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EDITED BY

Laura Thomas,
PARSEC Space, United Kingdom

REVIEWED BY

Holly Elisabeth Carter,
Public Health England, United Kingdom
Lintang Ronggowulan,
Universitas Sebelas Maret, Indonesia

*CORRESPONDENCE

Tauqeer Faiz,
✉ tauqeer98@hotmail.com

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Does contextual learning matter in fire hazard recognition awareness campaigns?

Tauqeer Faiz^{1*}, Mark Kit Tsun Tee¹ and Abdullah Al Mahmud²

¹Swinburne University of Technology Sarawak Campus, Malaysia, ²Center for Design Innovation, Swinburne University of Technology VIC, Australia

Background: Urban residents are facing increasing levels of exposure to extreme conditions, driven by global warming, urbanization, and the abundance of combustible materials in heavily constructed environments. There is an urgent need for evidence-based, innovation-driven public safety awareness. Frequent fire incidents in the Emirates of Sharjah and Dubai highlight the glaring deficiencies in conventional awareness safety campaigns.

Objective: This study aimed to enhance fire hazard recognition skills among residents, enabling them to recall and apply fire safety guidelines in their homes or apartments within a contextual, engaging, motivating, and immersive learning environment.

Methods: Two virtual reality-based environments were developed and evaluated. The first virtual reality platform provided fire safety content in a non-contextual form based on available awareness campaign materials such as brochures, leaflets, and videos. The second virtual reality platform offered contextual simulations that mimicked realistic apartment and home fire hazard scenarios. A pre-test/post-test experimental design was employed, and data were analyzed using paired and unequal variances t-tests to evaluate learning outcomes and usability.

Results: Participants using the contextual virtual reality platform demonstrated significantly higher improvements in fire hazard identification skills than those using the non-contextual platform. The contextual group also showed higher engagement and perceived usefulness. Usability testing conducted using the System Usability Scale confirmed the superior performance of the contextual model, which achieved the highest mean score among the evaluated options.

Discussion: Contextual, immersive learning environments significantly outperformed traditional materials in promoting hazard awareness skills. This study supports the use of scenario-based virtual reality training as an effective tool for public safety education, particularly in high-risk and urban areas where traditional campaigns may be ineffective.

KEYWORDS

fire hazard recognition, virtual reality, engagement, motivation, contextual learning, awareness campaigns, brochures, leaflets

1 Introduction

Dubai and Sharjah, the twin cities of the United Arab Emirates, face significant risks from global warming. Extreme weather conditions are especially concerning during the summer months when temperatures can exceed 50 °C (122°F) (Siricar, 2025). This intense heat increases the likelihood of house and industrial fires (Zhang, 2023). The moisture level

in construction materials, combustible items, and fabrics decreases gradually due to hot and dry winds. The summer season lasts 9 months to 10 months, during which air conditioning is mandatory (Komuscu, 2017). Residents are compelled to perform activities such as vaping, barbecue parties, and religious activities, including but not limited to celebrating Eid, Christmas, and Diwali, indoors. When these factors are combined with a hot and humid climate, a small spark, whether from faulty wiring, overheated equipment, the accumulation of flammable debris and waste around jammed exhaust fans, improper usage of chemicals and gas cylinders, human negligence, unattended cooking, or many other aspects, can rapidly escalate into a major fire outbreak. In congested countries, including Australia and the United Arab Emirates, a high proportion of deaths and injuries are related to residential fires (Alqassim and Daeid, 2014; Ghassempour et al., 2022).

The UAE, through entities like the Civil Defense General Command, organizes public awareness campaigns and seminars to educate civilians on hazard recognition (Defense, 2022). Despite these efforts, fires continue to pose a significant risk. Live fire training resulted in the deaths of 91 firefighters (Fahy, 2020). Several incidents resulting in casualties among firefighters during a search and rescue training in a specially designed training setup were reported. The National Fire Protection Association (the leading information and knowledge resource on fire, electrical, and related hazards) offers resources and instructions in fire safety on a range of fire and life safety themes, which include manuals, booklets, pamphlets, and safety tip sheets (National Fire Protection Association (NFPA), 2018). These resources aim to help individuals understand fire dangers and prevention techniques. Residential fires, seasonal fires, and festival fires are all included in the NFPA's educational resources on fire dangers. According to the NFPA (2018), the most frequent type of fire in houses is a kitchen fire, and the NFPA's resources offer advice on how to prevent them, including never leaving cooking unattended and keeping combustible materials away from the stove.

Fire misfortunes can still occur, despite efforts made by entities such as the Civil Defense UAE to organize public awareness campaigns and seminars to educate civilians about hazard detection and prevention during extreme weather conditions (Spence, 2021). The fire incident reports issued by the Government of Dubai highlight that smoking, improper use of electronic appliances, leakage of flammable materials, and human negligence are the factors that contribute to fire ignition (Defense, 2022). The brochures, leaflets, and videos used in awareness campaigns cover these threats; however, these materials require an initiative to investigate the training gap in these conventional means of knowledge delivery. Smoke alarm installation programs can help prevent residential fire injuries; however, the cost of running these programs is not well understood (Parmer et al., 2006). Shevchenko endorsed fire safety training for future teachers; however, the affordability of training workshops restricts many people from attending these trainings, although we cannot deny the importance of fire safety training (Shevchenko and Shevchenko, 2021). The current fire protection measures in buildings do not account for all contemporary fire hazard issues. The logistical nature of these mediums of skills delivery makes it difficult to create safe and contextual scenarios for developing skills.

Computer-generated animations avoid putting people in danger, provide a cost-effective solution, and foster the scope and effectiveness of training programs (Kodur et al., 2020).

Other factors contributing to fire mishaps include global warming, urbanization, and the use of combustible materials in construction. Heavy air conditioning systems used in tall buildings operate 24/7, which increases the outside temperature. Light rainfall in urban cities can lead to floods that cause power outages. Due to extreme temperature and weather conditions, using candles and storing gas cylinders and chemicals inside the house have become societal norms that pose significant risks. Dust and smoke accumulations around the kitchen or bathroom exhaust fans during sandstorms and faulty wires exposed to heat are associated with risks of urbanization and global warming. Residents must be aware of these risks and prepare in advance to respond to an emergency. The current awareness campaign materials lack motivation, engagement, and contextual and interactive learning. Additionally, the non-availability of resources, high training costs, and a mere virtual environment can not engage people.

House residents may not perform better or respond to a fire emergency due to the lack of fire safety education. The lack of knowledge about residential fires and the focus on workplace safety highlight a critical gap in hazard recognition efforts. To bridge this gap, it is highly recommended that modern and cost-effective training strategies be developed and implemented on a broader scale (Ezeani, 2019). These measures should focus on developing practical skills in assessing fire hazards, enabling inhabitants to identify the threats in their surroundings. In addition, the public awareness campaigns should be delivered frequently to educate people about fire hazards and preparedness (Kodur et al., 2020). By investing in comprehensive fire safety training for all segments of the population, rather than only teachers, we can substantially reduce the chances of fire occurring, resulting in fewer fire-related injuries and fatalities (Shevchenko and Shevchenko, 2021). The risks associated with global warming and urbanization can be ameliorated through immersive technology by increasing awareness, promoting preparedness, and encouraging sustainable practices. The primary objective of this experiment is to determine if contextual learning significantly improves learners' acquisition of hazard recognition skills compared to conventional non-contextual training. In essence, we aimed to answer the question: "Does contextual learning matter?" To establish a baseline understanding, all learners were assessed through a pre-test questionnaire on their knowledge about fire safety and hazard identification before participating in either contextual learning or non-contextual learning environments.

2 Literature review

The impact of global warming is evident in our daily lives. The Fire Weather Index system, evaluated by Dupuy et al. (2020) confirmed a future increase in fire risks in Southern Europe. Dubai experienced a rise in temperature over the past 20 years. Due to heavy rainfall, the entire city was flooded last year, which disrupted routine activities. Most fires are caused by human negligence and irresponsible behavior (Consulting, 2005). Unsafe

human behavior, the materials used in skyscraper buildings, and global warming, when combined, can lead to disastrous outcomes, significantly increasing the chances of residential fires. Global warming may be inducing a subtle change in regional fire dynamics in Europe (Carnicer et al., 2022; Vijayasree, 2019; Xiong et al., 2017). Conventional fire safety training and awareness campaigns are no longer enough as we enter a transformative era assisted by emerging technologies such as augmented and virtual reality. Fire safety professionals recommend fire safety awareness campaigns for residents, enhanced training content for maintenance staff, and that occupants remain vigilant—early hazard detection and prompt response can save lives. Enhancing awareness campaigns and educational content on fire safety by incorporating emerging augmented and virtual reality technologies can effectively engage the community and increase awareness.

Contextual learning (CL) is a teaching method in which learners develop knowledge within the context in which it is used (Johnson, 2002). Unlike traditional learning, such as MS PowerPoint slides, reading case studies, video demonstrations, brochures, and leaflets, which usually rely on abstract theories, contextual learning places learners in real-world scenarios, allowing them to gain practical skills and a deeper understanding through immersive experience (Suryawati and Osman, 2017; Zhang et al., 2017). Countries frequently incorporate fire safety awareness campaigns to enhance public preparedness. Fire safety education and awareness campaigns face several limitations, including engagement, motivation, lack of feedback, individual learning styles, and weak methodological designs (Faiz et al., 2024; Johnston and Tyler, 2022). Training workshops are conducted in large groups, which lack individual attention and feedback and require additional resources (Kodur et al., 2012). These training workshops are paid as they require training equipment and qualified instructors (Engelbrecht et al., 2019a). While this approach is practical, it has its limitations in managing extensive group training, creating a safe environment for learners, and providing effective feedback when mistakes are made. The awareness campaigns require a budget to print brochures and leaflets, as well as to disseminate the material to the public (Zhuang et al., 2017). There is no assurance that the awareness campaign material reaches the target audience and meets the individual learning style. Although the technology has been used to address this gap, it was previously restricted to operating fire extinguisher training, a type of learning environment that is uncomfortable, such as CAVE-based training, where movement of players was restricted, leading to cybersickness (Grabowski, 2021). The use of outdated devices has led to issues with teleoperation, sensory input, and GPU performance (Lebram et al., 2007). Above all, it lacked contextual learning, as most of the training consisted of mere animation.

