 1974). In educational settings, the model points out that creating a particular type of stimulus can lead to desired responses, and individuals can learn from such a process (Lin & Kuo, 2016; Mpinganjira, 2016). However, it is not always easy to offer real stimuli in educational environments when potential risks and dangers with limited resources outweigh the necessity of implementing certain education and training programs, such as learning essential fire-escape knowledge and skills without proper and adequate equipment. Migrating such training programs into immersive virtual reality (VR) systems would be one of the ideal alternatives and might open up another way to understand the S–O–R process to improve the effectiveness of VR programs (Kourouthanassis et al., 2015; Lopatina et al., 2020). Eventually, when the device becomes more affordable, VR objects have the potential to be integrated into virtual programs for users to interact and learn knowledge in a virtual world (Hwang & Chien, 2022; Jaung, 2022).

VR technology is a popular medium that enables immersive environments to be used in a multitude of learning domains (Collins et al., 2021; Goedicke et al., 2018). Moreover, by integrating VR into training programs that teach how to cope with life-threatening incidents (e.g., fires), learners can practice repeatedly to master required knowledge and skills without the risk of incurring costs or triggering accidents that often occur in real-life situations (Song et al., 2021). Furthermore, the S–O–R theory helps researchers model the psychological process and outcomes of learning the knowledge and skills of fire escape via a VR system.

A variety of key indicators have been used to assess users' experience of immersive technology, including presence (Cummings & Bailenson, 2016), engagement (Boyle et al., 2012), and enjoyment (Dey et al., 2018). The achievement emotion theory (Pekrun, 2006) and Makransky et al. (2017, 2020) further conceptualized that learning outcomes in VR settings stem from the simulated presence of stimuli and feedback

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embedded in the VR program along with affective factors, and are mediated by cognitive factors (e.g., self-efficacy). Thus, it is necessary to measure the sense of presence and motion frustration, and further evaluate their impact on user performance (Menin et al., 2022). Accordingly, in the present study, we asked: *How are frustration and the presence of fire influence the learning progress in a VR Fire-Escape program, and how does self-efficacy of game play mediate the aforementioned relationship?*

## 2. Theoretical background

### 2.1. Gameplay self-efficacy

Self-efficacy refers to a belief in one's ability to successfully resolve problems and accomplish tasks in a specific domain (Bandura, 1977). Researchers have identified self-efficacy as a critical precursor of learning outcomes and achievement (Høigaard et al., 2015; Wang & Degol, 2013), including in technology-mediated training programs (Saville & Foster, 2021). Therefore, cultivating learners' self-efficacy should be treated as a core learning objective in educational programs. In addition to retaining learners' attention and concentration, VR further enhances the effectiveness of on-site practice (Tai et al., 2022). In the context of VR modes that vary in terms of their technological sophistication, gameplay self-efficacy in the context of VR may play an important role in improving performance in real-life situations. Thus, we investigated how gameplay self-efficacy (GPSE) when playing VR Fire-Escape was related to the learning outcomes in this study.

### 2.2. Fire presence

Virtual presence determines the user's feeling that the mediated environment is either real or virtual through the user's sensations and actions responsive to their sense of presence (Fox et al., 2009). Presence is defined as "... a human reaction to immersion. Given the same immersive system, different people may experience different levels of presence, and different immersive systems may give rise to the same level presence in different people" (Slater, 2014, p. 2). Furthermore, Steuer (1992) described the concept of virtual presence as "a sense of being physically present with visual, auditory, or force displays generated by a computer" (p. 78). In a virtual environment, presence is a psychological state in which individuals feel or experience *being there*, as if the VR experience was real (Nichols et al., 2000). Successful interactions between individuals and the virtual world largely depend on the conscious experience of the spatial presence (Denzer et al., 2022). Particularly, when users put on a VR headset, they are blocked from stimuli from the outside world. In the current study, the virtual stimuli arguably generated a sense of presence in fire evacuation (Kwegyir-Afful, 2022).

