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Evaluating the Effectiveness of Virtual Reality Fire Extinguisher Training: Mixed Method Approach

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Safety training is standard practice across various industries and helps reduce the number of accidents. Certain industrial tasks pose a high risk of injury, even with training, such as welding, construction, and mining. Virtual Reality (VR) can serve as an alternative solution for training scenarios in these fields since it provides a safe and engaging environment. This research conducts a mixed-method analysis to evaluate the effectiveness of VR fire extinguisher training. A hybrid experimental approach was adopted during the study, offering both practical and VR training to students. The factors considered in the effectiveness evaluation included usability, realism, engagement, knowledge acquisition, knowledge retention, and ease of navigation. Qualitative and quantitative data were analyzed jointly using Kirkpatrick's Model and the Technology Acceptance Model. The analysis revealed that VR training successfully developed situational awareness and emergency preparedness among the trainees. The developed VR module was highly engaging and provided an interactive virtual environment. However, there were reports of navigation challenges and sensory sickness. User feedback indicated that a highly immersive VR environment with high-quality visuals and interactive components can enhance the effectiveness of VR training. The established effectiveness evaluation framework in this study can be adopted as a standard tool for evaluating further developed VR-based training modules. The findings contribute significantly to the development of VR as an alternative tool for safety training across various sectors.

Key words: Virtual Reality, Virtual Training, Fire Safety, Mixed-Methods, Realism, Engagement, Knowledge Retention, Kirkpatrick's Model, Technology Acceptance Model, Framework

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Abbreviations

HMD-Head Mounted Display

VR- Virtual Reality

3D- Three-Dimensional

SD- Standard Deviation

M- Mean

PU- Perceived Usefulness

PEOU- Perceived Ease of Use

ATU- Attitude Towards Use

BI- Behavioural Intention

1 Introduction

1.1 Background

Virtual reality (VR) has evolved as a transformative technology, it has transitioned from primarily entertainment-based applications to significant roles across various industries. According to Gigante (1993), VR can be defined as an illusion of participating in activities within a synthetic environment, it relies on three-dimensional space, head-tracked displays, hand/body tracking, and binaural sound. Early VR application was facilitated by military and aerospace applications, specifically flight simulators, which required high realism and rapid response capabilities (Gigante, 1993). Last few decades, VR has expanded dramatically across multiple industries, mostly due to the advancements in graphical technology, computing power, and interactive designs. It allows the user to interact more realistically inside the virtual realm, which has enabled its application across industries like healthcare, entertainment, education, and professional training (Sherman & Craig, 2018). Virtual reality has been used for safety training in multiple sectors, specifically the construction industry, chemical industry, mining industry, and energy sector, where VR can safely simulate dangerous scenarios (Grassini & Laumann, 2020).

Fire safety training is very crucial to develop situational awareness (Kwegyir-Afful et al., 2023) among trainees, and it is a critical component of occupational safety programs, which are designed to prepare individuals to act proactively in an emergency fire scenario. Traditionally, fire safety training is done with approaches such as classroom instructions and live fire drills, which are often constrained by safety risks, high costs, and logistical complexity (Kinateder et al., 2014). To address these challenges, VR can be used as a viable alternative for fire extinguishing training. Applying VR technology for fire safety training can have a positive impact on participants' knowledge retention, situational awareness development, and decision-making (Grassini & Laumann, 2020).

Inside the virtual realm, trainees can interact with the virtual fire scenarios, and the training scenario is repeatable, providing the participants a safe environment to participate in the training multiple times. As computing technology has advanced, some more powerful processors facilitate making the learning environment in VR more immersive and engaging. Furthermore, VR has the potential to make a scalable and customizable training environment that can be customized according to the specific building layouts, fire scenarios, or occupational contexts.

Multiple factors define the effectiveness of VR-based training, specifically fire extinguishing training. According to multiple studies, crucial elements of VR training are immersion and presence, realism of the scenario, interactivity and user control, consequence visualization, feedback, and gamification elements (Patle et al., 2019; Smith & Ericson, 2009). Immersion and realism define how well the participant feels present in the virtual environment. Active participation inside the virtual realm, navigation, and interaction with the virtual components make the training more engaging and increase the transferability of the skills learnt in the virtual realm to the real world.

Despite having promising potential, VR-based training and the implementation of VR in safety training are relatively new. A thorough investigation is required to establish its efficacy compared to the traditional training methods. Evaluation of factors such as knowledge retention rate, realism, immersion, engagement, and the limitations of VR fire extinguishing training is essential to validate its broader adoption. Effectiveness measurement for virtual reality-based training is crucial as this ensures that learning outcomes are achieved and the skills acquired virtually are transferable to the real world (Abich et al. 2021).

1.2 VTC (Virtual Training Certification)

Virtual Training Certification **(VTC)** is a multi-partner initiative among multiple SMEs and universities. The initiative aimed to develop a globally scalable digital certification platform for training achieved using Virtual Reality (VR) and Artificial Intelligence (AI). VTC focused on two major user cases: certifying the skills learned at vocational training and certified competency cards (fire safety, crane operation, and general work safety certifications). VTC integrates VR-based training modules and their assessment through case studies across Finland, Poland, Singapore, and Oman. Figure 1 illustrates the VR environment developed by project partner.

However, the scope of this thesis work contributes to the second user case for fire safety training. This thesis work combines quantitative and qualitative data. The completion of this thesis work assesses learning outcomes and the effectiveness of VR fire extinguisher training. As a partner of this project, I contributed through data collection, surveys, and data analysis. Finally, developing an effectiveness evaluation model for VR-based training which is done through the completion of this thesis work.

Figure 1. Virtual Training Facility Developed by Project Partner[1]

1.3 Research Objective and Research Questions

1.3.1 Research Objective

The core aim of this research work is to evaluate the effectiveness of VR-based fire extinguishing training. Multiple factors are very crucial and affect the learning experience of trainees. This research work outlines those factors that have a significant influence on the overall effectiveness of VR fire extinguishing training. In a broader perspective, this research work assesses how effective VR training was in improving the knowledge retention and skill preparedness among the training participants.

This study investigates the effect of engagement and realism of virtual fire scenarios on the overall effectiveness of the training. Factors such as usability challenges, navigation difficulties, and external or virtual distractions are also investigated, which are very crucial and has an immense effect on the overall learning experience.

Ultimately, this research work has a significant contribution to the growing body of knowledge on immersive learning technologies. It serves as empirical evidence offering practical recommendations for designing user-centric virtual training environments that are not only pedagogically sound but also engaging and highly adaptable across industries and regions. The findings have remarkable implications for educators, VR developers and policy-makers who are interested in developing VR technology to be used in safety training industries.

[1] https://virtualtraining.ade.fi/en/certified/european-hot-work-certificate-2/

1.3.2 Research Questions

This study explores the effectiveness of VR fire extinguisher training based on user experience analysis. The evaluation of the effectiveness of fire extinguisher training is done based on themes. The following research questions in Table 1 are formulated to investigate the various aspects of the VR training. This research question (RQ) covers the key themes and the improvements required for these themes. It also explores participants' perceptions of learning outcomes and knowledge retention.

Table 1. Research Questions

No	Research Questions
RQ1.	How effective is VR-based fire extinguisher training in enhancing participants' **knowledge retention** and **skill preparedness**?
RQ2.	What is the participants' perception on **realism and engagement** of VR training?
RQ3.	What are the **usability challenges**, such as navigation difficulties, reported by participants?
RQ4.	How do participants' experiences and **learning outcomes** vary based on prior VR experience?
RQ5.	What **improvements** can be made to **enhance the effectiveness** of VR-based fire extinguisher training?

1.4 Research Significance

In the last few decades, employing VR in education and training has gained extensive popularity. Flight simulators powered by virtual reality and augmented reality have become a standard component in pilot training. These simulations offer a cost-effective simulation and diverse situations to train pilots without the risk of injury or danger. Chittaro & Buttussi (2015), have found that mobile VR safety briefings have been proven more effective than traditional safety information video instructions.

According to Radianti et al. (2021), VR applications are particularly effective in teaching practical knowledge, such as safety training. They have stressed that extensive research is required to address the gap in the educational potential of VR and the knowledge acquisition depth of existing VR applications. Figure 2 sums up the growing demand for VR from 2024 to 2029 in the context of the global market. The Business Research Company has claimed in their annual report that the market is expected to grow 40.6% per annum (The Business Research Company, n.d.).

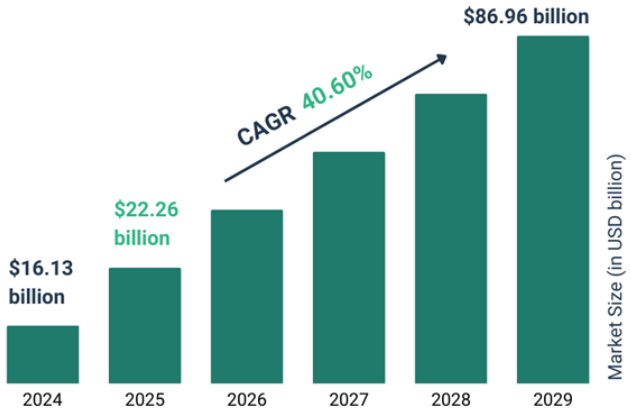

Figure 2. VR Education Global Market (The Business Research Company, n.d.)

Furthermore, Kwegyir-Afful & Kantola (2021) have argued that VR can be a revolutionary tool to transform vocational training if it is designed according to the user experience and with a focus on skill transfer. This study responds to this call by analysing the qualitative and quantitative feedback from the user.

Currently, different researchers are using experimentation methods according to their scope to determine the effectiveness of the developed VR platforms for safety training, so there is no standardised framework available on how to determine the effectiveness of the developed VR platforms and what factors require subsequent improvement. Completion of this research work provides an extensive mixed-method analysis, which can be used by future VR researchers as an established framework to evaluate their developed VR platforms. As this research work is based on user experience, it can contribute to the wider academic communities regarding human-centric design and the role of immersive technologies in improving experiential learning.