According to the Honeywell report (2013), 30% residents do not care about fire alarms and exit plans, 53% residents of the UAE were unaware of how to test fire safety equipment, and 48% of the recruited population have not taken part in any fire safety operations such as evacuation drills and making emergency calls (Staff, 2013). A recent survey report by the Government of Dubai identifies candles, cigarettes, mechanical faults in electrical appliances, unattended cooking, flying sparks, chemical spills, and other factors as the leading causes of fire events (DCD, 2017;

Omar et al., 2023). Recent research conducted by Faiz et al. (2024) has shown that fire safety education training may fail to achieve the expected results due to the absence of contextual learning, engagement, motivation, duration, cost, and feedback. Conventional awareness campaigns often lead to limited engagement, are less motivating, require resources, demand supervision, incur setup costs, and lack real-life scenarios. In contrast, interactive VR-based hands-on training is relatively inexpensive and effective in teaching (Sankaranarayanan et al., 2018). These teaching aids focus on the lowest level of Bloom's taxonomy, understand and remember. A fire safety skills assessment requires a further understanding, such as applying and analyzing (Sivaraman and Krishna, 2015). The promotional materials on hazard recognition and fire safety skills lack higher-order cognitive skills, such as logical reasoning and decision-making, engagement, motivation, and elements related to contextual learning (Bjørnsen et al., 2023; Rone et al., 2023; Sun et al., 2024).

By simulating real-life challenges through technology, gamified learning has a positive impact on motivation, feedback, interaction, and engagement (Bodzin et al., 2021). This approach fills in gaps commonly found in conventional training methods, such as a lack of tools, real-time feedback, and attention to individual learning, yet makes it affordable, scalable, and presents relevant training to learners (De Lorenzis et al., 2023; Lopez et al., 2021; Zhao et al., 2021). These interventions can contribute to enhanced fire safety training, not only for residential settings but also for workplaces, schools, and civil defense training programs. Through understanding common vulnerabilities in current education and designing an innovative solution, the study project can increase public awareness about fire safety, reduce the potential for fire events, and safeguard lives and property.

2.1 A virtual environment cannot engage people

According to Smith and Ericson (2009), to engage individuals in a virtual reality-based fire safety program, more is required than simply creating a virtual world. VR technology offers engaging and realistic experiences; however, it requires a careful setup and attention to ensure successful participation. Simply placing people within a virtual space does not guarantee that they will participate or have meaningful cognitive experiences; therefore, VR learning environments warrant serious investigation (Roussou et al., 1999). Other interactive elements, such as realistic simulations and kinesthetic learning activities, must be considered when teaching fire safety in VR to maintain engagement (Dianatfar et al., 2023; Shafer et al., 2018). Providing learners with hands-on experiences, real-life problems to solve, and opportunities to make decisions can increase engagement and motivation. Gamification elements such as points, awards, and progress tracking could also augment motivation and engagement (Williams-Bell et al., 2015). Incorporating feedback and evaluation systems, customizing training materials to cater to different learning styles, and considering learners' unique requirements and preferences can all contribute to developing an engaging and successful VR-based fire safety program (Bliss et al., 1997).

2.2 Lack of motivation

It is challenging for instructors to develop an effective training strategy for teaching people about fire safety (Gwynne et al., 2019; Warda et al., 1999). In reality, numerous conventional methods are employed to educate the general public on responding to emergencies and extinguishing fires using firefighting equipment, including speeches, discussions, evacuation drills, videos, pamphlets, and online exercises. However, these conventional methods are expensive and are not the most effective approaches for developing skills (Williams-Bell et al., 2015). Live training in specially designed classrooms is the most typical type of firefighting instruction. Both types of training are required; in the classroom, you learn about rules, chemistry, *etc.*, while in real-world training, you learn how to use the equipment, deal with heat, and work under pressure, among other things (Backlund et al., 2007; Heldal et al., 2016). Lectures, slide shows, and video demonstrations in classroom-based training are passive learning techniques as learners become bored and demotivated due to the lack of interactivity (Ribeiro et al., 2020; Sagnier et al., 2020). Safety training, most importantly, fire safety training, requires the full involvement of participants due to the practical and serious nature of the learning. Participants may become less responsive when there is a disconnection between their theoretical understanding and the acquisition of practical skills (Heldal et al., 2016). Learners become demotivated if the instructor only uses lecture slides and no real-time feedback is given to their responses. Learning will be less effective if problem-solving and analyzing critical situations are not incorporated in the learning, and such a platform will become passive in skills delivery (Williams-Bell et al., 2015).

2.3 Engagement issues

If learners are not provided with constructive feedback throughout the learning process, they will lose the opportunity to improve their understanding, leading to a lack of engagement (Bundick et al., 2014). Consistent feedback and appreciation for their achievements motivate them to boost their skills, and they feel a sense of advancement and development (Bundick et al., 2014). The engagement of learners in actively participating in the learning process may decrease if they are unable to connect the training material to their actual fire safety responsibilities and challenges. Engagement may be increased by making the training material relevant, applicable and tailored to specific fire safety conditions (Williams-Bell et al., 2015). Williams-Bell et al. (2015) mentioned that traditional methods prioritize performing physical and skill training with pictures. In contrast, fire safety tactical training is completed through live exercises, tabletop exercises, and paper-based study to ensure the success of firefighting and safeguard communities. Live exercise is essential, but it can be expensive and challenging to plan. Tabletop exercises require a significant amount of time to construct and do not facilitate real-time interaction. Research conducted on paper is less readable and can only provide an assumption and simulation of a straightforward event scene. The fire department must implement a safe and equitable training

technique to guarantee that firefighters can respond to fire events and natural disasters (Kang et al., 2016).

2.4 Passive learning techniques

Typical training methods that use text and multimedia materials may fall short in developing and memorizing special skills (Feng et al., 2018). Additionally, if learners are not psychologically engaged in the learning practices, the effectiveness of the knowledge development and retention process may be compromised (Gwynne et al., 2019). Learners not involved in learning content may not improve their behavior (Buttussi and Chittaro, 2018). These restrictions are significant when educating learners about practical skills such as firefighting and evacuation drills (Feng et al., 2018). The lack of interactive learning experiences in traditional fire safety training might limit effective engagement (Nousiainen, 2009). Lectures and slideshows are two examples of traditional training techniques that depend on passive learning strategies, where learners passively absorb knowledge without actively engaging in the learning process (Nousiainen, 2009). The training may be more dynamic, applicable, and engaging using interactive components like role-playing, group discussions, case studies, simulations, and hands-on activities (Maluk et al., 2017).

2.5 Lack of context-based learning

Firefighting training is generally conducted in training centers to experience and enhance firefighting skills. These techniques have been proven to work, but they are not the best option in every circumstance (Backlund et al., 2007). The fact that each type of setting, such as restaurants, airplanes, and gas stations, requires a different physical model makes this approach expensive (Backlund et al., 2007). Despite the instructor sharing a personal experience, learners will likely understand it significantly differently than the instructor does, as the instructor is connecting it to a different set of past experiences (Jonassen et al., 1999). According to constructivists, learning is the process of assisting learners in creating meaning from their experiences by presenting them with those experiences directly and directing the cognitive construction (Jonassen et al., 1999). Furthermore, according to constructivists, understanding the context is a component of the knowledge that the learner constructs to explain or make sense of the phenomena, and application is what we actually understand about skills and knowledge (Brown et al., 1989). Hence, fire safety training lacks context-based learning, and most required fire safety scenarios remain unaddressed.

2.6 Absence of interactive learning

Due to the absence of interaction, students may be less engaged and less motivated to properly comprehend and apply the topics they have learned (Nousiainen, 2009). Additionally, traditional education frequently fails to connect theory to real-world situations through practical application (Cecilio-Fernandes et al., 2019). Trainees may be challenged to apply newly acquired knowledge in real-world firefighting scenarios. The lack of

interactive learning is further exacerbated by inadequate hands-on experience, as trainees often have limited opportunities to practice firefighting methods (Feng et al., 2018). When learners actively participate in their education, firefighting training may become more interesting (Jonassen et al., 1999). Training can be made more dynamic, helpful, and engaging by incorporating interactive components such as scenario-based learning, simulations, hands-on activities, and role-playing (Lacko, 2020). Failure to address the gap in concepts and everyday life may result from fire safety training that only emphasizes theoretical knowledge without providing practical application opportunities (Dianatfar et al., 2023; Noghabaei and Han, 2020). Applying newly learned information in real-world firefighting scenarios may be difficult for trainees to comprehend (Goodson and Murnane, 2011). Hands-on experience is essential for the development of practical abilities and confidence in firefighting. Unfortunately, standard training frequently denies students the chance to work in actual firefighting situations (Czarnek et al., 2019).

2.7 Fire safety education

Pooley et al. (2020) highlighted that a younger age group has limited capacity to understand the hazards and their implications of fire and cannot prompt reactions. She emphasized the importance of incorporating safety education into a school curriculum, which should bridge the physical and social worlds, helping students understand the complexities of fire. However, there is no single format that fits all types of learning styles. Extended reality offers several physical and social features tailored to meet the needs of individuals across all age groups. It is highly recommended to integrate extended reality into fire safety education programs worldwide to increase fire safety knowledge and skills among all age groups.

3 Development of FireGuard non-contextual and contextual games

Considering the above issues, we conducted an experiment to identify the efficacy of contextual learning *versus* traditional learning resources. For transparency, we utilized a VR platform with two distinct types of content. The first platform was designed to present brochures, leaflets, and an instructional video, followed by an assessment, as shown in Figure 1a and referred to as VR-enabled non-contextual training. In this non-contextual training, learners are trained through reading brochures, leaflets, and watching an instructional video presented in this environment, as shown in Figures 1c,e. After completing the training, participants complete an assessment embedded within the environment, consisting of ten questions; sample questions are illustrated in Figure 1g. During this assessment, a minimum score of 7 is required to complete the training; otherwise, the system redirects the user to the training again. This feature is added to ensure that the participants have gone through the instructional material and raised their awareness to a satisfactory level. Training and assessment within the VR environment are completed in 20–30 min; participants are then asked to complete a post-test questionnaire.

The second platform featured a gamified learning environment that provided contextual learning through training and assessment, as illustrated in Figure 1b and referred to as VR-enabled contextual training. The training mode in VR-enabled contextual training lasts for 10–15 min to showcase various hazards, including electrical, mechanical, chemical, kitchen, candle, and smoking hazards. The first platform requires more time for training because reading brochures and leaflets takes longer than observing scenarios. Figures 1d,f show examples of hazards. Learners experience how different situational factors, such as a cluttered environment, human negligence, exposure to combustible materials, and mechanical dysfunctions, can escalate a dormant fire into a full-blown blaze. Brochures, leaflets, and instructional videos demonstrate similar information items utilized here. The proposed game has cognitive aspects to enhance engagement, motivation, and immersion, such as audio instructions, fire and smoke effects, spatial recognition, and narrative-driven emotional regulation. Once the training is over, learners can progress to assessment, during which they are presented with various hazard scenarios such as kitchen, living room, electrical, mechanical, and emergency, as shown in Figure 1h, which are sub-categories of the assessment. They must determine whether or not each context presented to them contains a potential hazard, as illustrated in Figure 1i. Participants must achieve at least a 7 of 10 score to complete this training; otherwise, the system redirects participants to train again until they achieve the desired score. Audio feedback was incorporated to indicate the correct or incorrect selection during the assessment, such as a clapping sound effect for a correct answer and a buzzer sound for an incorrect answer, along with an on-screen player score. VR-enabled contextual training and assessment also lasts 20–30 min, after which participants attempt the post-test questionnaire. Both applications were designed and developed using the Unity 3D game engine and the XR-Interaction toolkit.