Presence in VR is a technology-induced subjective experience when the individuals are placed in a simulated environment but gain similar experience to interacting with real objects. Individuals experience an increased sense of presence while using VR for training that could cause an increase in their learning efficacy (Ding et al., 2020). Students who are engaged in a high-presence VR environment were found to show more confidence in using VR (Song et al., 2021). It is thus important to study the roles of presence in virtual environment that can vary in different disciplinary contexts (Lim & Richardson, 2022). As such, the present study explored the role of fire presence in VR after players experienced interaction with the VR Fire-Escape program.

### 2.3. Frustration when playing VR fire-escape

Navigation largely relates to wayfinding and travel in virtual environments (Bowman et al., 2001). The former involves planning and following a route, whereas the latter refers to movement from one point to another. In VR, navigation is transformed into the movements that players perform using a designed interface, which also allows them to change their viewpoints and directions, creating a sense of walking (Hale & Stanney, 2014). Nevertheless, if users find it hard to self-propel their movement through the vergence of their eyes, it will affect their interaction performance and may lead to increased visual fatigue and frustration (Iskander et al., 2019). Essentially, this type of frustration affects the cognitive processing of the environmental features and observable behaviors (Maranges et al., 2017). Moreover, other frustration in VR may arise when the experience is not in accordance with the user's daily habits. Therefore, such interaction requires greater mental demand and physical effort (Wu et al., 2021).

According to Lombard and Ditton (1997), frustration stems from the extent to which users cannot manipulate attributes of media, such as a mismatch between users' input and the type of corresponding response or no response at all. In the present study, we treated frustration as an emotional state that can be triggered by VR programs, which in turn may lead to an inaccurate perception, failed operation of technology, and a decreasing self-efficacy in game-play (Pence, 2022; Puente-Díaz & Cavazos-Arroyo, 2016). Previous studies indicated that interacting with objects via VR is complicated; for example, when it is hard to use VR properly to pick up objects virtually, frustration ensues (Calvert & Abadia, 2020). In the task of navigation, it is easy to feel frustrated with the thought that "I was arriving more slowly than expected" (Kim & Rhiu, 2021; Reeves et al., 2021). Similarly, in an empirical study, nursing professionals found VR training programs fun, challenging, and engaging, but they were frustrated with technical issues (e.g., object pick-up; Breitkreuz et al., 2021). However, since most existing literature focus on frustration in training programs, the degree to which players feel frustration when using VR (hereafter, frustration) to learn survival skills in a simulated life-threatening environment, such as fire-escape, has not been discussed; thus, the present study explored the relationship between frustration evoked by our design of VR fire escape program and gameplay self-efficacy.

### 2.4. Learning progress

VR is found to facilitate learning (Wu et al., 2020), but the effectiveness of VR programs may vary by subject matter (Villena-Taranilla et al., 2022). In their review, di Natale et al. (2020) revealed that the usage of VR programs positively influences students' performance and learning motivation, whereas Yang and Goh (2022) found that VR simulation improves motivation for learning, but not the knowledge or perceived effectiveness of the lesson. However, VR can facilitate learning progress (i.e., making sufficient progress that will ensure the culmination of completing the program) if the VR practice increases over time (Buentello-Montoya et al., 2021; Villena-Taranilla et al., 2022; Yang & Goh, 2022). If users can practice repeatedly, their procedural performance can be anchored; thus, VR may allow users to successfully anchor their procedure correctly in virtual contexts (Andreatta & Pauli, 2021). In the context of VR Fire-Escape, how participants used VR as a tool to repeatedly practice to promote their learning progress was explored.

## 3. Research model and hypothesis

### 3.1. Research model

In the present study, we considered both affective (i.e., frustration) and cognitive factors (i.e., gameplay self-efficacy) that influence learning outcomes in VR programs by following Makransky et al.'s (2019) findings. From a motivational perspective (Ryan & Deci, 2017), the two factors can be addressed by providing goals and process feedback (Mouratidis et al., 2013). That is, VR Fire-Escape provides feedback as a procedural response for players to achieve learning effectiveness. This study therefore presented a conceptual framework to explore the correlates between their emotions including frustration when using VR, and the sense of fire presence that affected participants' learning progress through GPSE (see Fig. 1).