This research work is conducted using a mixed-method that combines qualitative and quantitative feedback. A holistic understanding of trainees' perceptions of the training approach, cognitive understanding, and emotional responses is captured by this research. Since this research is based on user experiences, it highlights crucial factors that require significant improvements to enhance the design and delivery of VR-based safety training.

Quantitative data analysis identifies essential factors such as realism, engagement, knowledge acquisition, knowledge retention, and usability. Qualitative findings provide further insights into these factors as well as other key themes, such as usability challenges, limitations of VR training, and suggestions for improvements. This multi-dimensional analysis shapes the research and identifies how VR training can be truly effective and what crucial factors require further improvement.

2 Literature Review

2.1 Virtual Reality

Virtual reality (VR) is a simulation environment, where users are allowed to interact with components through sensory stimuli such as visuals, sounds, and haptics. Users can immerse themselves in the virtual realm through the multisensory experience offered by the VR technology. This immersive experience is primarily delivered through head-mounted displays (HMDS). The primary goal of VR is to simulate a convincing virtual environment in which users can sense their presence (Cipresso et al., 2018; Mazuryk & Gervautz, 1996). VR technology is based on three principal features: immersion, interactivity, and the sense of presence inside the virtual realm with the use of an avatar, which enables users to act and interact with elements in real time(Cipresso et al., 2018).

Early VR systems can be traced back to the 1960s. One of the first multisensory VR experiences was provided by Morton Heilig's Sensorama (1962), this prototype provided the users with the sense of visuals, audio, and scent (Mandal, 2013). After a while, Ivan Sutherland brought a revolutionary " Ultimate Display" (Mandal, 2013). Figure 3 explains the chronology of technological developments in virtual reality technology in the last few decades.

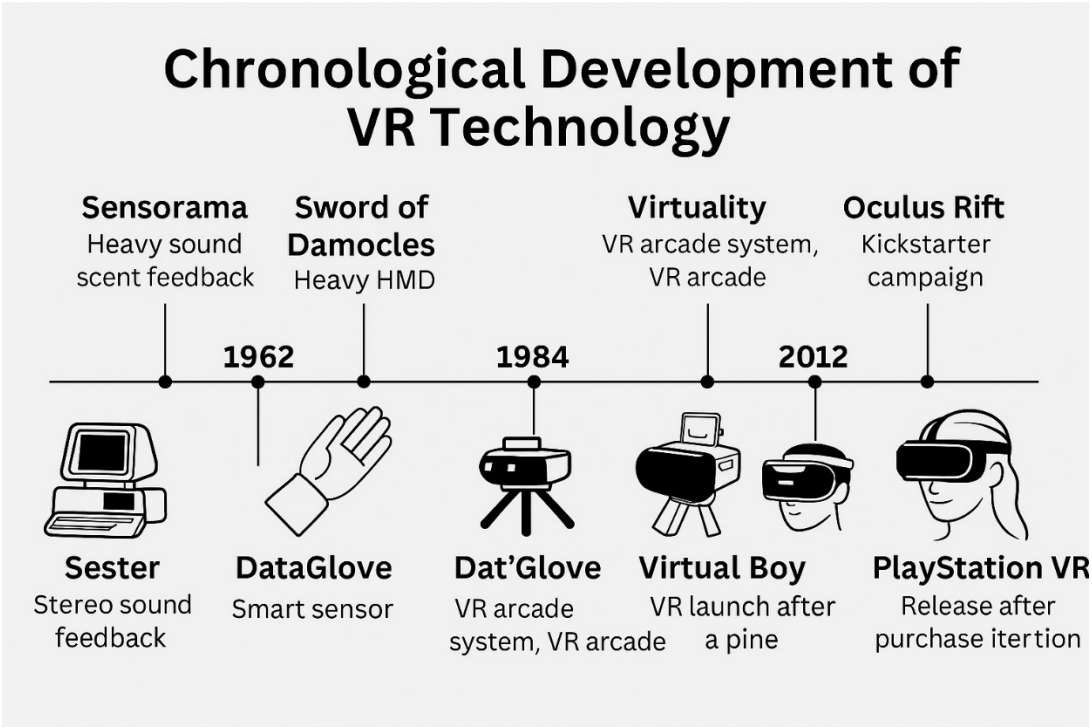

Figure 3. Chronology of Developments in VR Technology

VR systems can be categorised into three types based on the level of immersion provided, firstly non-immersive systems, which are 2D display-based systems such as VR game play on computers. The second type is semi-immersive systems, which offer partial immersion for the users. An example could be a flight simulator (Martirosov et al., 2022) where in-depth 3D images are displayed, but the user does not fully immerse in the VR environment. The third type is the most commonly used VR available currently, which is fully immersive systems. Figure 1 displays a fully immersive VR technology; this experience is provided by HMD gear. HMDS are head-mounted gear that is worn by the user, and it offers full immersion by providing a wider 360 view of the virtual realm. The VR systems can also be classified based on types of locomotion and control while the users are inside the virtual realm. The type of locomotion and control is very crucial since it affects the overall VR experience (Hufnal et al., 2019). According to Capece et al. (2023), button-controlled HMDS use buttons, triggers, or joysticks for user interaction, while motion-tracked HMDS use external sensors to track full body interaction of the user and the natural hand and or head movement in a real environment tracks the movement inside the virtual realm (Cannavò et al., 2021).

The future of VR technologies is shifting towards offering full immersion, greater realism, and ease of interaction. Currently, there are innovations ongoing for the inclusion of eye tracking and AI-based avatar personalisation, which offers users more freedom and inclusivity inside the virtual realm. VR is expected to be integrated in everyday contexts such as education, therapy, training, and medical as it is getting more affordable and portable (Akinola et al., 2020).

2.2 Application of VR Across Various Fields

Virtual reality has emerged as a transformative tool that is revolutionising different industries such as training, education, hospitality, and aviation. Traditional methods of training are costly and logistically challenging, whereas VR-based technologies are portable and easy to set up, and they only have a one-time cost of buying the equipment. Therefore, VR has become a viable option to redefine training and workshops, and it is also very crucial for data visualisation, such as 3D models or layouts.

2.2.1 Aviation and Ergonomic Simulation

VR has been employed in the aviation industry as a crucial tool for pilot training. It is applied to develop flight simulation, crew training, and enhance cockpit ergonomics. Designers have

access to pre-prototype models of cockpits through VR technology, where they can assess reachability, visibility, and take into consideration human-machine interaction, which helps to reduce the redesign costs (Brown et al., 2023). VR tools have been used for pilot training for decades; the biggest advantage of VR is that it can demonstrate the scenario without the risk of any real danger. It has been an essential tool for flight training, especially in the low-altitude flying zones (Liu et al., 2018).

2.2.2 Defence Training

VR has become an integral part of combat training among the modern military since it provides tactical simulation, virtual combat experience, and technical skill development. According to Liu et al. (2018) VR VR-based combat training provides a controlled environment for trainees, which assists them in enhancing training motivation and combat accuracy. Large-scale combat game simulations are available for military training, which helps reduce operational costs and mitigate the risk of injury during training.

2.2.3 Industrial Skills Training:

VR is widely used in training industrial workers for sophisticated skills such as welding. Practical training for welding is challenging and resource-intensive (Porter et al., 2006). VR can easily replace costly training, such as underwater welding training. The developed VR welder training by Porter et al. (2006) simulated an arc welding scenario in a mixed-reality setting. The developed system could track the torch angle, movement speed, and standoff distance. Porter et al. (2006), claimed that the use of VR technology was successful in improving skill acquisition among the participants as it provided instant feedback as well as it has reduced material waste.

2.2.4 Healthcare

VR has a wider range of applications, ranging from surgical training to diagnostic planning in healthcare industries. Virtual reality-based training has been very efficient in providing an immersive simulation for 3D anatomical visualisations and surgical process simulations. VR assists clinical practitioners gain insights and hands on experience inside virtual realm in low-risk environments. Previous studies have found out VR based clinical simulations are able to

improve skill retention, reducing surgical errors and building skill preparedness among participants (Javaid & Haleem, 2020; Lv & Guo, 2022).

2.2.5 Education and Safety Training

VR training has transformed and changed the scenario of how occupational hazards are taught and experienced. Traditional safety training, such as classroom lectures, safety manuals, and physical drills, has limitations in providing the urgency factor while training, and they lack real-time feedback for the learners, especially when it comes to high-risk scenarios (Tichon & Burgess-Limerick, 2011). The meta-analysis conducted by Tichon & Burgess-Limerick (2011) revealed that studies across diverse safety domains such as fire, construction, aviation, mining, and industrial training have revealed that VR-based training has outperformed compared to traditional training methods in terms of knowledge retention and knowledge acquisition. VR-based safety training provides a more promising alternative to traditional safety training, which lacks the urgency factors. VR can be used as a tool in the fields of occupational health and safety to prepare workers for emergencies, and it can improve how workers learn, recognise, and respond to emergencies.

2.3 VR in Fire Safety Training

According to the studies mentioned in the previous sections, VR is a powerful tool for safety training. It offers an immersive training environment, and the scenarios are repeatable. Users can learn about the critical safety procedures in a risk-free training environment. Multiple studies have claimed that VR-based fire safety training has the potential to improve participants' procedural performance, confidence in handling fire scenarios, and knowledge retention (Lovreglio et al., 2021; Morélot et al., 2021; Saghafian et al., 2020). Previously, researchers have used different kinds of methods to verify the effectiveness of VR fire safety training. There are different measures adopted by researchers during the experimentation; some of them adopted fully immersive VR technologies, and some of them used partially immersive VR. The findings from these previous studies demonstrate interesting findings regarding the effectiveness of VR fire safety training.