3.1 Pseudocode: unveiling game mechanics

The pseudocode below explains the operating principles of both non-contextual and contextual game models:

Non-contextual Game Mechanics Pseudocode

GAME START

```
Choose player code from the drop-down menu
Click the start button
Load main menu
Display "READ BROCHURES, WATCH VIDEO, ASSESSMENT"
WAIT for player to choose READ BROCHURES
Load BROCHURES
```

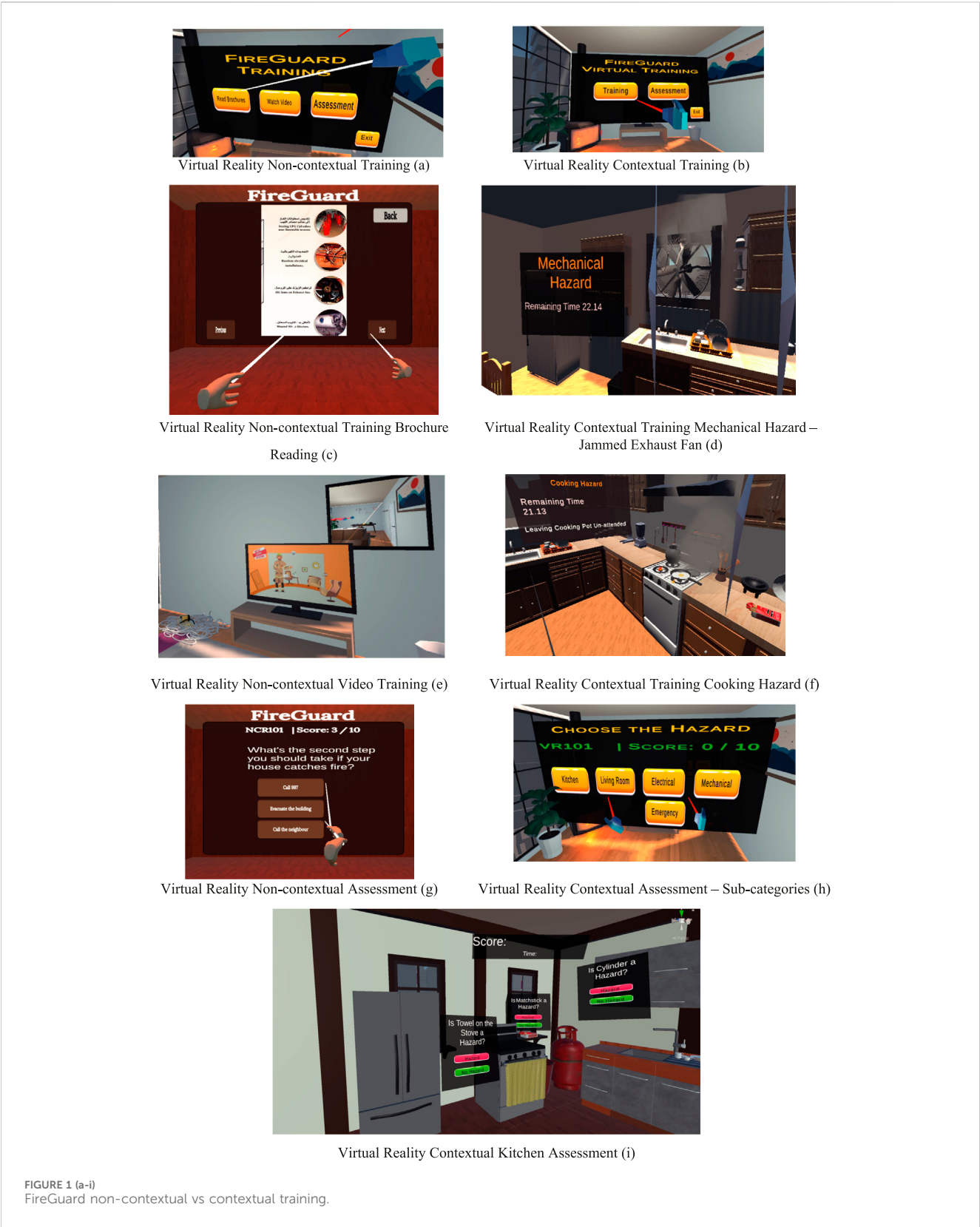
TRAINING MODE:

SCENE: READ BROCHURES OR WATCH VIDEO

```
Display environment (Kitchen Safety Brochure + Electricity Safety Brochure + Exhaust Fan Safety Brochure + Chemical Safety, TV Room)
```

```
TV ROOM: playing a fire safety awareness video
```

```
IF the player has completed reading brochures and watched the video:
```



LOAD ASSESSMENT
ELSE
Stay in TRAINING MODE
END SCENE READ BROCHURES OR WATCH VIDEO

SCENE: ASSESSMENT
SET HAZARD COUNT = 0
SET PLAYER SCORE = 0
DISPLAY PLAYER CODE AND PLAYER SCORE

```

IF Hazard COUNT == 10 && PLAYER SCORE >=7
  ENABLE "EXIT BUTTON"
  Load SCOREBOARD
ELSE IF Hazard COUNT == 10 && PLAYER SCORE <7
  RESET HAZARD COUNT = 0
  RESET PLAYER SCORE = 0
  DISABLE "EXIT BUTTON"
  RESTART TRAINING MODE
END IF
END SCENE ASSESSMENT
SCENE: SCOREBOARD:
  Display
  - PLAYER Code
  - PLAYER SCORE
  - Save PLAYER SCORE TO GOOGLE SHEET
OFFER "EXIT"

```

Contextual Game Mechanics Pseudocode

```

GAME START
  Choose player code from the drop-down menu
  Timer = 30 seconds
  Click the start button
  Load main menu
  Display "Welcome to FireGuard VR Training"
  Display "Training" & "Assessment" MODE
  WAIT for PLAYER to choose TRAINING MODE
  Load TRAINING MODE

TRAINING MODE:
  SCENE: Hazard Awareness
    Display environment (Living room, Kitchen, Bedroom)
    3D Models: candles, gas cylinders, ashtrays, chemical bottles,
    cluttered wires, jammed exhaust fan, pedestal fan, frying
    pan, lights
    cooking range, towel, hot plate, electric kettles, etc.
  Sound effects: Relevant sound effects played in the
  background, such as fire sound effect, jammed fan, spark
  sound effect, etc.
  Animation: fan rotation, spark, rain, etc.
  Particle effects: smoke, liquid, fire particle effects
  Voice narrations: Hazard-relevant instructions played in the
  background
  Display "Hazard Type"
  WHILE Timer >0 seconds
    Scene observation: Player observes the hazard type placed in
    the scene
    Scene observation: After 5 seconds, the dormant
    hazard first produces smoke, which quickly escalates to a
    full-blown fire
    Scene observation: The player observes the entire scenario in
    the virtual simulated environment
    Scene observation: Player listens to voice narrations played in
    the background related to the hazard
    The player enhances cognitive skills related to hazard
    in 30 seconds
    CANVAS UI continuously decreases the timer by 1-second
    intervals until it reaches 0
    Players observe the timer in the UI CANVAS

```

```

END WHILE
Player explores all seven contextual learning scenes
END SCENE Hazard Awareness
IF SCENE 1 - SCENE 6 Training Finished
  UNLOCK ASSESSMENT MODE
  Display "Complete the assessment"
  Load ASSESSMENT MODE
END IF
ASSESSMENT MODE:
  DISPLAY "Make a selection from given choices and observe
  the context to identify hazards"
  Spawn contextual hazards UI interface showing kitchen,
  living room, electrical, mechanical, and emergency contexts
  SET PLAYER SCORE = 0
  HAZARD COUNT = 0
  CONTEXT: Hazard Type Context
  Display environment (kitchen + gas cylinder + matchstick +
  kitchen towel hanging near the burner, ashtrays, pedestal fan, hot
  plate, kettle, bulb, etc.)
  Place: Kitchen/Living Room/Bedroom
  No. of hazards placed: 10
  Particle effect: smoke and fire particle effects
  Display "Determine if a specific hazard is present by following
  the instructions and context provided in the assessment scene?"
  SET Timer = 30 seconds
  WHILE Timer > 0 AND Hazard COUNT < 10
    WAIT for player action
    IF the player identifies the correct hazard
      ADD PLAYER SCORE to player inventory by
      incrementing 1
    ELSE
      Do not add player score to player inventory
    END IF
  CANVAS UI UPDATES THE PLAYER SCORE IN THE
  PLAYER INVENTORY SECTION, along with the player code
  AUDIO FEEDBACK: If the player gives a correct answer, an
  applause sound is played, motivating players; while an incorrect
  answer plays a feedback tone indicating error.
  PLAYER gets 30 seconds to clear each ASSESSMENT stage.
  There are five assessment stages.
  CANVAS UI continuously decreases the timer by 1-second
  intervals until it reaches 0
  UPDATE HAZARD COUNT BY 1 after every player response,
  irrespective of its correctness
END WHILE
UI UPDATE: contextual hazard learning option disappears
from the screen after completing a particular hazard type
IF Hazard COUNT == 10 && PLAYER SCORE >=7
  ENABLE "EXIT BUTTON"
  Load SCOREBOARD
ELSE IF Hazard COUNT == 10 && PLAYER SCORE <7
  RESET Hazard COUNT = 0
  RESET PLAYER SCORE = 0
  DISABLE "EXIT BUTTON"
  RESTART TRAINING MODE
END IF
SCOREBOARD:
  Display

```

- PLAYER Code
 - PLAYER SCORE
 - Save player score to Google Sheet
- OFFER “EXIT”

Two VR training environments were created to provide similar content training and observe which training environments outperform the others, as shown in [Figures 1a–i](#), to investigate the impact of non-contextual vs. contextual training.