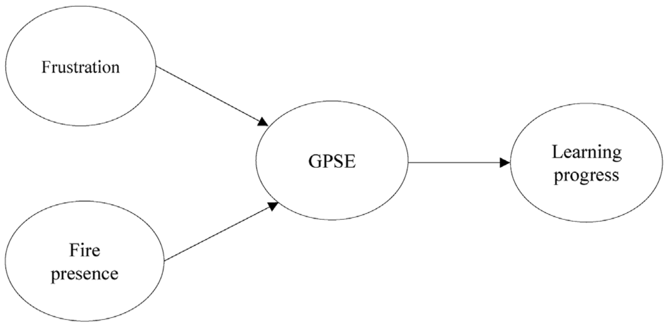


**Fig. 1.** Conceptual model diagram.

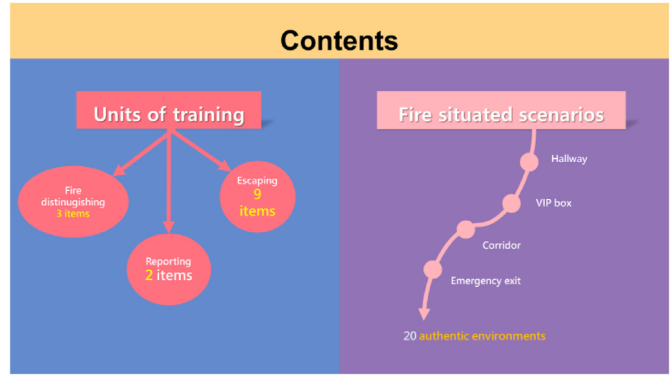


**Fig. 2.** Content of the unit-based and situated training sections.

### 3.2. *Hypotheses*

We followed the Cognitive-Affective Theory of Learning with Media (CATLM; Moreno, 2006) to chart the hypothesized paths in the current research. CATLM posits that multimedia can regulate learners' cognitive and affective processes that influence learning outcomes. Also, following Makransky et al. (2017), cognitive factors (e.g., self-efficacy) can be influenced by affective factors (e.g., frustration). Whereas self-efficacy supports individuals' interactions with virtual environments (Mabry et al., 2020), when individuals operate in environments or contexts where challenges routinely exceed their abilities, frustration may rise and further compromise self-efficacy. Moreover, playing in virtual worlds with learning materials may increase the user's sense of presence and enhance the simulation efficacy (Zuniga Gonzalez et al., 2021). Finally, existing literature indicates that in a learning environment, self-efficacy mediates the relationship between academic performance and learning environment-related perception and affective responses of the learning environment (Høigaard et al., 2015; Llorca et al., 2017). In short, in VR training programs, perceived frustration and presence may cast opposite effects on the learning progress, and such effects may be mediated by gameplay self-efficacy. Therefore, we aimed to explore the relationships between the constructs inherent in VR experience as opposed to the effect of the VR program. We proposed four hypotheses as followed:

1. Frustration when using VR is negatively related to GPSE,
2. Fire presence is positively related to GPSE,
3. GPSE is positively related to learning progress, and
4. Frustration and fire presence are negatively related to learning progress mediated by GPSE.

## 4. VR Fire-Escape program

The VR Fire-Escape program designed in this study focuses on pre-evacuation and evacuation behavior in a fire scene, covering three actions: turning on the fire alarm, distinguishing fire in the pre-evacuation stage, and escaping from the fire scene. The program includes a training mode and an assessment mode. In the training mode, the training content included unit-based training and situated training (see Fig. 2). In the unit-based training part, learners can choose one of the 14 units to master the procedure of 14 different fire responses. In the situated learning section, content from the 14 units were integrated in the 20 situated scenarios for learners to practice. The scene of fire escape was set in a karaoke, since such places are highly popular among high school students in Taiwan for after-school leisure. The training program was considered a game because of the game-like features, such as the rule-governed manipulations, the use of cognitive reasoning under time pressure, and a scoreboard for the ranking of performance that may trigger users to try more practice to top other users (Gomila & Calvo, 2008). An example scenario is shown in Fig. 3. Fig. 4 shows an example of automated feedback if users do not move for a while.