2.3.1 Experimentation Procedure

The majority of the studies conducted previously have used a hybrid approach as a method of experimentation. They have combined either traditional fire extinguishing training with VR fire extinguishing training or different kinds of control groups where all the participants took the fire extinguishing training in the virtual realm only. Lovreglio et al. (2021) conducted the experimentation using a video tutorial and a VR training. They analysed task accuracy and the knowledge gain. In some cases, the difference in immersion level was studied, which provides a comprehensive overview of the conceptual and procedural learning (Morélot et al., 2021). The difference between immersion levels was analysed using desktop training vs head-mounted VR display in other studies. Purnomo et al. (2024) have different fire types and differences in interaction levels for the fire scenario inside the developed VR model. Saghafian et al. (2020) conducted a study where the participants participated only in the VR fire extinguisher training.

2.3.2 Data Collection Method

Mostly, researchers used a hybrid approach for data collection. Structured questionnaires were used to collect the data in some cases, and a Likert-scale-based questionnaire collected quantitative data (Lovreglio et al., 2021; Morélot et al., 2021; Purnomo et al., 2024). In some cases, researchers conducted detailed interviews (Saghafian et al., 2020), mostly for the qualitative data. Pre and post-training data were collected by some researchers to understand the impact of VR training on participants' knowledge retention rate. Fu & and Li (2024) collected data using a usability and engagement survey, which was conducted both pre and post-tests. Most of the studies collected data based on the user perception, and the goal was to analyse the user experience of VR training.

2.3.3 Data Analysis

Previous research focused mainly on two kinds of data: quantitative data, such as user ratings, satisfaction level and qualitative data, which are collected using interviews or detailed feedback. One sample t-test was conducted to provide performance-based scoring (Lovreglio et al., 2021), and ANOVA was applied to analyse if the learning outcome was achieved during the training by Morélot et al. (2021). Descriptive statistics were used by researchers based on satisfaction score or the data collected from engagement surveys (Fu & Li, 2024; Purnomo et al., 2024). In some studies, there was only an analysis of qualitative data where they applied hybrid thematic

analysis (Saghafian et al., 2020). Figure 4 shows the mind map of how the themes for deductive thematic analysis were connected to the sub-themes in one of the studies.

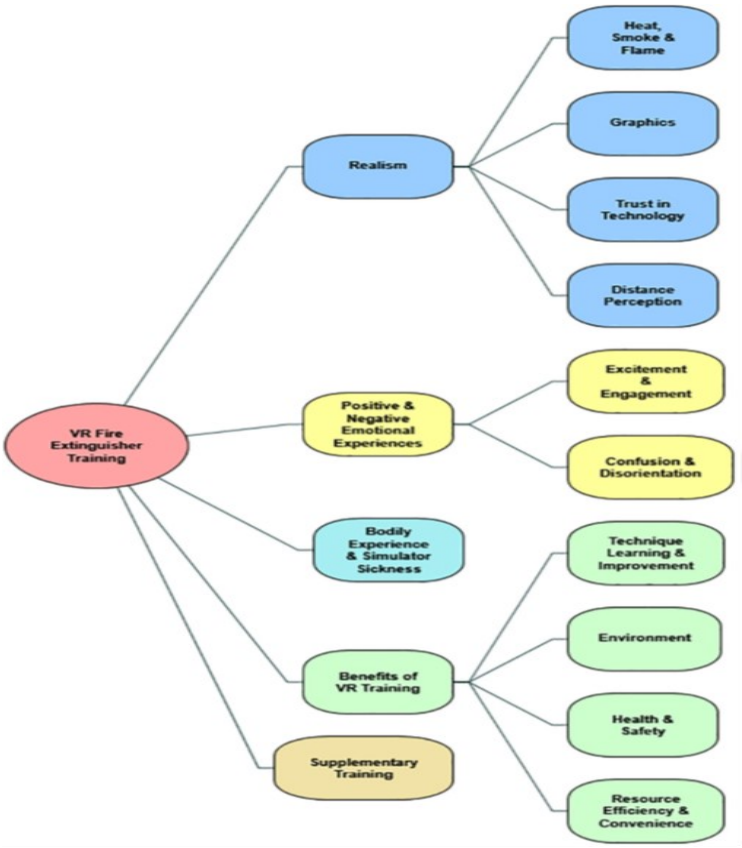

Figure 4. Key Themes for Thematic Analysis (Saghafian et al., 2020)

Depending on the category of the data, researchers have employed statistical approaches such as the T-test and ANOVA. However, to analyse qualitative data, the common approach was thematic analysis (Braun & Clarke, 2006). Studies that collected both qualitative and quantitative data employed a mixed-methods approach to complement the findings from the analysis.

2.3.4 Effectiveness Evaluation

The impact of VR training among participants can only be understood through an effectiveness evaluation. This is a key element, which outlines whether the participants have improved in competence after the virtual training. As a measure of effectiveness evaluation, researchers have looked into satisfaction level, behavioural change, and feedback on specific factors such as usability, ease of use, interaction immersivity of the developed VR module (Lovreglio et al.,

2021; Morélot et al., 2021; Purnomo et al., 2024). Some effectiveness measurement methods are similar to Kirkpatrick's model of training evaluation and game-based learning theory. Previously, researchers have evaluated the effectiveness based on factors such as skill preparedness after participation in fire safety training or simply the satisfaction level. Table 2 summarises the different effectiveness measurement methods previously adopted by researchers.

Table 2. Overview of the Various Effectiveness Measurement Methods

Name of the Method	Details
Pre / Post-Experimentation Comparison	Statistical modelling based on task performance and retention rate
Deductive Thematic Analysis	Qualitative responses are coded according to themes.
Statistical Modelling	T-test and descriptive statistics, and regression based on user satisfaction level
Implicit Kirkpatrick's Model	Analysing the factors from level 1 implicitly
Extended Technology Acceptance Model	The Technology Acceptance Model was modified according to the research needs.

The effectiveness evaluation method is different for each study, as per the type of data collected. Studies that have employed models have been unable to explain it fully, and rarely went over level 3 (behaviour) for Kirkpatrick's model. Multiple studies have mentioned that participants who participated in VR-based training simply outperformed compare to those who took traditional training. It is evident, based on previous empirical evidence, that VR improves user confidence and participants prefer VR over traditional training (Scorgie et al., 2024).

2.3.5 Factors Affecting the Effectiveness of Training

Realism of the virtual environment is an important factor which has a significant influence on the effectiveness(Abich et al., 2021; Alexander & Fromm, 2019). It includes how the virtual components look and how the movement of the avatar is guided. Increasing the fidelity improves engagement and the possibility of transferring the virtual skill to the real world.

Active learning makes the whole training experience more engaging. The participants have to carry out the task by themselves inside the virtual environment to actively learn rather than just clicking a button or hand gesture (Vasquez et al., 2019).

Some participants experience motion sickness while participating in VR training, which is reported by most of the researchers. This is a key issue which directly affects the learning experience, as due to the physical discomfort, participants are unable to focus on the training. Simulator sickness is mostly reported for users who have had less or no familiarisation with VR technology (Pedram et al., 2019). Familiarisation with the VR technology is necessary, since first-time users need some time to get used to the gear and the immersive experience. Written instructions or detailed feedback affect the training experience negatively. A combination of voice-based feedback, visuals and short task feedback enhances the learning (Vasquez et al., 2019). (Toyoda et al., 2022)

Low latency and lower frame rates reduce learning quality. System lags or virtual distractions, such as if the simulation gets stuck in a frame, cause discomfort among trainees. Rendering techniques such as foveated rendering lower system demands while maintaining the high-quality realism of the scenario (Aggarwal et al., 2019). This rendering strategy can be adopted to avoid system failure at the time of training.

Some participants tend to face navigation challenges. For example, a participant has to go to a certain place to pick up the fire extinguisher and then move from there to extinguish the virtual fire. It is common for them to encounter issues while moving from point A to point B. Novice users tend to experience this kind of locomotion challenge more than experienced users do. The inclusion of visual indicators and stable point of view controls can reduce navigation difficulties and also improve motion sickness issues (Burov & Pinchuk, 2023).

2.3.6 Enhancing the Effectiveness of VR Training

Improving the efficacy of VR training is related to offering a highly engaging learning experience towards participants. This requires integrating the enhancement of technical designs with pedagogical strategies. Multiple studies have pointed out key factors which significantly influence knowledge retention and learning outcomes.

The virtual realm should be well-designed and integrated with components that offer interactivity. This improves the immersion in VR for users. Toyoda et al. (2022) have highlighted the importance of visual realism and high fidelity can enhance the psychological

immersion experience. Inclusion of hazards, smoke and realistic flames is very crucial for improving the learning experience. Lovreglio et al. (2021) emphasised that increasing visual and behavioural realism improves user engagement and situational awareness.

Introduction of tactile-based haptic feedback to simulate the weight of the extinguisher or pressure improves the interactivity inside the virtual realm. Tasks such as pulling a pin or carrying the fire extinguisher in real life, while doing it virtually, can improve the quality of immersion. Sacks et al. (2013) developed a system that provided prompt assistance to the participants in case of a mistake. It has been proven to be efficient as learners tend to adapt successfully with the feedback loop-based system.

Improvement of spatial awareness can eradicate the navigation issues faced by the participants. Cherni et al. (2020) found that using room-scale VR makes navigation easy and reduces motion sickness issues. Inclusion of voice-based instruction is a solution to provide clear guidance for students. The learners have varying abilities and experience levels clear instruction can positively influence the learning experience.

Realism of the training plays a pivotal role in providing a smooth learning experience. Developed virtual realm should closely resemble the real world, and the camera angles are crucial as they affect learners' point of view. Including realistic fire scenarios with components which are easily accessible and interactive components such as guided aiming inside the virtual realm, can drastically change the learning experience.