The non-contextual VR training utilizes brochures, leaflets, and awareness campaign videos sourced from the local authorities. These brochures, leaflets, and instructional videos demonstrate the safety guidelines one should follow to recognize hazards in their surroundings that could lead to a catastrophic situation. Participants were required to review these materials and complete an assessment within the VR environment of ten questions derived from the training materials. A minimum score of 7 was needed to advance to the next stage; otherwise, attendees had to repeat the non-contextual training. In contrast, VR-enabled contextual training is designed based on common incidents reported in a living community, such as people living in villas or flats. These incident reports are published by government entities such as the Civil Defense General Command. The awareness campaign materials, such as brochures, leaflets, and instructional videos, also focus on everyday incident awareness to educate the general public about what can cause fires in a residential environment. These reports only mention the root cause of a fire, such as a fire started due to candles, human negligence, gas leakage, *etc.* Similar scenarios are created in the game to portray what common mistakes in a living community can lead to fire. However, the reports shared by the civil defense authorities do not provide complete details, such as how the candle led to the fire or how the gas leak remained unnoticed and subsequently ignited the fire.

The game-based contextual learning was designed to train inhabitants to avoid these common mistakes at home. The game's features were determined based on a shared understanding of the day-to-day issues people face regarding common fire incidents. For example, keeping candles near flammable materials can cause them to catch fire, unattended cooking can also ignite, and a chemical spill in the kitchen can escalate a fire. Although the list of these common mistakes is long, we relied on incident reports shared by the Civil Defense General Command and portrayed such incidents in the game.

The FireGuard game is divided into two stages: training and assessment. Players initially engaged in the training stage, developing essential skills in recognizing hazards in their living environment ([Tao et al., 2021](#)). These hazards include candles, smoking, electrical, mechanical, cooking, and miscellaneous. Each hazard training lasts 30 s, simulating real-life scenarios based on the respective hazard categories. During the training stage, players observe how a hazard turns into a full-blown fire. Upon successful completion of the training modules, players proceed to the assessment stage. The assessment stage evaluates players' understanding of the knowledge and skills gained during the training stage. This game emphasizes the importance of catering to diverse individual learning styles, including scenario-based contextual learning, immersion, a sense of presence through VR integration, engagement through sound and reward systems, and

effective feedback. The game was evaluated by experts from the domains of human–computer interaction (HCI), game development, augmented and VR application development, mobile application development, and computer vision. The feedback received from these experts was used to improve the strategies, design, reward system, and feedback process. Ultimately, we ensured that the pre-test, peri-test (assessment within the game), and post-test questionnaires were based on the instructional media used in their respective trainings.

4 Methodology

4.1 Research design

This empirical study employed a mixed-methods approach, beginning with pretest questionnaires that participants completed. After completing the pretest questionnaire, the participants used either non-contextual or contextual training and completed an assessment within the training environment to ensure that they had completed the instructional content. Ultimately, participants completed post-test questions, along with providing feedback on the interface. This entire process involves analyzing textual responses received from participants during the pre-test and post-test. In the feedback phase, similar responses were coded by counting frequencies and calculating mean scores on the System Usability Scale to determine which interface is preferred by the participants.

4.2 Participants

The research ethics approval was obtained from Swinburne University of Technology, Australia, under the application number ref: 20247421-20383 as part of the Ph.D. project title “*Enhancing Fire Hazard Recognition Training through Game-based Contextual Learning in Virtual Reality*.” Email approvals were sent to the Amana Private School, Sharjah, University of Wollongong in Dubai, Rochester Institute of Technology, Skyline University, Pakistan Medical Center Dubai, and many other institutions to use their premises as a research venue. Skyline University in Sharjah (SUC) and Pakistan Medical Center Dubai (PMC-Dubai) approved the request to use their premises for data collection. So, prior approval was obtained from SUC and PMC to conduct research involving staff, faculty, students, and visitors.

The participants were members of the general public who were 18+ years of age and living in Dubai or Sharjah, United Arab Emirates.

4.3 Procedure and instruments

The research used two groups. Group 1 received non-contextual training, whereas Group 2 received virtual reality-based CL training. The groups were formed through a random draw; a box containing an equal number of chits labeled Group 1 and Group 2 was prepared. This chit also lists the player code to be used in pre-test, peri-test (assessment within the virtual reality environment), and post-test.

These player codes were used as entry codes for the pre-test, peri-test, and post-test questionnaires. The two distinct codes were NCU101.NCU150 and VR101.VR150. NCU101.NCU150 codes were used for pre-test, post-test, and peri-test for non-contextual training, whereas VR101.VR150 codes were used for pre-tests, post-tests, and peri-tests for contextual training. Out of 50, only 40 codes were randomly picked by the participants and used. Each participant picked one chit from the box and was assigned to the group indicated on the chit, along with the player code.

The experimental data were gathered at Skyline University, Sharjah, and Pakistan Medical Centre, Dubai. The administration announced that visitors, students, staff, and faculty members could visit the data collection center and participate in the research study during working hours. The student investigator briefed the participants about the research and its objectives and shared the informed consent and VR headset usage screening questions. If a participant agreed to participate, they were asked to pick a chit from the random draw to assign them to either Group 1 or Group 2. Participants were compensated with food vouchers worth AED 18, which they could spend in the premises cafeteria. However, the participants recruited during the holy month of Ramadan were given a box of chocolate-coated dates, as the cafeterias were not operating during the day. Data were collected over 6 days, due to the varying times each participant spent on different days of the week. The student investigator arranged three VR headsets to be used simultaneously to carry out the experiment. Once the participant received their group information, some VR-related screening questions were asked, such as “Did you experience motion-sickness while playing any VR Game?” and “Did you experience discomfort, dizziness, or motion-sickness using a virtual reality headset?” If the answer to any of these questions was “Yes,” then such participants were withdrawn from the study to ensure participant safety.

Once a healthy participant was recruited, he/she was given initial training on how to use VR headsets and how to make object selections using the controllers. After completing the screening questions and initial VR usage training, participants were asked to complete the online pre-test questionnaire to record their initial knowledge and understanding of fire safety using the player code on their chit picked from the random draw box. Group 1 participants used the reading of brochures, leaflets, and watched the instructional video to boost their knowledge and understanding about fire hazard recognition at homes. Group 2 participants were given contextual training through multiple real-life scenarios to increase their understanding of fire hazard recognition. After completing the training, they were asked to answer ten questions, requiring seven correct answers of the ten questions to proceed to the next step. Participants who did not meet this threshold were automatically redirected to repeat the training. Upon successful completion of the training and assessment, both groups took a post-test assessment. Group 2 also completed additional survey questions to gather feedback on the CL model of the proposed fire guard training, including survey questions about system usability. The entire process took approximately 45–60 min per participant. For the cumulative population of 5.64 million in Dubai and Sharjah for the year 2023–24, a minimum sample size of 69 was required for this study. This sample size was calculated using the Qualtrics sample size calculator. We successfully recruited 80 participants with

40 members in each group. This entire process is illustrated in [Figure 2](#) below.

No personal information was collected during the research study as each participant was assigned a unique player code that they were required to use throughout the data collection process. However, information regarding age, gender, education, and the emirates in which they live was recorded after the screening questions and before the pre-test questionnaire. [Table 1](#) lists the pre-test questions that were asked of each participant.

After completing the pre-test, participants received training on their designated platform, such as non-contextual or contextual training. The student investigator ensured that participants received proper training and achieved a minimum score of 7 during the VR assessment (peri-test). The participants' scores were recorded via Google Forms embedded within the proposed VR environment and were later compared with their statements after the training. After completing non-contextual or contextual training, post-test questionnaires were given along with additional questions, which are listed in [Table 2](#) below.

Some open-ended additional questions relevant to the platform used for training (Q7–Q12) were asked of both groups to determine which group developed a better understanding of the medium used by the participants. It was also vital to determine whether they answered these questions based on prior knowledge or had attended any fire safety workshop. Questions 7–12, denoted as Post_7–Post_12, specifically assess the knowledge they gained through this particular medium of instruction; broader responses were expected to the other questions. To limit broad answers, questions 7–12 were only included in the post-test questionnaire. In addition to assessing the knowledge and skills acquired by the participants, we asked them to provide feedback on their experience using the proposed platform. [Table 3](#) lists the scaling questions used to record participant feedback on contextual learning, engagement, motivation, and system usability.

4.4 Data collection and analysis

The results of the gathered data were compared using the two-sample paired t-test for means and a two-sample assuming unequal variances ([Kim, 2015](#); [Manfei et al., 2017](#)). The two-sample paired t-test for means performs a paired two-sample t-test to ascertain whether the null hypothesis (two population means are equal) should be accepted or rejected ([Rietveld and van Hout, 2017](#)). The test does not assume that both population variances are equal. Paired t-tests are typically used to test the difference in population means before and after an intervention, such as comparing two samples of student math scores before and after a lecture. Questions 1–11: The collected data were graded, and the t-test was used for analysis. For Q12, frequencies were calculated, and a word cloud was constructed. For the remaining questions Q13–Q18, system usability was measured in terms of usage, engagement, motivation, and immersion.

The results obtained through the paired two-sample t-test for means depend on the p-value, usually the two-tailed p-value. If the p-value is less than alpha (often 0.05), the null hypothesis is rejected, which means that there is a statistically significant

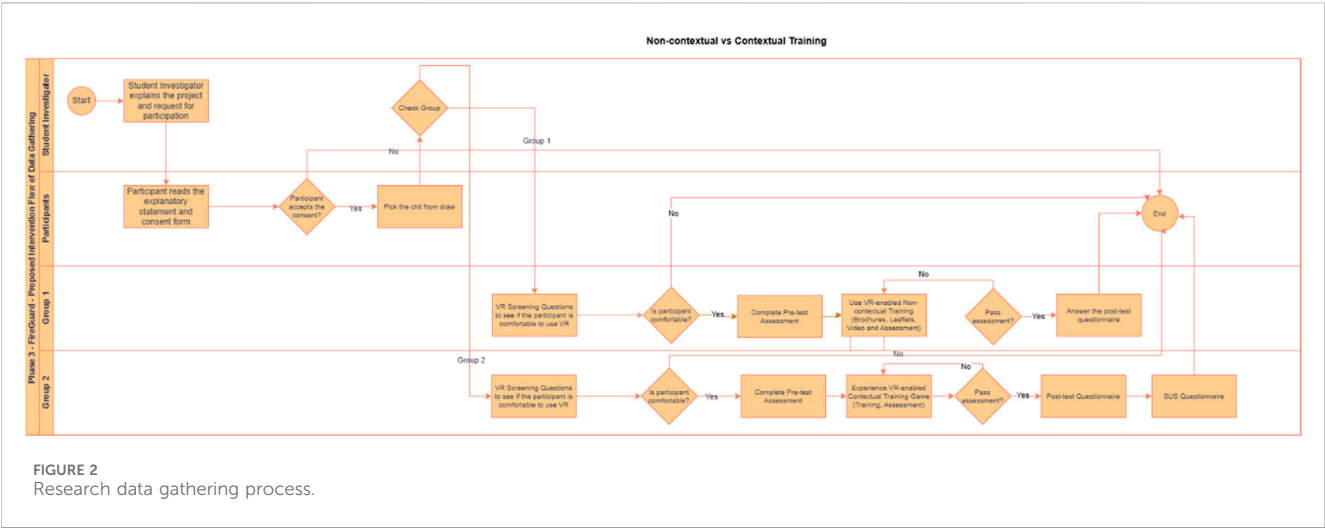


TABLE 1 Pre-test questionnaires.