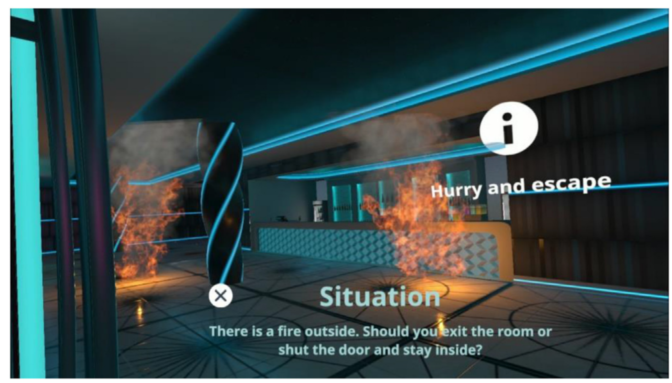


**Fig. 3.** A screenshot of a fire situation. *Note*: In the assessment mode, flame bursts out of a cabinet inside a karaoke room and the user has to run away. The program prompts a series of description of the scene and the user has to choose the right move. If the users got the wrong answer, they will lose some hit points (HP) and would "die" when using up all the HP.


**Fig. 4.** Feedback on the action. *Description of the scene*: You have already run away from the fire, but should you return to the room to pick up something you left in the cabinet? If the users choose to return, the message above will pop out to warn them.

## 5. Methods

### 5.1. *Procedure and participants*

To avoid the Hawthorne effect, a quasi-experimental single group study was adopted in this study. This research course was conducted over a period of 4 weeks. Each participant turned in a completed informed consent signed by one parent or guardian before participation in the study, indicating that participants and at least one of the parents/

guardians were aware that they were taking part in an experimental study and that the data they provided were anonymous. The study was approved by the Research Ethics Committee of National Taiwan Normal University (No. 201812HS020).

Purposive sampling was adopted in this study, and 160 participants from a high school in Northern Taipei provided the data. The sample comprised 150 (93.75%) boys and 10 (6.3%) girls. As for grade level, 117 (73.0%) were from the first year of senior high, 24 (15.0%) were from the second year, and 19 (12%) were from the third year. High school students were chosen as the target population because high school students are more familiar with the karaoke environment to ensure a high level of presence. The spatial presence of life-threatening scene is also more manageable for adolescents than younger children (Baumgartner et al., 2006). In addition, whereas most high school students in Taiwan have learned the fundamentals of fire escape in elementary school, they may had forgotten the related knowledge and skills. A quick review in an immersive mode may help revive the essential knowledge and skills that are deemed necessary for protecting themselves (see below for the effect on re-learning the knowledge and skills of fire escape).

After the study was approved by the research ethics review board, we received the signed informed consent form from one parent or guardian of each participant. Afterward, we adopted the following three-phase protocol to complete the study (see Fig. 5 for the flowchart):

Phase 1: When the program starts, the participants completed a tutorial that familiarizes them with the features and control of VR.

Phase 2: In three weeks, the participants completed the unit-based and situated training in the VR program for 20 minutes every day.

Phase 3: After completion, all participants filled out the survey questionnaire to measure the perceived frustration, presence, GPSE, and the knowledge of fire escape.

### 5.2. Instrument

#### 5.2.1. Questionnaire

We consulted relevant literature when developing the survey questionnaire. Three experts were invited to validate the accuracy of the translation of items. Afterward, we conducted cognitive interviews with 10 students to ensure face validity. All items were measured by a 5-point Likert-type scale (1 = *strongly disagree*, 5 = *strongly agree*). The psychometric properties and sample items of each scale measurement are described below:

*5.2.1.1. Gameplay self-efficacy (GPSE).* Self-efficacy is a judgment of one's confidence in the domain-specific ability to successfully complete a task (Bandura, 1977). The gameplay self-efficacy scale used in this study was modified from Hong et al.'s (2023) gameplay self-efficacy scale. Six items were designed. Example items are: "I was good at moving the VR device smoothly," "It was easy to learn, and I quickly became proficient in using VR," and "I took a short time to physically master the VR interface."