2.4 Research Gap

Inclusion of virtual reality in fire safety has gained considerable attention as a tool which delivers an interactive safety training in a safe environment. Numerous research works have documented the benefits of VR training in enhancing skill acquisition and emergency preparedness. However, despite these significant developments, key gaps remain in the current studies.

- **Standardised Experimentation Method:**
  Researchers have used different methods to run the VR training. Although the hybrid approach was the most common method, some studies have mentioned stand stand-alone VR approach. This makes it difficult to compare the VR learning experience with traditional learning methods. Further VR training effectiveness-based research should

be done with a focus on establishing a standardised experimentation process, such as combining practical training with VR training, so that the gap between the virtual world and real-life experiences can be figured out.

- **Standardised Framework of Effectiveness Evaluation:**
  Most of the studies have employed only a standard statistical approach as the data analysis approach. Some studies collected quantifiable data, while others simply approached with qualitative feedback. Therefore, only one kind of analysis was done, and the analysed data was not compared with an established framework such as Kirkpatrick's model for evaluation of training effectiveness. Employing mixed methods for the studies would have been a wiser choice, and the data should be compared with the established models to designate the factors which require significant improvement. It is essential to have a standard framework for the evaluation of VR-based learning and skill development modules. Since the world is more approaching towards adopting these immersive technologies, having an established framework to evaluate these training modules will justify and provide actionable insights to develop these modules more effectively.

- **Limited Attention to Navigation Issues and Motion Sickness:**
  Motion sickness is frequently cited which is a crucial barrier to the effectiveness of VR training. These findings are cited in some studies, while others simply focus on reporting the knowledge acquisition and retention rate among participants. In-depth analysis is required from user feedback on how to ease the navigation methods and reduce motion sickness.

- **Overreliance on User Satisfaction Survey:**
  Studies are mostly dependent on user-reported subjective data. They have mentioned the error rates or response timing rarely. More research work is required to develop VR modules which can analyse participants' performance and provide scores or real-time feedback based on the in-game data.

VR as a training tool has the potential to be developed as a safety training, which is pretty evident according to the research works mentioned in this section. Developing a standardised framework for VR training will enhance the design, accessibility, and real-world effectiveness.

It is very crucial to develop VR as a standalone training tool for situations where participating in the training poses a potential risk for the trainees. Addressing the gaps can develop VR as an innovative training tool across industries.

3 Research Methodology

3.1 Research Design

This study provides in-depth insights regarding the participants' perceptions towards virtual reality-based training, which is further complemented by statistical data. Therefore, there are two kinds of data sets: firstly, the open-ended qualitative feedback, and the other one is the numerical ratings. The next section will provide information regarding how the data was collected, the experimentation procedure and the size of the datasets. Standard ethical considerations and the University of Turku's policy for data collection were maintained during the timeline of this research work.

3.1.1 Research Tool

This research work is primarily based on user experience with virtual reality-based training. To collect the user feedback, two research tools were developed by the partners of the VTC project.

- **Quantitative Questionnaire:** A Likert scale-based quantitative questionnaire was developed. Trainees provided numerical ratings based on a scale which ranges from 1 - 5, the 1 represents participants strongly disagree with the question, and the highest number depicts that participants strongly agree with the specific question. These questions were mostly self-evaluation questions. There were in total of 15 questions which measured participants' perception of various aspects of VR training.

- **Qualitative Questionnaire:** This questionnaire was open-ended, where participants provided their general perceptions regarding the specific themes of the questions. There were two kinds of questions, firstly, general questions regarding the instructions and participants' liking and disliking of the three specific aspects of the VR training. Secondly, the VR training interview questions. The first few questions determine if participant have previous exposure to VR and their perception regarding the acceptance of VR training. The other questions capture the emotional responses, usability challenges, and possible suggestions for improvement provided by the trainees.

3.1.2 Experimentation

The experimentation was done using a hybrid approach. As part of this, all the research participants participated in both the VR fire extinguisher training and practical fire extinguishing. The VR fire extinguisher training was conducted in the “Turku Game Lab” located in ICT City. Figure 5 illustrates how the participants participated in virtual reality fire extinguisher training. When the participants arrived at the facility, they were given instructions and a research ID before participating in the VR fire extinguisher training. During the time of training, there were multiple instructors to assist the participant if they got stuck inside the virtual realm.

Figure 5. VR Fire Extinguishing Training

The following day, participants were called out to participate in the practical fire extinguisher training. It was conducted in the presence of a fire safety expert. Participants came to the training facility, and they provided their research ID. After that, they were given a pair of safety gloves, safety shoes, and safety jackets. Figure 6 depicts the practical fire extinguisher training. The fire safety expert provided the necessary safety instructions, and then the participants did the same task that they did in the virtual realm the previous day

Figure 6. Practical Fire Extinguishing Training

3.1.3 Data Collection

After the completion of both the training sessions, participants were provided with the printed-out qualitative and quantitative questionnaires. They wrote their research ID in the questionnaire, and they were given enough time to answer the questionnaire in a proper manner. Both of the questionnaires were collected on the same date. These physical questionnaires were converted into digital form as script documents and an Excel chart.

3.1.4 Dataset & Sample Size

There were two datasets. The VTC project was conducted in several countries, including Finland, Poland, Oman, and Singapore. This particular research work only focuses on the datasets from Finland. The sample size was n=71, participants were final year engineering students.

3.1.5 Ethical and Safety Considerations

This study was conducted in accordance with the data protection and data collection guidelines of the University of Turku. Anonymity of the participants was ensured by providing each of them with a random research ID. Before the experimentation, participants provided their written consent to participate in the training in a signed consent form, and participants were thoroughly guided during the VR experimentation phase. During the practical experimentation, participants were provided with enough safety gear, and the fire safety expert was always present. At the

time of both training sessions, participants were closely monitored, and the instructors were always present to ensure a smooth training environment. The pictures that are used in this thesis were also taken with the consent of the participants.

3.2 Research Approach

A mixed-method approach was adopted as the primary research method to evaluate the effectiveness of VR fire extinguisher training. This strategy assists in combining the numerical data with the qualitative feedback. This research approach complements the quantitative findings with the open-ended, detailed feedback provided by the participants.

During the experimentation phase of the study, participants received both the quantitative questionnaire and the open-ended qualitative questionnaire. After participation, they provided statistical and detailed feedback. The quantitative data measures key dimensions such as perceived realism, engagement, usability, and knowledge retention. Whereas qualitative feedback covers a vast spectrum of VR training from clarity of instructions to the suggested improvements and some other key aspects which are very crucial for the effectiveness of VR fire extinguisher training.

The first research method that was applied to both of the data was thematic analysis. The questions were mapped according to some pre-defined themes. This thematic analysis can be defined as deductive thematic analysis since the themes of both the qualitative and quantitative analyses were pre-defined (Proudfoot, 2023). Multiple researchers Kinateder et al., 2014; Min et al., 2024; Saghafian et al. 2020; Talan et al. 2025 have previously used thematic analysis to analyse the qualitative data from surveys and interviews for VR-based fire extinguisher training. In this particular study, since there is both numerical and qualitative data to integrate both datasets, deductive thematic analysis was used.

Furthermore, after the individual quantitative and qualitative analyses were done, both the analysis results were integrated using two models Technology Acceptance Model (TAM) and Kirkpatrick's Model for determining the overall effectiveness of the training module. (Zhang et al., 2022), have used an extended technology acceptance model to measure the perceived ease of use for their developed VR module for construction safety. Kirkpatrick's model has been widely used for evaluation of training effectiveness by providing a structured multi-level framework which assesses participant's reactions, learning outcomes and behavioural changes (Rasouli et al., 2023).

3.2.1 Quantitative Analysis

The quantitative analysis in this study focuses on measuring the effectiveness of VR fire extinguisher training based on five key factors. An explanation of these themes is given in Table 3. The data gathered from the Likert-scale based questionnaire is further analysed using statistical techniques such as descriptive statistics, frequency distribution, one-sample T-test, and regression analysis. These statistical models explain the variations in the quantitative data from the user's numerical perception, they provide a comprehensive analysis of the factors that are affecting the effectiveness of the developed VR model.

Table 3. Explanation of the themes in quantitative analysis

Themes	**Explanation**
Knowledge Acquisition	The process of understanding and learning the information provided during the VR training
Knowledge Retention	Participants' ability to recall and retain the knowledge gained during the VR training
Realism	Participants' perception of how closely the virtual world resembles the real world
Usability	The clarity of the instructions and information provided during the training
Engagement	Participants' perception of interactivity, immersivity, and emotional involvement during the training.

The statistical tactics that are employed in this research is explained below:

- **Descriptive Statistics:** It summarizes the quantitative data across all variables. Standard statistical measures such as mean, median, standard deviation (SD), and variance portray participants' overall perception from their numerical rating systematically. It provides crucial insights regarding the tendencies and dispersion of ratings related to the key themes explained in Table 2. Previous studies have adopted this standard statistical measure to depict an overall picture of their quantitative data (Lovreglio et al., 2021; Stefan et al., 2023). Since the participants provided their feedback across these five key themes, descriptive statistics summarize their feedback regarding these themes. It also provides an insight into which themes are key indicators in determining the

effectiveness of VR training and identifies themes that require significant improvement to make the VR training more effective.

- **Frequency Distribution Analysis:** Frequency distribution analysis provides the general trend regarding the key themes. This analysis illustrates how participants rate specific dimensions such as usability, engagement, and realism. Rasouli et al. (2023) utilized this measure to provide their perception on VR training efficacy, which highlighted the common response patterns.