Player code	Choose your code [drop-down menu appears]	Possible answers
Pre_1 (Q1)	In the event of a catastrophic house or apartment fire, what steps would you take to ensure your safety and the safety of others?	Evacuate the building and call 997. Other acceptable answers may include informing others if emergency alarms are absent or providing any reasonable, relevant information.
Pre_2 (Q2)	What are the common fire hazards that can ignite a fire in a home or apartment?	Chemicals, such as storing petrol at home, mechanical issues like jammed exhaust fans, electrical problems like overloaded sockets, and any other relevant hazards, such as candles, cigarettes, matchsticks, or lighters.
Pre_3 (Q3)	What potential electrical hazards in your home or apartment can lead to a fire?	Overloaded sockets or extensions, a jammed exhaust fan, or faulty appliances and cluttered wires or any other reasonable relevant answers.
Pre_4 (Q4)	How can exhaust fans lead to fire?	Sparks in the exhaust fan due to cooking oil vapors gathered on the exhaust fan or a jammed exhaust fan can ignite a fire.
Pre_5 (Q5)	How can candles, matchsticks, or lighters cause a fire in a home or apartment?	When you keep candles near curtains or flammable materials.
Pre_6 (Q6)	What precautions are required related to gas cylinders?	Store them outside the house or turn off the cooker burners and close the gas supply.

difference between the means of the paired samples. We used the two-sample t-test to compare Group 1 vs Group 2, assuming unequal variances, which yields similar results, as discussed above. ANOVA could also be used, and it yields the same results as the t-test. The results were then tested against ANOVA, t-test, and the Python SciPy package.

5 Results

5.1 Demographic characteristics

Table 4 below summarizes the participants based on gender, education, age group, and emirates. In Group 1 (non-contextual), 30 men and 10 women participated, while Group 2 (contextual) included 27 men and 13 women. A total of 34 participants were from Dubai, while the remaining 46 participants were from Sharjah. The education and age group information are shared in Table 4.

Once the data were collected, we rearranged them in Microsoft Excel according to the required format using the

Data Analysis ToolPak. We performed the paired two-sample t-test for means on the Group 1 data (Mondal and Mondal, 2016). Although we also used ANOVA and the Python SciPy package and obtained similar results, we chose to present the Excel results, as shown in Tables 5–8, because the Excel summary table is easier to understand than the results obtained through Python SciPy.

5.2 Group 1: non-contextual pre-test vs post-test results comparison

The Group 1 non-contextual pre-test vs Group 1 non-contextual post-test questionnaire results, presented in Table 5 below, indicate that the pre-test score for Q1 is 31.37, as determined using a two-sample paired t-test for means. The two-tailed p-value is less than 0.05. This table explains the improvement of learning within the same group. The Q2 pre-test value is 31.37, and the post-test shows a minimal improvement with a value of 45.25 and a p-value of 0.018, which is <0.05. The pre-test score for Q3 is 21.25; it increases

TABLE 2 Post-test questionnaires.

Player code	Choose your code [drop-down menu appears]	Participant selects their participation code from the drop-down menu. This code was assigned to the participant during the random draw.
Score	What was your score on the FireGuard assessment?	After completing training in the virtual reality platform, the participant was asked to answer ten questions provided within the VR game-based learning system.
Post_1 (Q1)	In the event of a catastrophic house or apartment fire, what steps would you take to ensure your safety and the safety of others?	Participants were asked to answer the question again in the post-test questionnaire to compare the pre-test and post-test results. Sample accepted answers are listed in Table 1.
Post_2 (Q2)	What are the common fire hazards that can ignite a fire in a home or apartment?	Sample accepted answers are listed in Table 1.
Post_3 (Q3)	What potential electrical hazards in your home or apartment can lead to a fire?	
Post_4 (Q4)	How can an exhaust fan lead to fire?	
Post_5 (Q5)	How can candles, matchsticks, or lighters cause a fire in a home or apartment?	
Post_6 (Q6)	What precautions are required related to gas cylinders?	
Post_7 (Q7)	What are the most potential hazards in the kitchen, bathrooms, and living rooms?	Jammed exhaust fan, overloaded sockets, malfunctioning heaters, gas cylinders, or any reasonable relevant answers.
Post_8 (Q8)	What cooking hazards have you learnt through this instructional medium?	Unattended cooking can ignite a fire, keeping combustible materials near the cooking range can ignite a fire, or any other reasonable and relevant answers.
Post_9 (Q9)	What chemical hazards have you learnt through this instructional medium?	A chemical leakage or keeping chemicals near the burner can ignite a fire.
Post_10 (Q10)	What smoking hazards have you learnt through this instructional medium?	Smoking in bedrooms or keeping ashtrays on the bed or sofa can ignite a fire. Do not smoke inside the house.
Post_11 (Q11)	Discuss the fire safety guidelines you have learnt using this medium of instruction.	Any reasonable, relevant answers were accepted, such as dealing with chemicals, electrical, or mechanical issues, cooking safety guidelines, and evacuation guidelines.
Post_12 (Q12)	How do you find the interface for developing fire hazard recognition skills?	An open-ended question asking participants for feedback about the interface they experienced.

TABLE 3 Scaling questions.

Question No.	Question	What was measured?
Post_13 (Q13)	On a scale of 1–5, where 1 means “Not at all” and 5 represents the “Extreme” value, rate your experience of the proposed game system usability. How do you believe the game-based learning approach contributes to contextual learning for fire hazard recognition?	Usability
Post_14 (Q14)	On a scale of 1–5, where 1 means “Not at all engaging” and 5 means “Extremely engaging,” how would you describe the level of engagement fostered by the VR application?	Engagement
Post_15 (Q15)	On a scale of 1–5, where 1 means “Not at all applicable” to daily life and 5 means “Extremely applicable” to daily life, how do you believe the VR learning approach contributes to contextual training for fire hazard recognition?	Contextual learning/daily life situations
Post_16 (Q16)	On a scale of 1–5, where 1 means “Not motivating at all” to develop fire hazard recognition skills and 5 means “Very motivating” to develop fire hazard recognition skills, how would you rate the motivational elements of the game?	Motivation
Post_17 (Q17)	On a scale of 1–5, how likely are you to play the game again?	Willingness to play again/likeability
Post_18 (Q18)	On a scale of 1–5, how engaging did you find the game’s immersive experience?	Immersion

to 33.87 in the post-test, with a p-value of 0.003. Q4 has a pre-test value of 16.25, which significantly increased to 56.5 during the post-test, with a p-value of $0.4e^{-6}$. Q5 exhibits a pre-test score of

27.25 and a post-test score of 33.875, with a p-value of 0.126. Q6 has an initial pre-test score of 24.5, rising to 31.62 in the post-test, with a p-value of 0.09.

TABLE 4 Demographic characteristics of Group 1 (non-contextual) vs Group 2 (contextual).

Category	Group 1 (Non-contextual learning)	Group 2 (Contextual learning)
Participants	40	40
Gender	Men: 30, Women: 10	Men: 27, Women: 13
Education	Less than high school: 0 High school diploma or equivalent: 14 Bachelor's degree: 13 Master's degree: 7 Doctorate (Ph.D.): 6	Less than high school: 2 High school diploma or equivalent: 11 Bachelor's degree: 13 Master's degree: 8 Doctorate (Ph.D.): 6
Age (Years)	18–24: 12 25–34: 15 35–44: 9 45–54: 2 55–64: 1 Older than 65: 1	18–24: 13 25–34: 4 35–44: 16 45–54: 6 55–64: 1 Older than 65: 0
Emirates	Dubai: 18, Sharjah: 22	Dubai: 16, Sharjah: 24

5.3 Group 2: contextual pre-test vs post-test results comparison

The Group 2 contextual training pre-test and post-test results were compared within the same group, as shown in Table 6 below. The Q1 pre-test score was 40.87, and after contextual training using the VR platform, the score increased to 88.75, with a two-tailed p-value of $0.006e^{-6}$. The Q2 pre-test score was 26.25, whereas the post-test scores significantly improved to 78.125, with a p-value of $0.8e^{-12}$. The Q3 initial pre-test score was 20.125, while the post-test score increased to 64.5, with a p-value of $0.18e^{-7}$. The Q4 pre-test score was 18.5, and the post-test score rose to 70.25, with a p-value of $0.28e^{-10}$. The Q5 initial pre-test score was 21.875, improving to 48.5, resulting in a p-value of $0.12e^{-8}$. The Q6 pre-test score was 17.75, increasing to 39.25, with a p-value of $0.80e^{-5}$.

5.4 Group 1 and Group 2 (non-contextual vs contextual) results comparison

Table 7 below reveals interesting insights into the comparison between Group 1 and Group 2, as it compares the post-test questionnaire results for both groups. Because we are dealing with two independent groups, we worked under the assumption that their variances are not equal. Looking at Q1, Group 1 scored an average of 60.5, while Group 2 came in higher at 88.75, with a p-value of $0.3e^{-4}$. On Q2, Group 1 scored 45.25 on the post-test, while Group 2 did significantly better with a score of 78.125, resulting in a p-value of $0.017e^{-8}$. Moving to Q3, Group 1 was restricted to 33.875, whereas Group 2 scored 64.5, with a p-value of $0.13e^{-4}$. On Q4, Group 1 scored 56.5, but Group 2 reached 70.25, showing a p-value of 0.109. For Q5, Group 1 scored 33.87, and Group 2 scored 48.5, with a p-value of 0.02. Finally, on Q6, Group 1 had a score of 31.62, while Group 2 scored 39.25, with a p-value of 0.260. Although there are some slight differences in the results for Q4 and Q6, the differences were not statistically significant.

Table 8 provides the results of the remaining questions Q7–Q11, which only appeared on the post-test questionnaire for both groups. On Q7, Group 1 scored 30.75, while Group 2 achieved 59.125, with a

p-value of $0.02e^{-4}$. Against Q8, the average score was 30.125 for Group 1 and 66.875 for Group 2, with a p-value of $0.03e^{-4}$.