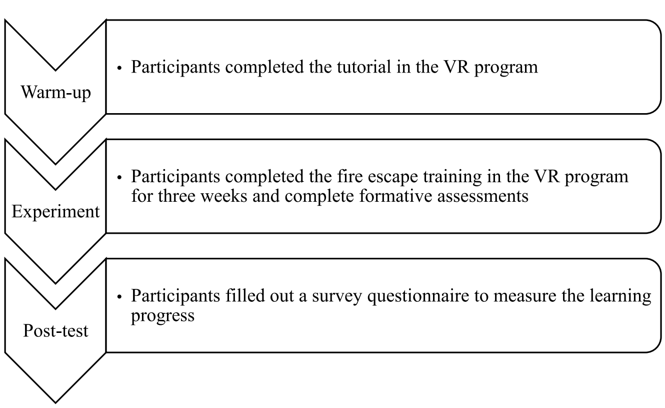


**Fig. 5.** Flowchart of the experiment.

*5.2.1.2. Frustration.* If motion-based navigation interfaces have been improperly designed, it can negatively impact the VR experience due to frustration (Kim & Rhiu, 2021); thus, to assess participants' negative experience of frustration when using VR to play VR Fire-Escape, six items were designed. Example items are "I felt frustrated with the interface because I was arriving more slowly than expected," "It took a long time to operate precisely," and "I felt frustrated that I could not move virtual objects naturally."

*5.2.1.3. Fire presence.* Presence is conceptualized as the feeling of *being there* and is a psychological state in which individuals feel as if the VR experience is real (Nichols et al., 2000). In line with VR environmental presence that contributes to cognitive performance (Makransky et al., 2017), for this study, we designed six items to test participants' Fire escape VR presence. Example items include "When I was involved in playing VR Fire-Escape," "I felt I was in a real KTV environment," "I felt the fire scenarios were lifelike when I played VR Fire-Escape," and "I felt those objects (e.g., hose) were similar to real objects."

#### 5.2.2. Pre-and post-test of learning progress

The difference between participants' test scores in the first and sixth sessions was used as the learning progress (Hong et al., 2020). In this study, we consulted the municipal fire department's handbook and developed a test of fire scene knowledge. The test was further validated by three domain experts to form the test items. Pre- and post-test example items are:

1. When you encounter a fire outbreak on the stairs, you should:
   A. Run downstairs
   B. Run upstairs
   C. Don't move.
2. When you are in a smoky room, if you want to escape you should:
   A. Not use a wet towel, just run out of the room.
   B. Use a wet towel to cover your nose to escape.
   C. Use a plastic bag to cover your head and run out of the room.
3. Please rearrange the sequence of fire extinguisher usage: (A) Sweep the fire from left to right in a back-and-forth manner, (B) Aim at the bottom parts of the fire, (C) Pull out the safety latch, (D) Squeeze the handle to push out the chemical agent.

### 5.3. Plan of analysis

We first examined the psychometric properties of the scales as outlined above. Second, we applied the structural equation modeling (SEM) framework and estimated an SEM model to answer the research questions. The measurement part of SEM retains the latent structure of the constructs and the structural part delineates the paths between the variables. If the model did not fit the data well, we consulted the modification indices to revise the model. After achieving a good model fit, we then focused on the magnitude of the path coefficients and the effect sizes in terms of $R^2$.

## 6. Results

### 6.1. Psychometric properties of the scales

We first checked the internal validity of the scales by conducting a one-level confirmatory factor analysis (CFA). We adopted the following cutoff values of various indices when evaluating our model: the chi-square statistics should be statistically non-significant, RMSEA smaller than 0.10, GFI and AGFI greater than 0.80, and factor loadings should be greater than 0.50. Items may be omitted when the model or item does not meet the criteria. As a result, two items in each of the fire presence, frustration, and GPSE scales were omitted.

Second, we examined the item discriminability by contrasting participants who scored in the top against lower 27% of each item, and conducted *t*-tests to explore whether the two groups significantly differed in the value of each item. Following Hankins's (2007) suggestion, items were determined to have good discrimination if the *t*-value was greater than 3 with a corresponding *p*-value smaller than 0.001. Consequently, the *t*-values across items were between 26.96 and 52.02, indicating that all items had good item discrimination. See Table 1 for details.