- **One Sample t-Test:** T-test, compares and analyzes the contribution of each theme in the case of the overall effectiveness of VR training. A benchmark for effectiveness was chosen for the t-test (Kamal et al., 2025). Results from the t-test determine which themes are well established according to the trainees. The themes that have a p-value lower than 0.05 signify that they require a significant improvement, and themes which has a score over the effectiveness threshold score are high performing, and it also depicts that they do not require that much improvement. Previously, the t-test was used by other researchers to score the post-training satisfaction level for VR-based training (Mousavi et al., 2023; Peek et al., 2023)

- **Regression Analysis:** At the final step, Regression analysis was done to examine the relationships and the impact score of each theme on the overall effectiveness. Regression determines which is the most important factor that has the most impact on the training effectiveness. It is important as it quantifies the strength and significance of predictors that influence the effectiveness. It quantifies how much change in one variable can affect the other. (Falcone et al., 2024; Hjellvik & Mallam, 2024; Y. Kim & Park, 2024; Moulaei et al., 2024) demonstrated the application of regression in understanding the effectiveness of VR training across different industries such as healthcare, engineering, and cognitive rehabilitation.

All of these standard statistical modelling shapes this research work. They determine the key findings from the quantitative data. SPSS was used as the data analysis tool since it provided the freedom of running all these analyses altogether, and the data could be compared. Later on, the results from this analysis are reported using graphs and tables in the results section of this thesis work.

3.2.2 Qualitative Analysis

Qualitative data is collected using an open-ended qualitative survey. Feedback was collected for different aspects of training. The data is analysed mainly using deductive thematic analysis. Qualitative questionnaires were designed with some specific goals, they measure participants' feedback in a wider range. These responses can be categorized into nine themes.

According to (Braun & Clarke, 2006), thematic analysis can be divided into two categories: inductive and deductive. In contrast to the inductive approach, in the deductive thematic analysis, the themes do not emerge from the data or the open-ended feedback. Themes are already pre-determined before doing deductive thematic analysis, as mentioned earlier, the questionnaire was designed to channel participants' responses into specific themes based on the prior theoretical assumptions. Deductive thematic analysis was adopted since the questionnaire collected insights regarding specific themes. Realism, engagement, skill preparedness, usability challenges, etc., these themes were already predefined, and they emerged in participants' responses. In previous studies (Proudfoot, 2023; Saghafian et al., 2020), researchers have employed deductive thematic analysis to analyse their qualitative insights for VR training methods.

Deductive thematic analysis was done using the standard procedure mentioned by (Iqbal & Sidhu, 2022) in their research work. The procedures are explained below:

- The data was studied thoroughly to familiarize myself with it.
- Initial codes were generated using the specific themes that were decided during the design of the questionnaire.
- Sub-themes were created to capture the wide range of responses provided by the trainees.
- The themes and sub-themes were reviewed to ensure that they reflect participants' perceptions properly.
- Qualitative data was coded under the sub-themes and themes.

Table 4 summarizes all the themes and their explanation that were used during the deductive thematic analysis. Each theme was categorized into sub-themes, since participants provided variety of response as the nature of the questionnaire was open ended.

Table 4. Explanations of Themes for Qualitative Analysis (Hossain et al., 2025)

Key Themes	Sub-Themes	Description
Clarity and Usability of Instructions	Clarity of instructions, points of confusion, suggestions for improving guidance	Determines the clarity of the instruction given before the VR training and areas of confusion
Realism of the Training Environment	Perceived realism of fire scenarios, immersion in VR, alignment with real-world experiences	Explores how realistic the fire scenario felt for the users and their sense of immersion
Engagement and Interactivity	Immersive aspects of VR training, ease of interaction, and emotional responses	Evaluates how immersive and interactive the VR training environment felt, including emotional responses such as joy and frustration
Skill Preparedness and Knowledge Retention	Confidence in handling fire emergencies, transferability of skills, long-term knowledge retention	Measures how confident the participants felt while interacting with a real fire, the retention of the knowledge learned in VR, and whether they transfer it into real life
Usability Challenges	Motion sickness or nausea, navigation and control issues, external or virtual distractions	Identifies the difficulties faced by participants, such as motion sickness, navigation problems, or any other distraction that affects their VR experience
Comparison with Traditional Training Methods	Effectiveness of VR vs. traditional training, realism and engagement differences, preferred training methods	Compares the participant's experience of traditional and VR training methods
Advantages and Limitations of VR Training	Advantages, limitations	Highlights the strengths and weaknesses of VR-based fire extinguishing training
Suggestions for Improvement	Enhancing realism and fidelity, reducing usability issues	Focuses on enhancing the training experience, such as improved realism, and addresses usability issues
Influence of Prior VR Experience	Ease of navigation, adaptability to the virtual environment, and engagement differences	Explores how previous exposure to VR can influence a trainee's adaptability and overall engagement

NVivo 20 was used as the data analysis tool. This was chosen as the data analysis tool since the responses from the questionnaire script can be directly coded into the specific themes easily. There were queries such as word such query and word frequency query and word cloud. These queries assist to find out the dominant words among the response.

3.2.3 Data Integration

This research work employed a mixed-methods approach due to the two different kinds of data. To successfully generate the outcome of this research work. The integration process is done by an established approach, involves further analysis of both kinds of data using a standardized framework or model. Keeping this view in mind, two very popular models were adopted during this research work to integrate findings. The first model is Kirkpatrick's four-level model (Kirkpatrick & Kirkpatrick, 2016) of training evaluation, and the second one is the Technology Acceptance Model (TAM) (Marangunić & Granić, 2015).

Kirkpatrick's Model:

This model is widely used for evaluating the effectiveness across different industries. Figure 7 displays all four levels of Kirkpatrick's training evaluation model. Level 1 measures participants' responses regarding satisfaction, engagement. Level 2, asses the status of knowledge and skill acquisition. Level 3 provides a brief evaluation where the knowledge that was gathered during the training is applicable during a real-life scenario or a specific job scenario. The final level deals with the broader impact of the training among the participants.

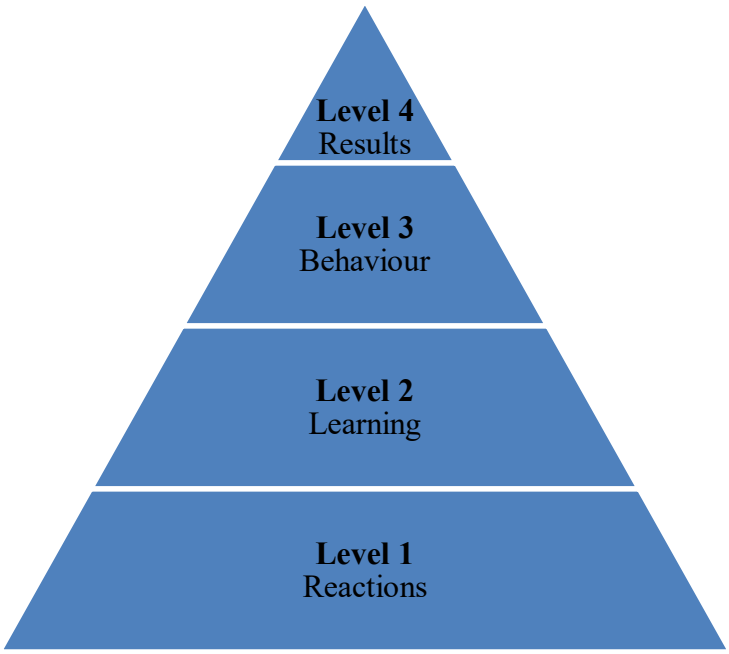

Figure 7. Kirkpatrick's Four-Level Learning Model (Mohamed & Alias, 2012)

Kirkpatrick's model was used by VR researchers to determine the effectiveness of their developed module in previous research works (Carnell et al., 2022; Phillips et al., 2023; Rasouli et al., 2023). This model assists in determining the key factors that affect the training experience and participants' knowledge acquisition perception.

Technology Acceptance Model (TAM):

TAM is a widely used theoretical model, it provides a direct insight how users accept and use a technology. It also identifies key factors such as users' behavioural intention towards a particular technology. TAM is adopted in this study to measure user's intention to accept or reject virtual reality module as a training method for fire safety training.

Figure 8 shows the original technology acceptance model developed by Davis 1989. TAM constructs are Perceived Usefulness (PU) and Perceived Ease of Use (PEOU). PU provides insights about the degree to which a training participant believes that the VR fire safety training has enhanced their performance. PEOU provides an analysis of the crucial factors that are necessary to use this technology effortlessly. Attitude Toward Using (ATU) analyses the positive or negative feelings of the training participants. Behavioural Intention (BI) measures the likelihood of recommending this technology or method to another person or the user is likely to continue this training method.

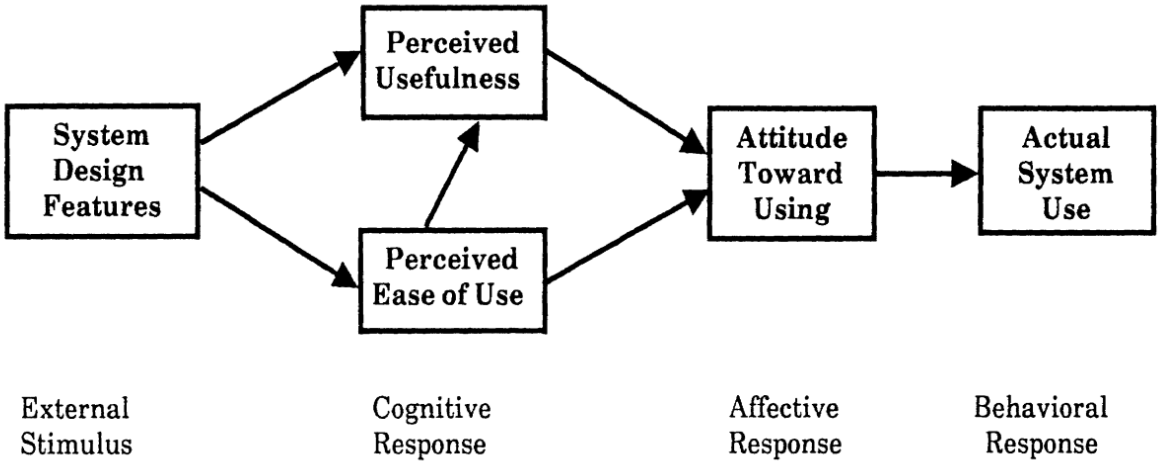

Figure 8. Technology Acceptance Model (TAM) (Davis, 1989)

Iqbal & Sidhu (2022) have employed the TAM model to understand participants' perception towards VR training in augmented reality-based dance training. This dual-model approach ensures that the training outcomes are achieved, and it also illustrates participants' perceptions

regarding the acceptance of technology. Integration of the data summarizes the findings, and it points out the key factors that are crucial in VR-based fire extinguishing training.