Figure 3 depicts the Group 1–Non-contextual (NCQ) question mean scores vs Group 2–Contextual (VRQ) question mean scores. The box plots in Figure 4 reflect the median, mean, and dispersion of data. On Q9, Group 2 recorded double the score of Group 1 (20.125 vs 41.365), with a p-value of $0.1982e^{-2}$. A significant difference was observed on Q10, where Group 1 scored 24.125 while Group 2 scored 64, with a p-value of $0.06e^{-5}$. Lastly, on Q11, Group 1 and Group 2 scored 30.625 and 53.25, respectively, with a p-value of $0.175e^{-3}$. Overall, Group 2 outperformed Group 1 in all aspects.

5.5 Participant feedback on the non-CL vs CL interface

Post_12 How do you find the interface for developing fire hazard recognition skills? Question 12 pertains to reviewing the platforms for developing fire hazard recognition skills, where participants were asked to give feedback on the interface. Participants provided reviews of both platforms, and their reviews included insightful comments. These reviews were compiled and categorized using similar terms or keywords; for example, “valuable information,” “Explains everything,” “Informative,” “Developed Skills” and similar comments were replaced with “Informative Session,” negative comments such as “No big difference, I can read from brochures and watch videos on my mobile,” “It’s just like reading,” “Somewhat useful, but needs to be more precise and interactive and catchy,” etc., were replaced with “Improvement required” for Group 1 comments. A similar approach was followed with Group 2 comments by replacing positive and negative comments with similar keywords.

This step was crucial, as we received a broad range of perspectives from users; a frequency table was required to group similar keywords and visualize the text data. Figures 5a,b show the word cloud and frequency table. Figure 5a represents Group 1–non-contextual comments, while Figure 5b displays a frequency table and word cloud for Group 2–CL. Most Group 1 users expressed dissatisfaction with the interface and suggested platform

TABLE 5 Two-sample paired t-test for means (Group 1 non-contextual pre-test vs Group 1 non-contextual post-test results).

Q No.	Group 1 NC-Pre	Group 1 NC-Post/	Variance (Pre vs Post)		Pearson Correlation	t Stat	P (T ≤ t) one-tailed	t Critical one-tailed	P (T ≤ t) two-tailed	t Critical two-tailed	Significance (p < 0.05)	Improvement % (Gain)
Q1	31.37	60.5	1,064.08	1,139.48	0.324197322	−4.7726676	0.000012796	1.684875122	0.000025593	2.02269092	Yes	93%
Q2	31.37	45.25	601.27	776.86	0.067953114	−2.447771	0.009489252	1.684875122	0.018978503	2.02269092	Yes	69%
Q3	21.25	33.875	548.40	596.78	0.435043263	−3.1381114	0.001616584	1.684875122	0.003233168	2.02269092	Yes	59%
Q4	16.25	56.5	497.12	1,686.15	−0.05671307	−5.3229433	0.000002250	1.684875122	0.000004500	2.022690920	Yes	248%
Q5	27.25	33.875	862.76	535.24	0.499060947	−1.5618229	0.06320437	1.684875122	0.126408741	2.02269092	Yes	24%
Q6	24.5	31.625	572.82	721.01	0.464118249	−1.7065052	0.047933095	1.684875122	0.095866189	2.02269092	Yes	29%

TABLE 6 Two-sample paired t-test for means (Group 2 contextual pre-test vs Group 2 contextual post-test results).

Q No.	Group 2 VR-Pre	Group 2 VR-Post	Variance (Pre vs Post)		Pearson correlation	t Stat	P (T ≤ t) one-tailed	t Critical one-tailed	P (T ≤ t) two-tailed	t Critical two-tailed	Significance (p < 0.05)	Improvement % (Gain)
Q1	40.875	88.75	1,238.32	513.78	0.232859205	−8.148936	0.000000000300	1.6848751217	0.000000000600	2.02269092003	Yes	117%
Q2	26.25	78.125	359.94	522.68	0.038056045	−11.25592	0.00000000000004	1.6848751217	0.00000000000008	2.022690920037	Yes	198%
Q3	20.125	64.5	304.47	1,111.28	0.103700249	−7.798564	0.00000000009	1.6848751217	0.0000000018	2.0226909200	Yes	220%
Q4	18.5	70.25	359.23	1,201.22	0.030836481	−8.395135	0.0000000000028	1.684875122	0.000000000283	2.022690920	Yes	280%
Q5	21.875	48.5	239.34	978.46	0.36890828	−5.739582	0.0000005956	1.6848751	0.0000012	2.0226909	Yes	122%
Q6	17.75	39.25	330.71	1,087.88	0.387196884	−4.40221	0.0000404	1.6848751	0.0000808	2.0226909	Yes	121%

TABLE 7 Two-sample paired t-test assuming unequal variances (Group 1 non-contextual vs Group 2 contextual training post-test result comparison).

Q No.	Group 1 NC- Post	Group 2 VR- Post	Variance (Post vs Post)	t Stat	P (T ≤ t) one- tailed	t Critical one- tailed	P (T ≤ t) two- tailed	t Critical two- tailed	Significance (p < 0.05)	Improvement % (Gain)
Q1	60.5	88.75	1,139.49	513.78	-4.3941679	0.00001997	0.00003994	1.99546893	Yes	47%
Q2	45.25	78.125	776.86	522.68	-5.767687	0.00000008	0.00000017	1.99210215	Yes	73%
Q3	33.875	64.5	596.78	1,111.28	-4.686563	0.000006	0.000013	1.993464	Yes	90%
Q4	56.5	70.25	1,686.15	1,201.22	-1.618383	0.054862	0.109723	1.991673	No	24%
Q5	33.875	48.5	535.24	978.46	-2.377419	0.010046	0.020093	1.993464	Yes	43%
Q6	31.625	39.25	721.01	1,087.88	-1.133870	0.130230	0.260460	1.992102	No	24%

improvements. In contrast, Group 2 users provided positive feedback, as shown in the word cloud in Figure 5b. Some of the prominent features highlighted by Group 2 users are “Engaging,” “Fun,” “Informative Session,” “Good,” “Immersive,” and “User-friendly.” A few users also suggested some improvements to the CL platform.

5.6 Non-contextual vs contextual system usability scores

Table 3 lists the scaling questions starting from Post_13–Post_18. The System Usability Scale (SUS) scores are tabulated in Table 9. These scaling questions were rated on a scale of 1–5, where 1 represents the lowest value and 5 the highest value. Post_13 pertains to CL system usability. The average recording of Group 1, of 40 participants, was 2.58, indicating that participants felt the non-contextual training platform was not well-suited for a CL system usability. In contrast, Group 2 CL platform users gave an average rating of 4.45, strongly supporting the system usability for contextual learning and the development of hazard recognition skills. Post_14 focused on user engagement. Group 1 disapproved of engagement factors in the non-CL application, as reflected in their low average score of 2.98. On the other hand, Group 2 participants provided a significantly higher score of 4.56, supporting the platform’s appeal for engagement. Post_15 assessed daily life application to contextual learning for fire hazard recognition with Group 1 and Group 2 learners. While Group 1 participants gave an above-average score of 3.13, suggesting a satisfactory experience, Group 2 participants demonstrated a stronger connection with the platform, as reflected in the highest score of 4.73. Post_16 evaluated the motivation level in the non-contextual and contextual VR applications; the score of 3.00 of Group 1 shows a satisfactory motivation level. However, Group 2 again outperformed with a score of 4.68, which promoted the motivation level. Post_17 measured how likely the user is to play the proposed game again. Group 2 received the highest score of 4.73, showing that users are more inclined to play the game again using this platform, whereas Group 1 received a satisfactory response of 3.10. Finally, Post_18 question assessed the immersion level or feel of presence. Group 1 received a score of 2.98, indicating a weaker level of immersion, while Group 2 achieved a score of 4.58, suggesting a better immersion and feel of presence in the proposed platform.

6 Discussion

Eighteen different parameters were used to assess the two VR-based platforms. Group 1 participants experienced the non-contextual learning using a VR platform to develop their knowledge and understanding of fire hazard recognition skills and recorded their responses during the pre-test and post-test questionnaires. Group 2 used a VR-enabled CL platform to develop fire hazard recognition skills. According to Table 5, there was a significant improvement within Group 1 (the non-CL group), as evident from the difference between the pre-test and post-test scores. For Q1 in this group, participants’ knowledge increased by 93% after using the VR-enabled non-CL application. This

TABLE 8 Two-sample t-test sample assuming unequal variances (Group 1 non-contextual vs Group 2 contextual training post-test result comparison).

Q No.	Group 1 NC-Post	Group 2 VR-Post	Variance (Post vs Post)		t Stat	P (T ≤ t) one-tail	t Critical one-tail	P (T ≤ t) two-tail	t Critical two-tail	Significance (p < 0.05)	Improvement % (Gain)
Q7	30.75	59.125	410.96	784.47	-5.190430	0.000001	1.666600	0.000002	1.993943	Yes	92%
Q8	30.125	66.875	758.32	1,352.16	-5.059372	0.000002	1.666294	0.000003	1.993464	Yes	122%
Q9	20.125	41.375	419.86	1,311.52	-3.229929	0.000991	1.669804	0.001982	1.998972	Yes	106%
Q10	24.125	64	690.88	1,424.62	-5.4830790	0.0000003	1.6669145	0.0000006	1.9944371	Yes	165%
Q11	30.625	53.25	595.11	721.22	-3.943993	0.000088	1.664885	0.000175	1.991254	Yes	74%