Third, for the scales of fire presence, frustration, and GPSE, we computed Cronbach α to examine the internal consistency and the composite reliability (CR) to test external consistency. We adopted Emerson's (2019) recommendations that a scale has good internal and external consistency with a Cronbach α and CR value greater than 0.70. For the convergent validity of each scale, Hair et al. (2019) suggested that factor loadings (FL) and average variance extracted (AVE) should be higher than 0.50. Across scales, the Cronbach α values ranged between 0.89 and 0.95, CR between 0.89 and 0.94, FLs between 0.89 and 0.94, and AVE between 0.76 and 0.88. We thus considered that all three scales had acceptable internal and external consistency and convergent validity (see Tables 2 and 3). Finally, to test the divergent validity, Rönkkö and Cho (2022) suggested that the square root of AVE should be higher than the absolute value of the Pearson correlation coefficient between constructs. As shown in Table 3, construct discriminative validity was acceptable.

### 6.2. Learning progress

The participants completed one test before the fire escape programs (i.e., pre-test) and five follow-up tests on the content knowledge covered in the fire escape program as the participants completed the modules. A paired-sample *t*-test showed a significant difference ($t = -7.65$, $p < 0.001$) between the pre-test ($M = 10.96$, $SD = 2.18$) and the fifth follow-up test (i.e., post-test; $M = 16.08$, $SD = 2.06$; see Table 4).

### 6.3. Path model

We adopted the same cutoff values of model fit indices as we did in CFA (Hair et al., 2019), and the results revealed that the model fit the data ($\chi^2/df = 1.71$, RMSEA = 0.07, GFI = 0.91, AGFI = 0.87, NFI = 0.94, NNFI = 0.96, CFI = 0.97, IFI = 0.97, RFI = 0.92, PNFI = 0.74, PGFI = 0.77). All fit indices met the thresholds suggested by Hair et al. (2019).

As summarized in Fig. 5, frustration was negatively related to GPSE ($\beta = -0.28$, $t = -3.71$, $p < 0.001$), whereas fire presence was positively related to GPSE ($\beta = 0.36$, $t = 4.48$, $p < 0.001$). In turn, GPSE was positively related to learning progress ($\beta = 0.16$, $t = 2.07$, $p < 0.05$; see Fig. 6). The indirect path from frustration to learning progress through GPSE was statistically significant and negative ($\beta = -0.43$, $p < 0.001$). In addition, the indirect path from fire presence to learning progress through GPSE was statistically significant and positive ($\beta = 0.48$, $p < 0.001$).

In terms of effect sizes, we calculated explanative power between constructs $R^2$ and effect size by Cohen's $f^2$. The results demonstrated a moderate effect size of frustration and fire presence on GPSE ($R^2 = 0.16$, $f^2 = 0.19$) and GPSE on learning progress ($R^2 = 0.24$, $f^2 = 0.16$; Cohen et al., 2007).

**Table 2**
Reliability and validity analysis.

| Constructs | *M* | *SD* | Cronbach's α | CR | FL | AVE |
|---|---|---|---|---|---|---|
| Fire presence | 3.45 | 0.86 | 0.89 | 0.93 | 0.87 | 0.76 |
| frustration | 2.44 | 0.98 | 0.92 | 0.94 | 0.89 | 0.80 |
| GPSE | 3.83 | 0.89 | 0.95 | 0.97 | 0.94 | 0.88 |

**Table 3**
Construct discriminative validity.

| Constructs | 1 | 2 | 3 |
|---|---|---|---|
| 1. Self-efficacy | (0.93) | | |
| 2. Frustration | 0.26 | (0.89) | |
| 3. Fire presence | 0.23 | 0.13 | (0.87) |

*Note*. Divergent validity is presented on the diagonal.

**Table 4**
Comparative analysis of learning performance.

| No. of times | *M* | *SD* | *t*-value | *d* |
|---|---|---|---|---|
| Pre-test | 10.96 | 2.18 | −7.65*** | 0.61 |
| Post-test | 16.08 | 2.06 | | |