3.3 Research Workflow

This section will provide a comprehensive, holistic view of the whole research methodology and some brief details regarding the steps of the research work.

- University of Turku, was responsible for work package 4 of VTC project, the work package included development of a standardized framework for evaluating virtual reality-based training.
- Existing literatures on the evaluation of safety training effectiveness and virtual fire safety training effectiveness were studied in order to develop the whole research framework.
- Project contributors met to develop the standard open-ended question and the Likert scale-based questions based on the empirical evidence from the previous research work to meet the project requirement.
- Project partners developed the VR fire extinguishing modules and tested it before providing the actual training to the participants.
- The experimentation was done last year, and data were collected right after trainees participated in the fire extinguishing training.
- Qualitative data was recorded as a form of script and imported into the NVivo environment to be coded using the themes. It was analysed using deductive thematic analysis.
- Quantitative data was analysed using SPSS by integrating the statistical models explained in the earlier section.
- The results of the datasets were presented at a conference.
- Datasets were integrated using two models.
- Kirkpatrick's model was revised to be used in this research work.
- The Technology Acceptance Model was also altered to fit in the research framework.
- The findings from the analysis and integration of data are presented using tables and graphs.

Figure 9 summarizes the research workflow that was adopted during this thesis work.

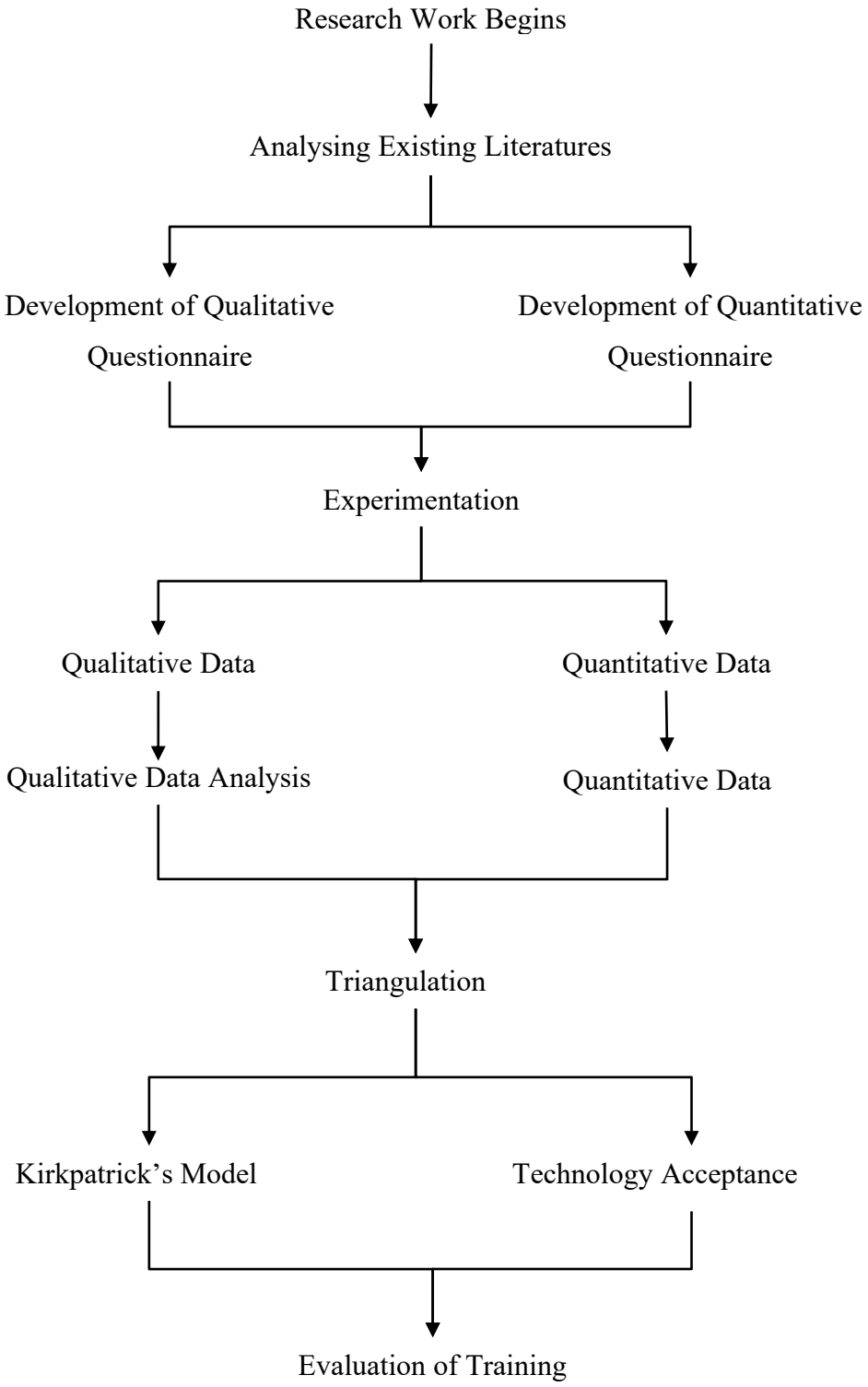

Figure 9. Research Workflow

3.4 Question Mapping Over Themes

The research work focused on integrating two datasets, and questions from both surveys were mapped into common themes. Qualitative analysis covers more themes compared to quantitative analysis. The qualitative responses are open-ended and they cover a wider range aspect compared to the numerical ratings.

3.4.1 Question Mapping for Quantitative Analysis

Quantitative questionnaire is distributed among five key themes. Table 5 explains the distribution of questions according to the themes. Knowledge acquisition covers five questions, and knowledge retention has two questions. Realism and engagement, which deal with immersivity, are also covered in a total of nine questions. Usability, which refers to the clarity of instructions and information provided by the training, is covered by only one question.

Table 5. Distribution of Quantitative Questions Over Themes (Kamal et al., 2025)

	Distribution of questions over themes
Theme 1	**Knowledge Acquisition**
	This training has offered you with adequate fire extinguisher knowledge
	The training has enabled you to know what to do in case of an accident
	The training will affect your capability to quench an emergency fire positively
	The training provided you with adequate learning experience
Theme 2	**Knowledge Retention**
	You will remember what you've learned about fire extinguishers a year from now
	The training will most likely help you avoid accidents at the workplace
Theme 3	**Realism**
	The dangers were demonstrated realistically
	The demonstrations represented real factory situations
	The level of the theoretical fire extinguisher representation complied with practice
	The training illustrates realistic situations in the field
Theme 4	**Usability**
	The obtained information was adequately understandable to you
Theme 5	**Engagement**

	You concentrated during the fire extinguisher training
	The training provided you with a pleasant learning experience
	You will most likely recommend this kind of training to others
	You would most likely participate in this kind of training in the future
	The time of the training was a worthwhile investment

3.4.2 Question Mapping for Qualitative Analysis

Qualitative response covers a wider range of themes. As it was an open-ended survey, students provided a variety of responses. Table 6 summarizes the distribution of qualitative questions according to the nine themes. There are more themes compared to the quantitative analysis to capture the depth of the responses.

Table 6. Distribution of Qualitative Questions Over Themes

	Distribution of questions over themes
Theme 1	**Clarity and Usability of Instructions**
	Did you find that the instructions of the tutorials were clear and easy to follow?
	Was something confusing to you?
Theme 2	**Realism of the Training Environment**
	How natural did your interactions with the virtual environment seem during the VR training?
	In the virtual realm, how were you able to actively survey or search the VR environment using the controllers?
Theme 3	**Engagement and Interactivity**
	What were 3 things you liked most about the entire fire extinguisher training experience?
	How did you feel during the VR training?
	Were there any distractions you experienced when performing the assigned tasks or required activities in VR?
Theme 4	**Skill Preparedness and Knowledge Retention**
	How do you evaluate the fire extinguisher training with the use of VR?
Theme 5	**Usability Challenges**
	What were 3 things you did not like about the entire fire extinguisher training experience?
	Did you experience nausea or motion sickness during the VR training?
	Were there any distractions you experienced when performing the assigned tasks or required activities in VR?
Theme 6	**Comparison with Traditional Training Methods**
	How was the VR fire extinguisher training compared to classroom, and practical training?
Theme 7	**Advantages and Limitations of VR Training**

	Are there any advantages and disadvantages you experienced in the VR training?
Theme 8	**Suggestions for Improvement**
	What were 3 things you did not like about the entire fire extinguisher training experience?
Theme 9	**Influence of Prior VR Experience**
	Do you have previous experience with VR?

3.5 Revised Models

These models assist in integrating the qualitative and quantitative findings and provide a joint result from individual analysis. Kirkpatrick's model follows a linear progression and has four levels, while the TAM model has some constructs, therefore, some minor alterations are made to these models so that they can fit into the research framework. Previous studies have included Kirkpatrick's model to compare VR with traditional methods, and they have emphasized different levels of the model (Carnell et al., 2022; Phillips et al., 2023; Suraj & N, 2023). However, in the case of the TAM model used by Zhang et al. (2022) have used an extended version of the existing model enhancement was used according to the requirement of the research framework.