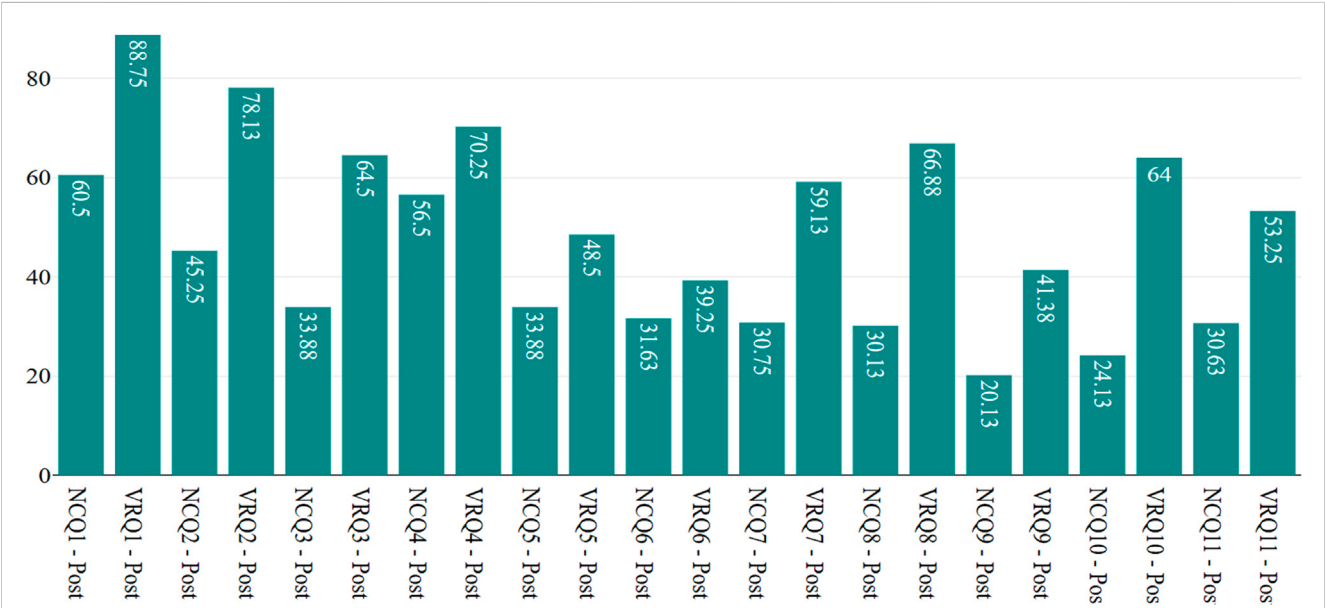


FIGURE 3 Non-contextual (NCQ) vs contextual (VRQ) post-test questions means comparison.

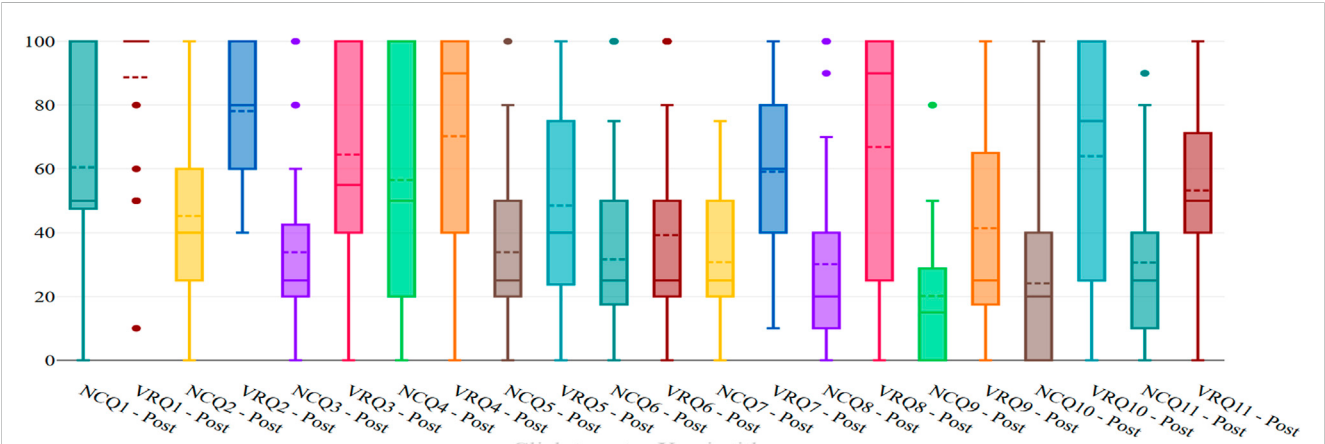
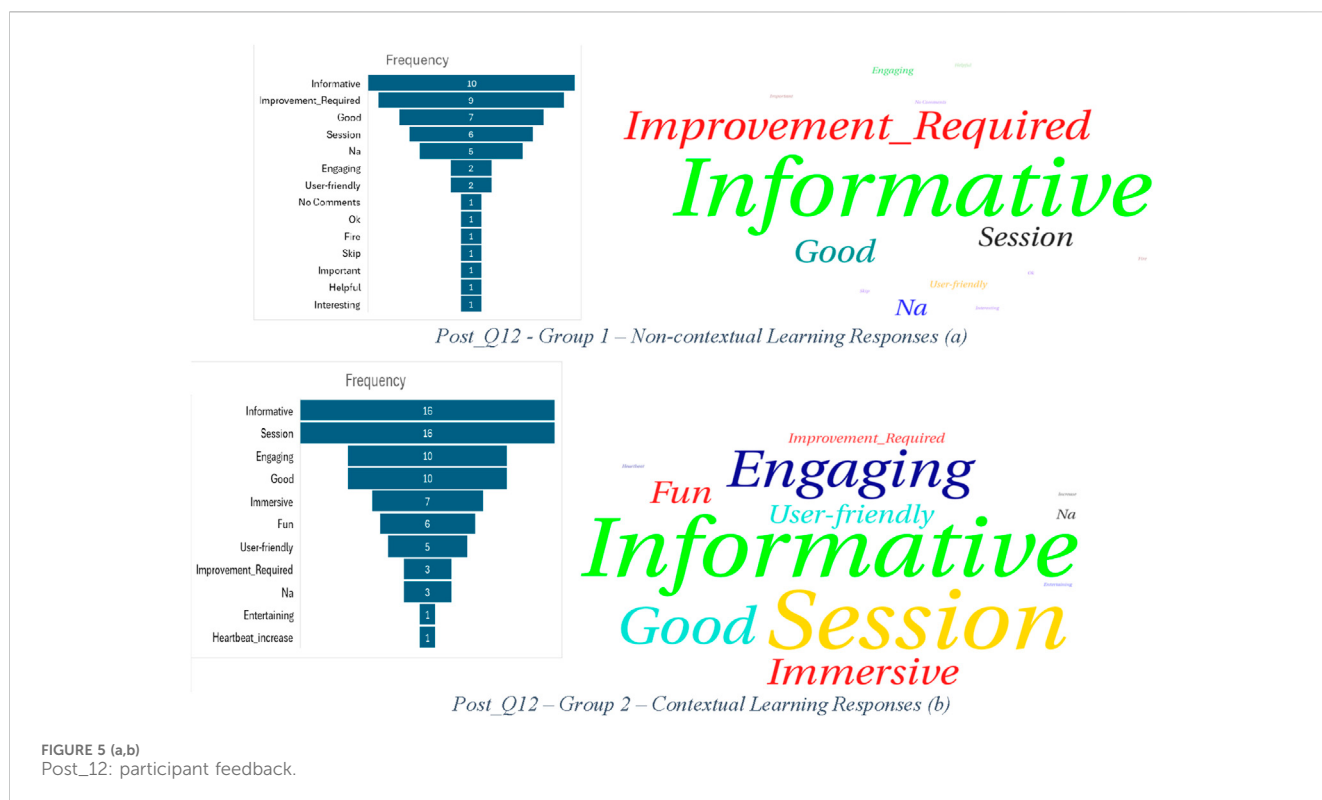


FIGURE 4 Non-contextual (NCQ) vs contextual (VRQ) post-test results box plots.



percentage was calculated by subtracting the pre-test score from the post-test mean score, then dividing the result by the pre-test mean score, and finally multiplying by 100. For Q2 in Group 1, knowledge increased by 44%. Similarly, for the remaining questions (Q3–Q6), the improvements in knowledge gains were 59%, 248%, 24%, and 29% respectively. Although we should compare the scores without using the virtual reality platform to generalize the results, the VR platform plays a specific role in improving knowledge and skills.

The CL group (Group 2) also showed significant improvement, as reflected in **Table 6**. The mean scores of pre-tests and post-test training were compared, revealing increased knowledge and skills development related to fire hazard recognition. For Q1, Group 2's knowledge increased by 117%, while Q2 revealed 198% improvement. Similarly, Q3–Q6 recorded improvements of 220%, 280%, 122%, and 121%, respectively.

Tables 7 and 8 compare the non-contextual and contextual groups (Group 1 vs Group 2). After undergoing two different training methods, their post-test scores were compared and analyzed, revealing several valuable insights. On Q1 of the post-test results for Group 1 and Group 2, Group 2 performed 47% better than Group 1, indicating they are better prepared to respond in the event of a catastrophic house or apartment fire. This is a crucial finding, as civil defense and emergency departments strive to educate citizens on how to handle such situations. The results suggest that contextual learning can significantly enhance an individual's understanding of emergency response. Additionally, VR game-based learning proves to be a more cost-effective approach than the expenses associated with developing and distributing brochures and leaflets.

The unequal variances two-sample t-test revealed that Group 2 performed 92% better than Group 1 on Q7, specifically in

understanding potential hazards in the kitchen, bathroom, and living room. This indicates that Group 2 provides a better understanding of hazard identification in the kitchen, living room, and bathrooms, making participants more aware of these common hazards that can lead to fire. Recognizing these hazards at an early stage is always recommended to avoid a fire. Therefore, Group 2 in this study is significantly better prepared than Group 1. The Q8 post-test reveals that, based on the mean score, Group 2 performed 122% better than Group 1. This indicates that Group 2 developed a better understanding of common cooking hazards in living communities, making participants more aware of the situations. This is because participants were fully immersed in a kitchen, observing cooking hazards and remembering.

Chemical hazards, addressed in Q9, can be of different types. Group 2 outperformed Group 1 by a factor of 106%. Although the leaflets and brochures contained sufficient information, participants in Group 1 struggled to relate this information. In contrast, participants in Group 2, who experienced the storage and spill of a chemical hazard in a scene that caused an instant fire, were able to correlate this situation and respond to this question effectively. Smoking is common in Sharjah and Dubai, and many fire incidents have happened due to smoking. This is addressed in Q10 in the post-test questionnaire, where participants were asked about smoking hazards and safety precautions. People in Group 2 responded 165% more accurately than people in Group 1. Everyone should be aware of these hazards and follow the safety measures. In Q11, participants were asked to discuss fire safety guidelines they learned. Although clear instructions were provided on the brochures, leaflets, and instructional videos in Group 1, Group 2 demonstrated increased comprehension of open-ended questions. Group 2 summarized everything they observed during the situational training, resulting

TABLE 9 System usability scale (SUS) scores for non-contextual and contextual VR applications.

Metric	Result	Interpretation
Group 1 (non-contextual SUS mean score comparison)		
Overall average score	2.96	The overall mean value for usability is 2.96 for the Group 1 non-contextual training virtual reality application, indicating that there are likely areas for improvement in system usability, engagement, motivation, and contextual learning.
Post_13	2.58	
Post_14	2.98	
Post_15	3.13	
Post_16	3.00	
Post_17	3.10	
Post_18	2.98	
Group 2 (contextual VR application SUS mean score comparison)		
Overall average score	4.62	The mean score for usability is 4.62, indicating a generally positive perception of the system's usability, engagement, motivation, and contextual learning.
Post_13	4.45	
Post_14	4.56	
Post_15	4.73	
Post_16	4.68	
Post_17	4.73	
Post_18	4.58	

in more concise answers. There was a 74% increase in knowledge and skills among Group 2 participants compared to Group 1.