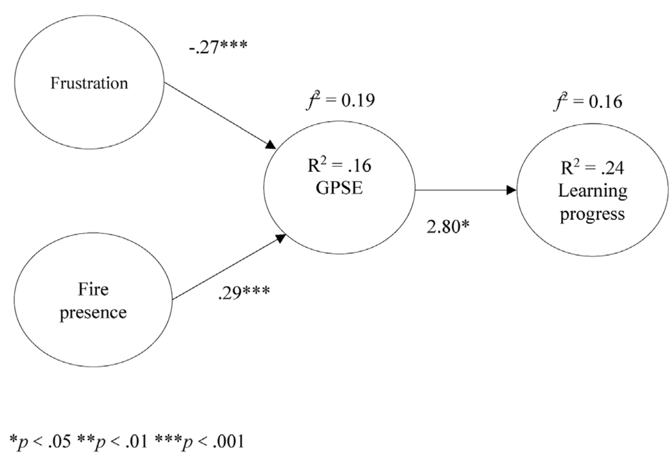


**Fig. 6.** Summary of the path model.

## 7. Discussion

This study highlights the important role of game-play self-efficacy that may maximize the potential of VR programs to help learners immerse in a controlled, danger-free virtual world to gain new life-saving knowledge and skills (Yang & Goh, 2022). Given our findings, first, frustration slows down learning progress by lowering individuals' gameplay self-efficacy. When fundamental physical functioning can only be carried out through controllers, and when visual stimuli deviate from previous real-life experience (Calvert & Abadia, 2020; Wu et al., 2021), individuals waste cognitive resources on learning the use of gadgets and familiarizing themselves with the virtually constructed sight. Instead of paying due attention to the authentic learning task, frustration with VR

**Table 1**
Summary of the first-order CFA.

| Fit index | $\chi^2$ | *df* | *p*-value of $\chi^2$ | RMSEA | GFI | AGFI | FL | *t*-value |
|---|---|---|---|---|---|---|---|---|
| Cutoff | – | – | >0.05 | <0.08 | >0.95 | >0.95 | >0.50 | >3.00 |
| Fire presence | 3.60 | 2 | 0.17 | 0.07 | 0.99 | 0.95 | 0.84–0.90 | 38.58–48.52 |
| frustration | 2.30 | 2 | 0.32 | 0.03 | 0.99 | 0.96 | 0.86–0.92 | 26.96–27.89 |
| GPSE | 1.54 | 2 | 0.46 | 0.01 | 0.99 | 0.98 | 0.92–0.95 | 49.67–52.04 |

programs grow because of the gap between real-life and simulated perceptual experience (Iskander et al., 2019), and we found that such emotional reaction is in turn related to a lower self-efficacy (Pence, 2022). Despite the numerous strengths of VR educational programs for promoting positive learning outcomes (Coban et al., 2022), difficulties with the operation of VR appear to present unnecessary hurdles and lower the learning outcomes (Song et al., 2021). Given the importance of GPSE in VR programs, VR-related frustration as a representation of risks should be reduced to cultivate GPSE.

Second, beyond replicating the S–O-R model (Mehrabian & Russell, 1974) and the importance of virtual presence in VR programs (Nichols et al., 2000; Song et al., 2021; Steuer, 1992), our findings demonstrate that a realistic representation of the environment is necessary for a higher level of gameplay self-efficacy and learning outcomes. Presence in VR is a technology-induced experience that is a subjective property of a person. Students who are engaged in a high-presence VR environment were found to show more confidence in using VR (Song et al., 2021). Some may be worried that a realistic fire scene may trigger aversive reaction (Fu et al., 2021), although there is in fact no real threat. It is likely that, at least for high school students, learners can suppress their aversive emotional reactions to the fire scene when they know that the threat is not real. Indeed, psychophysiological evidence has shown that adolescents tend to experience a lower level of spatial presence in VR than before (Baumgartner et al., 2006); subsequently, a lower spatial presence may be related to a milder emotional arousal (Lee et al., 2023; Pavic et al., 2023). As such, VR programs should provide a more authentic presence vis-à-vis users' age and developmental stage to ensure a proper level of emotional arousal and, in turn, better gameplay self-efficacy and eventually a better learning outcome.

Third, resonating with existing literature (Meyer et al., 2019; Saville & Foster, 2021), we also highlighted the pivotal role of GPSE in promoting learning outcomes. In educational settings, self-efficacy is conceptualized as students' personal judgement of their ability to accomplish learning tasks or achieve specific goals (Han et al., 2020; Schunk & Pajares, 2009). In this study, gameplay self-efficacy is related to students' ability to handle VR equipment and interact with contents of fire escape. In turn, the sense of self-efficacy has been found to be closely related to learning performance (Zakariya et al., 2022). A heightened gameplay self-efficacy is particularly important in simulated tasks since a high level of self-efficacy helps ensure transfer so that learners can apply the knowledge and skills acquired in VR programs to actual problems and environments (Coban et al., 2022; Song et al., 2021; Tai et al., 2022).