3.5.1 Revised Kirkpatrick's Model

The datasets were analysed using some common themes. This study follows the hierarchy of the original model. Figure 10 displays the revised Kirkpatrick's model that was adopted during this study. However, at every level, data from specific themes will be analysed to compare both the quantitative data and qualitative insights. Level 1 measures participants' reaction towards the virtual training. Therefore, in this level, participants' perception of immersivity of the developed virtual realm is analysed using the themes engagement, realism, and usability (ease of use and challenges). Levels 2 and 3 deal with knowledge retention and skill preparedness, respectively. These levels are crucial in determining how effective the training was in increasing the level of learning. Finally, at level 4, the factors that require significant improvement will be recorded.

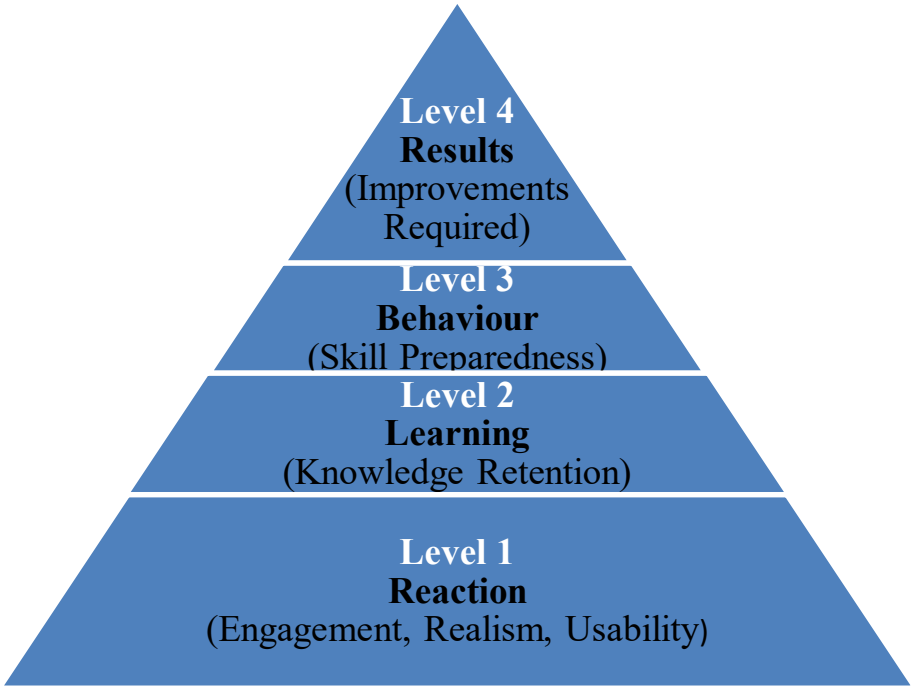

Figure 10. Revised Kirkpatrick's Model

3.5.2 Revised Technology Acceptance Model

The technology acceptance model analyses crucial factors such as knowledge retention and confidence after the training, as PU. Usability challenges, such as navigation issues inside the virtual realm and other controlling issues, are recorded in this section as PEOU. In the second stage, the participants' satisfaction with engagement level is measured. This is measured from the responses regarding the interactivity and engagement of the VR training environment. Figure 11 explains the revised TAM model that was adopted in this study

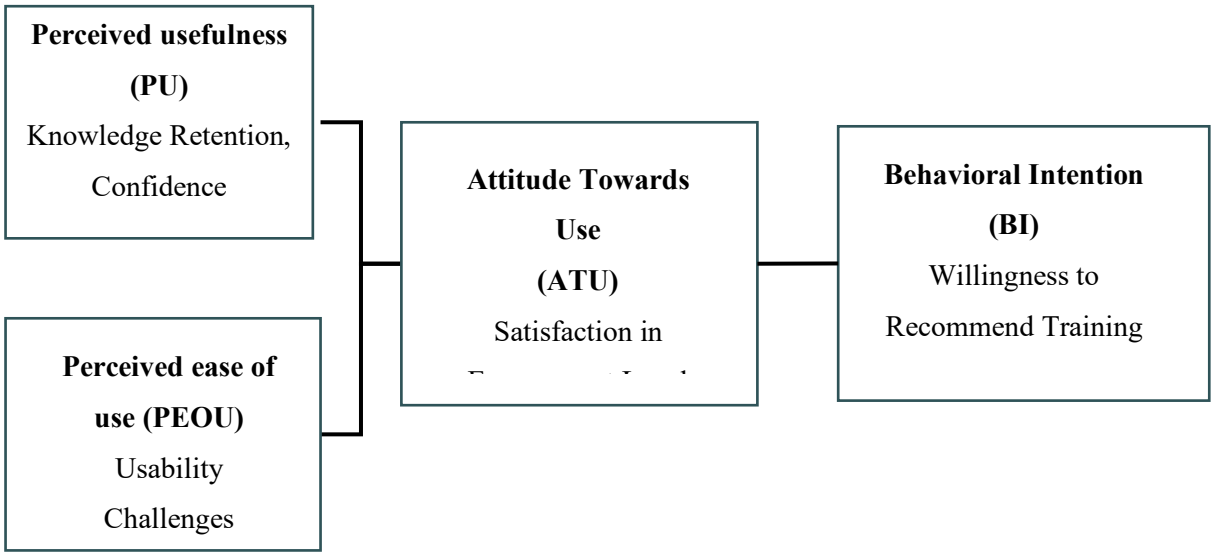

Figure 11. Revised TAM Model

4 Results and Discussions

In this section, the results from the quantitative and qualitative data analysis will be displayed and discussed thoroughly. Quantitative results are displayed using graphs and standard tables as per the results of the statistical modelling. Qualitative results involve the quotes' overall perception for each theme. The results from both of these analyses are merged using Kirkpatrick's model and the TAM model, which is displayed using the joint findings tables approach. Finally, the answer to the research questions, which are the basis of this research work, is provided.

4.1 Quantitative Results

Quantitative approach consists of Descriptive Statistics, Frequency Distribution Analysis, One Sample-T Test and Regression analysis. The results from these statistical approaches are discussed below.

4.1.1 Descriptive Statistics:

Table 7 depicts the results from descriptive statistics analysis. The maximum value represents the highest rating received by a certain theme, while the minimum value is the lowest rating provided by the participants for a theme. Mean value is the average rating points received by the themes. In this mean value, the following scale is used to see the effectiveness of each theme.

Mean (M), if M = 1-2.5 that defines that the theme is lowest performing, M = 2.6-3.5 is neutral, and M = 3.6- 5 indicates that the particular theme has higher efficacy. From Table 7, it can be concluded that themes such as Usability, Engagement, and Knowledge Acquisition were highly effective. Knowledge retention rate is neutral according to this analysis which has a mean value of 3.6056. The lowest performing theme was realism.

The standard deviation (SD) value outlines how spread out the responses were for a particular theme. The Std. deviation column in Table 7 portrays that the feedback from participants was consistent for all the themes. According to this analysis, it can be summed up instructions provided before the training were quite easy to follow, and they think that the developed VR fire extinguishing module was highly engaging. In case of understanding the purpose of the training and applying skills learned from the training, participants are confident that they can apply the knowledge in real real-life firefighting scenario. According to their feedback, the

realism, which refers to the immersivity of the virtual realm, has to be improved to achieve the training outcome more successfully.

Table 7. Descriptive Statistics Results (Kamal et al., 2025)

Themes	N	Minimum	Maximum	Mean	Std. Deviation
Knowledge Acquisition	71	1.25	5.00	3.8204	.71985
Knowledge Retention	71	1.00	5.00	3.6056	.87389
Realism	71	1.00	5.00	3.3662	.71153
Usability	71	2.00	5.00	4.0704	.76203
Engagement	71	2.40	5.00	3.9831	.72091
Valid N (listwise)	71				

4.1.2 Frequency Distribution Analysis

This analysis is done based on the frequency of ratings. Ratings that ranged from 1-2.99 are considered negative, 3.0-3.99 are neutral, and 4.0-5-0 represents a positive rating. Figure 12 displays the range of ratings for each theme. It is evident that usability has the highest positive ratings, which is 57, and it also has the lowest negative rating from only two participants. In contrast, realism received the highest negative ratings compared to all the themes. 16 participants negatively rated realism, and 34 were neutral about the theme. It only received 21 positive responses. In the case of Knowledge Acquisition and Knowledge retention, 42 and 37 positive feedbacks were recorded, respectively. Almost a similar number of participants had neutral feelings regarding these themes. These themes received in total of 15 negative responses. Engagement is the second-best theme according to the number of responses. 42 trainees have rated it positively, it received 22 neutral and 7 negative responses.

In conclusion, overall effectiveness for the virtual training is neutral according to frequency distribution analysis. 30 participants feel very positive regarding the overall effectiveness of the safety training, whereas 34 of them were neutral. Among the participants, only 9 of them have negative feelings towards the overall effectiveness of the developed VR module. This analysis points out that VR training has high engagement, and participants are confident that they have learned something new by participating in this training. However, realism requires some tweaking to make the virtual realm more realistic. Overall, trainees have perceived the provided

VR training positively, and they are confident that they can transfer the skills learnt in the virtual realm to real life.