The substantial difference between the two groups is mainly due to the nature of the training. Participants in Group 2 were fully immersed in real-life situations, which helped them develop cognitive skills of remembering and recalling information. This explains why their improvement was significantly higher than that of Group 1. In contrast, Group 1 struggled with retention of information. Some participants reported difficulty remembering information from brochures and leaflets, stating that they quickly forgot what they had read. Participants received more direct messages through game-based virtual reality training, which reduces their burden of remembering and recalling. We believe that adding the question, *Have you received prior training on fire hazard recognition?*, could provide further insights, as previous training might have influenced the results. However, the pre-test results clearly indicate that contextual training effectively increased participants' knowledge and skills. Although both groups used the same VR platform, the absence of immersion, situational awareness, motivation, feedback, and a sense of presence had a significant impact on participant understanding.

Q12 asked how participants found the interface for developing fire hazard recognition skills. We received a great deal of helpful information. Because the responses to this question were broad, we categorized them by replacing words of the same meaning with single terms, as explained earlier. Group 1 participants noted that while the session was informative, it required improvement. Additionally, Group 1 participants gave fewer responses than Group 2, as seen in Figure 5. In contrast, Group 2 participants provided more encouraging reviews, with keywords such as

“engaging,” “fun,” “informative session,” “immersive,” and “user-friendly” appearing more prominently. A few participants suggested improvement with respect to 3D models.

The system usability scale (SUS) questionnaire for Q13–Q18 has clear interpretations, as reported in Table 9. Group 1 expressed disapproval of system usability for contextual learning (Q13), user engagement (Q14), and immersion (Q18). Mild satisfaction was recorded in daily life situations (Q15), motivation (Q16), and how likely to play the game again (Q17). The overall SUS score for Group 1 was below the satisfaction threshold, indicating areas for improvement. On the other hand, Group 2 participants achieved a noteworthy overall SUS score and demonstrated complete confidence in system usability for contextual learning (Q13), user engagement (Q14), daily life situations or situational learning (Q15), motivation (Q16), how likely to play the game again (Q17), and immersive experience (Q18).

An increase in environmental temperature leads to global warming, primarily due to human activities (Yilmaz and Can, 2020). Due to extreme temperatures, floods, the use of combustible materials inside the buildings, and human negligence, fire incidents are reported frequently. To raise awareness among the general public, we designed an innovative solution for fire hazard awareness to reduce the risk of fires, as global warming and urbanization may not be entirely avoidable (Agusty and Anggaryani, 2021; Cho and Park, 2023; Jamei et al., 2017). Our evaluation revealed that contextual learning through emerging VR technology was more effective than conventional fire safety awareness campaigns and workshops. The accessible and immersive nature of this training significantly improved occupants' knowledge and skills in identifying fire risks.

The Chinese government has made considerable investments in using VR technology with the primary objective of addressing limitations of teaching and learning (Zhan et al., 2020). For many years, the country received complaints from the higher education department about the heavy reliance on lecturing and video demonstrations as a primary tool for teaching knowledge and skills-related concepts, which fail to incorporate context, leading to several drawbacks in the learning process (Zhuang and Tao, 2022). Many developed countries like the United States, the United Kingdom, Australia, and China, among others, have accredited virtual reality courses in various fields of life (Burdea, 2004; Whitman et al., 2004). These significant developments in VR-based training aim to make complex content, especially critical skills such as firefighting, more accessible to participants (Narciso et al., 2020). Through these innovations, people are no longer limited to observing complex and abstract knowledge; instead, they can engage in immersive, experiential learning. Among the many other research frameworks related to education, contextual learning, also known as situated learning, has proven to be highly effective, as it supports both physical and social context development, an essential part of any learning process (Suryawati and Osman, 2017).

Contextual or situated learning refers to thinking and processing in ways that enable the acquisition of knowledge and skills, according to Lave and Wenger (1991). Extended reality, as an emerging technology in education, provides learners with new opportunities that enhance innovation and engagement (Lave and Wenger, 1991). It creates an environment where learners experience immersion (a sense of presence) in a dedicated setting, engaging their visual and auditory senses through a focused task (Slater and Wilbur, 1997). With this, we recommend incorporating the emerging technologies, such as augmented and virtual reality, into fire hazard recognition to develop life-saving skills among the general public. Ishak et al. (2023) supported our outcomes through their results and strongly recommended the formulation of strategies in disseminating knowledge and awareness about fire safety measures.

We recorded the following observations during the data collection process, which are worth mentioning here:

- A few participants' extensive head movement caused them to lose focus on the main instruction written on screen.
- Although participants were given training on how to use VR controllers, they still pressed buttons unnecessarily, which delayed their training and assessment.
- Participants were moving unnecessarily to explore the immersive environment. The student investigator assisted them periodically in overcoming this issue.
- Some participants were more interested in exploring the scene and playing with game objects. A future recommendation is to deactivate object selection in the virtual environment to avoid this issue.
- Some participants experienced stress due to first-time use.
- An increase in heart rate was observed in some participants via their smart watches during the experiment.

- Taller participants faced calibration issues and were asked to sit in a chair for a better view during the experiment.
- Some female participants wore hair clips, which made it difficult for them to adjust the VR headsets. A female colleague assisted in adjusting the headset for these participants.
- Some participants repeated their training and assessment due to lower scores.
- Wi-Fi disconnection was observed, but it did not affect the experiment.
- Some participants were more focused on exploring the virtual environment rather than reading on-screen instructions. A guided map should be used within the virtual environment to assist participants with on-screen instructions.
- Older participants experienced vision difficulties even with glasses and required lens adjustments.
- Participants complained that they forgot the instructions in brochures and leaflets.
- The age difference between the two study groups was due to the different data collection venues. At Skyline University, we had a younger population of students, faculty, and staff, whereas at PMC, more middle-aged participants were recruited, primarily consisting of patients, staff, and visitors.

7 Conclusion

Fire incidents are a global problem, and the emirates of Sharjah and Dubai are facing challenges due to climate change and urbanization. The high temperatures, low humidity, and dry winds associated with global warming significantly increase the fire risk in the residential areas of Dubai and Sharjah. Global warming may be beyond our control, but we can prepare for the anticipated extremely hot and dry conditions to mitigate the fire risks. Combined with precautionary responses to extreme temperatures, risks such as storing chemicals and gas cylinders inside the home/apartment, using flammable materials in construction, and celebrating family occasions indoors can create a hazardous environment where fire safety must be the top priority. Although the official authorities have run several awareness campaigns regarding fire safety, the incidents are still being reported.

To study whether it is more effective to use awareness campaign materials such as brochures, leaflets, and instructional videos or a game-based virtual reality scenario-based learning, the two VR platforms were developed for promoting fire hazard recognition skills among the residents of both emirates in the quest of answering our research question: *Does the non-contextual vs. contextual learning of fire hazard recognition knowledge and skills influence the residents of Dubai and Sharjah Emirates to recall and apply fire safety guidelines at their home or apartment?* It was concluded that residents could not develop sufficient understanding using awareness campaign materials such as brochures, leaflets, and instructional videos in response to the hazard identification. The residents were unsure about the steps to take to ensure their own safety and the safety of others.

In contrast, VR-enabled contextual training significantly helped participants make appropriate decisions in the event of a catastrophic fire at their home or apartment. Similarly, the study

revealed that the passive nature of awareness campaign materials was inadequate in conveying common fire hazards in a living community. Many residents take no notice of jammed exhaust fans that could lead to fire. The study identified that the participants who received non-contextual VR training were unable to understand how an exhaust fan could lead to fire. On the other hand, VR contextual training, where participants observed how a jammed exhaust fan could lead to fire through simulations and experienced smoke and fire effects, helped build their understanding of this important hazard. Although the awareness campaign materials clearly state the inappropriate use-cases of candles, matchsticks, lighters, and gas cylinders, most participants could not relate these objects to high-risk situations, rendering the awareness campaigns ineffective. For instance, while the use of gas cylinders is common in the kitchen, the awareness campaign material failed to increase the general public's understanding of their associated risks. Compared to non-contextual training, VR-enabled contextual game-based learning provided participants with an immersive experience, helping them recognize and recall information to better understand hazardous situations.

The traditional awareness campaign materials did not effectively support the development of essential hazard recognition with regard to kitchens, bathrooms, living rooms, storing chemicals at home, and smoking hazards in homes or apartments. Participants in Group 1, who underwent non-contextual learning, admitted that they struggled to remember instructions written on brochures, leaflets, and videos. At the same time, the results indicated that CL virtual reality game-based learning was significantly more effective in developing these critical skills. Therefore, replacing awareness campaigns with VR game-based learning can be very effective in enhancing knowledge and understanding. Instead of spending vast amounts on these awareness campaigns, promoting VR-based fire safety skills is recommended as it significantly increases participants' knowledge and skills.

Because we implemented a threshold score of 7 in the VR application post-tests, failing to obtain this threshold redirected the participants to repeat the training. We acknowledge that we did not record the number of times the participants repeated any training. Future research can record this parameter to investigate any relationship between participant understanding and the development of fire hazard recognition skills. Participant age groups and educational backgrounds are critical factors, and we admitted participants from various age groups and educational levels, which may restrict generalization. Therefore, we recommend studying a specific age group in conjunction with certain education levels to generalize the results. Furthermore, this is the era of artificial intelligence, and using a conversational AI model to replace the pre-test and post-test questionnaires is recommended as some non-IT background participants may face challenges in typing answers for these questionnaires. Conversational AI models can overcome this challenge, making the pre-test and post-test more engaging and valuable for all types of participants.

We acknowledge that we should have asked participants whether they had prior training experience with fire safety skills before participating in this research study. However, the initial assessment suggested this was their first exposure to fire-related training. Additionally, participants varied in age groups due to the two different research data collection venues. Future research should investigate whether a participant's age group affects fire hazard recognition.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was obtained from the individual(s) for the publication of pre-test and post-test questionnaire results. The studies involving humans were approved by Swinburne University of Technology, Australia. 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 data included in this article.

Author contributions

TF: Writing – review and editing, Writing – original draft, Conceptualization. MT: Writing – review and editing, Supervision, Methodology, Project administration. AA: Supervision, Writing – review and editing, Validation, Investigation, Methodology, Visualization.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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