Our findings further demonstrate that a vivid visual and audio representation of the authentic task (i.e., presence) and a lower level of frustration are both essential for building higher gameplay self-efficacy, even for life-threatening stimuli that may influence participants' deep learning. The affective and perceptual experience appear to have distinctive relationship to GPSE that educators and VR program developers have to deal with both of the constructs to facilitate meaningful learning.

### 7.1. Implications

Based on the findings, our research highlights the value of VR programs for training adolescents to cope with stressful and life-threatening incidents, the necessity of realistic presence in fire scenes, and the importance of reducing technological barriers for learners. VR remains a useful tool for training adolescents about the knowledge and skillset necessary for fire safety and escape. With potential risks, danger, and other limitations of providing drill-type courses, VR programs appear to be a safe and effective alternative (Yang & Goh, 2022). Second, with such an understanding, our findings imply that a more authentic presence when using VR may lead to better gameplay self-efficacy and eventually a better learning outcome. VR program developers should construct a realistic environment in the VR programs to facilitate self-efficacy and mastery of life-saving skills. In this sense, program developers should work with content experts and designers to build a virtual world in which students are able to learn essential knowledge and skills to survive a fire scene.

Third, VR program developers should minimize technological barriers that may obstruct students' flow during the learning experience. In this context, effective VR programs in which users can practice by encountering dangerous fire situations should be designed (Çakiroğlu & Gökoğlu, 2019). As such, paying more attention to user experience to facilitate smooth human-computer interaction is highly necessary (Petersen et al., 2022). Particularly, when trapped in a fire scene, people may underestimate the danger (e.g., smoke) or misunderstand the physical environment (e.g., it is bright because of the presence of fire) and take a risky route when evacuating (Fu et al., 2021). Our VR design allows individuals to practice repeatedly to form conditional responses as it integrates training into the virtual environment. This positively contributes to the development of fire evacuative skills. Finally, despite its rocky inception, we anticipate that the program will be further integrated into the virtual technology in which learners are able to collaborate in skills training in an immersive environment and to better prepare learners for group fire escape drills (Hwang & Chien, 2022).

### 7.2. Limitations and future study

The findings should be interpreted with caution. First, our quasi-experimental design does not support a causal relationship between using the VR Fire-Escape program, gameplay self-efficacy, and mastery of content knowledge and skills because of the lack of a control group. As a result, the findings should be interpreted as correlational. Researchers should conduct a similar study in the future but with a randomized control trial to justify the causal relationships. Second, the effect size of GPSE on learning progress was small, indicating that other variables are at play. It is possible that the effect size is small because the content is too simple for high school students since students may have already learned the fundamentals earlier. Researchers can further identify salient predictors of learning outcomes that can also be promoted by VR programs besides self-efficacy or when the VR programs serve as a review of previously learned content. Third, we did not compare who has not practiced the VR Fire-Escape program to those of practiced, in terms of learning effectiveness in performance. Finally, the results can only be generalized to high school students. More research should be conducted with individuals of different ages to verify the effect of the VR Fire-Escape program.

## 8. Conclusion

VR programs provide a safe alternative for training students in the essential skills to cope with emergencies. In the current study, we documented that for high school-aged individuals, the vivid presence of the source of the risk—fire in this study—is positively related to gameplay self-efficacy, which in turn is related to students' knowledge and skills of coping (i.e., fire escape). However, frustration with control over VR programs is negatively related to gameplay self-efficacy. Our path model clearly delineates that gameplay-related self-efficacy, which can be cultivated by well-designed visual and auditory effects in VR programs, plays a pivotal role in facilitating learning outcomes for adolescents. Moreover, VR program designers and programmers should adopt intuitive control systems and modules to lower negative emotional reaction to VR programs.

## Statements on open data and ethics

The participants were protected by hiding their personal information in this study. They were voluntary and understood that they could withdraw from the experiment at any time. The data can be provided upon requests by contacting the corresponding author.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper


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