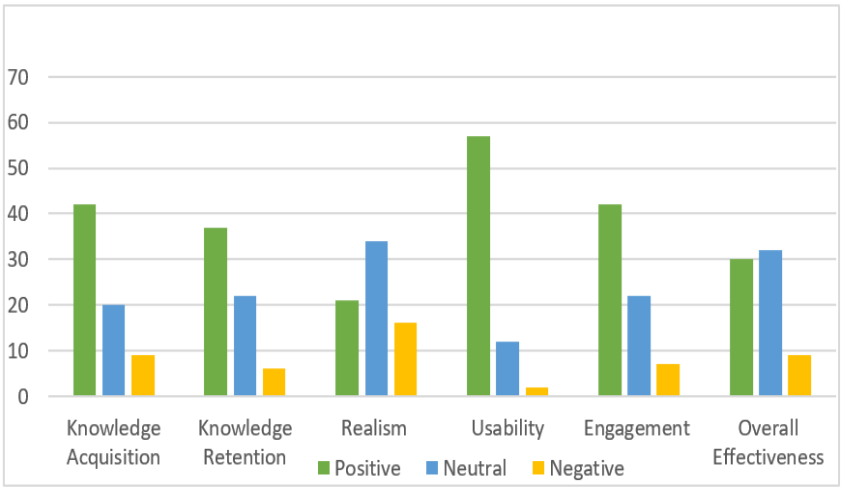

Figure 12. Frequency Distribution According to Participants' Response (Kamal et al., 2025)

4.1.3 One Sample-t Test

The purpose of this test is to verify the impact of each theme. In this analysis, a benchmark was set at 3.5. This is the effectiveness threshold; the highest rating possible was and the lowest possible rating was 1. The mean value from the descriptive statistics is compared against this threshold. Table 8 shows the results from one sample-t test. Usability and engagement, which have the scores of t = 6.307 and t = 5.647, respectively, are quite higher than the benchmark value of 3.5. It signifies that these themes are rated above the neutral point and are highly appreciated by the trainees. The t-score of knowledge acquisition is 3.751, which is slightly higher than the benchmark.

Table 8. One Sample-t Test (Kamal et al., 2025)

Themes	N	Mean	Std. Deviation	t
Knowledge Acquisition	71	3.8204	.71985	3.751
Knowledge Retention	71	3.6056	.87389	1.1019
Realism	71	3.3662	.71153	-1.1585
Usability	71	4.0704	.76203	6.307
Engagement	71	3.9831	.72091	5.647
Valid N (listwise)	71			

The T value for knowledge retention and realism is lower than the benchmark value. realism has a t-score of -1.1585, which is significantly lower than the threshold value and quite lower than $p < 0.05$. It can be summed up that the t-test further has similar results to the descriptive statistics and frequency distribution analysis. The t-test also signifies the importance of improving the realism of the training scenarios.

4.1.4 Regression Analysis:

Regression analysis further verifies the internal validity. It measures the impact of the five key themes in predicting the overall effectiveness of VR fire extinguisher training. Table 9 summarizes the regression statistics model. The correlation coefficient (R) has a value of 0.998 which refers that the dependent variable (overall effectiveness) has strong ties with the independent variables (Knowledge Acquisition, Knowledge Retention, Perceived Realism, Usability and Engagement).

Table 9. Summary of Regression Analysis (Kamal et al., 2025)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.998[a]	.997	.996	.03659

The R square value depicts 0.996 which indicates that 99.6% independent variables are able to explain the dependent variable. The standard error value refers that the key themes are highly reliable and accurate to predict the effectiveness. Table 10 illustrates the results from multiple linear regression analysis. Regression coefficient beta signifies which independent variable is strongest predictor of overall effectiveness of the VR training.

According to beta value engagement is the highest predictor of overall effectiveness as it has a beta value of 0.392. Next to engagement, there is realism, beta value is 0.334. Realism is highly connected to overall effectiveness since the realism of the fire scenario inside the virtual realm can affect how participants feel about the VR training. Usability has the lowest beta value, which indicates that it is not a strong predictor of VR training effectiveness. It can be concluded that regression analysis summarizes that the participant didn't face that many issues while engaging with the VR scenario. In contrast, they prefer a highly realistic VR scenario which offers an immersive VR training.

Table 10. Multiple Regression Analysis (Kamal et al., 2025)

B		Std. Error	Beta	
Constant / Independent Variables	-.023	.031		-.756
Knowledge Acquisition	.266	.010	.317	27.966
Knowledge Retention	.075	.009	.108	8.630
Realism	.284	.011	.334	26.884
Usability	.047	.006	.060	7.456
Engagement	.328	.008	.392	39.316
Dependent variable: Overall Effectiveness				

4.1.5 Overview of Quantitative Results

According to the descriptive statistics, usability has the highest mean score, next by it is Engagement. Knowledge acquisition and knowledge retention have mean scores that are very close to each other, while realism has the lowest mean score. These signify that most of the themes had high efficacy except realism. Similar results can be interpreted from frequency distribution analysis, where engagement and usability received more positive ratings compared to the other themes. Overall effectiveness of the training is neutral. The t-test further verifies the findings from descriptive statistics and frequency distribution analysis. According to the t-test, realism has the lowest t-score, which is significantly lower than the benchmark score. Regression analysis predicts that realism is the second strongest predictor of the overall effectiveness.

All the analysis indicates that, according to trainees, the strongest aspect of the VR training was the usability and the engaging factor of the virtual realm. Participants feel that they could understand the information easily, and they can apply the knowledge gathered during the VR training to a real-life scenario. However, all the analysis shows the importance of providing a highly immersive virtual realm. This has been evident in previous research works as well (Jeon et al., 2021; Khan & Nilsson, 2023; Oliveira et al., 2024; Saghafian et al., 2020). The fire scenario should closely resemble the real-world fire, and it should be designed with more immersion and realism.

4.2 Qualitative Results

Qualitative results consist of the detailed open-ended feedback provided by the trainees. Since the analysis method was deductive thematic analysis, each theme will be discussed thoroughly, and the most common quotes will be taken into account to provide a general overview. There are in total nine key themes, which are further divided into 25 sub-themes so that the responses can be mapped into the proper themes. This detailed analysis covers all the aspects needed to evaluate the effectiveness of VR fire extinguisher training.

As mentioned earlier, this analysis is based on the word frequency from the responses. A Word cloud was generated in NVivo 20 for the top 100 most frequent words among all the responses. Figure 13 illustrates the words that were very dominant in the response of participants. This word cloud further verifies the use of the themes mentioned in Table 4 were highly effective in predicting the effectiveness of the developed VR training.

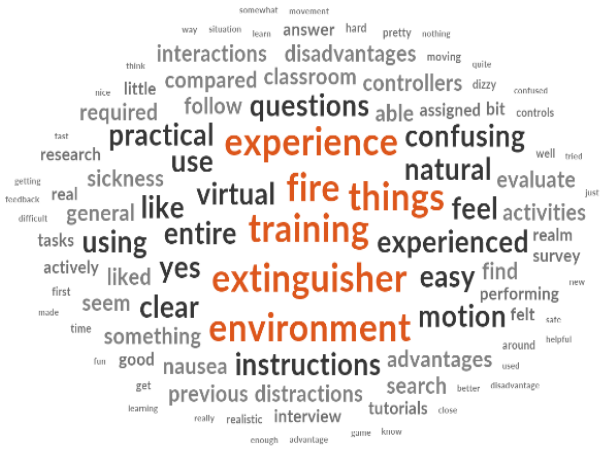

Figure 13. World Cloud of Most Frequent Words (Hossain et al., 2025)

4.2.1 Clarity and Usability of Instructions

This theme verifies that the instructions provided before the training and inside the virtual realm were pretty clear to the students. 90% of them have had positive insights regarding the instructions. Most common responses were “Yes” and “Very Clear”. Some of the participants have provided personal insights and highly appreciated the effort of the instructors who guided them clearly before the training, and if there was any lag during the training, they have provided them with instructions on how to re-run the training. However, there were a few participants who were confused regarding the instructions. They have mentioned a generalized response by

saying, “It was confusing”. There was a suggestion from the side of the participants to include voice command-based instruction inside the virtual realm, and some others have mentioned providing a tutorial as a form of video guidance before the training, rather than having human instructors.

4.2.2 Realism of Training Environment

In the case of realism, participants provided mixed reviews. A higher percentage have perceived that the virtual fire scenario can closely relate to a natural fire scenario. Though it was qualitative feedback yet some of them provided a score by responding “3 out of 5,” and some others scored “7 out of 10,” which depicts that the realism felt average for the participants. The most common neutral responses were “Felt Okay” and “Basic”. Around 75% of the participants were either neutral or thought that the virtual fire scenario was realistic. However, there was some negative feedback as well, the most common ones are “Worst”, “Unrealistic”, and “Not natural at all”. These responses were further investigated to find out the reason. one noteworthy issue was that these participants had faced a lag or bug while participating in the training. Some of them also reported about the confusion of navigation while they had to extinguish the fire inside the virtual realm.

4.2.3 Engagement and Interactivity:

In this theme, emotional responses and the ease of interaction with the virtual realm-based feedback are analysed. Participants have recorded the experience of VR fire extinguishing as highly engaging, and they responded as “Exciting”, “Fun”, and “Very good experience”. Some participants have pointed out the immersive aspects of the virtual realm, and they have appreciated the design and interaction method with the fire extinguisher. There was an aiming system to guide the participant in aiming while extinguishing. Most of the participants have exchanged positive feelings for this interaction method in the virtual realm. In total, 23 participants have directly mentioned that the VR environment was quite engaging. There was one mention of having the issue of interacting with the fire extinguisher, where the participant had complained by saying “Unable to see my hand while grabbing the fire extinguisher”. Overall, trainees have mostly positive feelings towards the instructiveness of the developed virtual realm, and they found it highly engaging.

4.2.4 Skill Preparedness and Knowledge Retention:

Among 71 trainees, 35 of them have reported that they feel more confident about real-life firefighting after participating in the virtual training. They have condemned that the skills gained through VR training are easily transferable to the real world. Most common responses were “I feel confident”, “I think it is useful before practicing in real life”. Participants appreciated the prompt feedback which were provided right after they completed a task. This helped to increase the knowledge retention rate among participants.

4.2.5 Usability Challenges

There were multiple reports of different kinds of usability challenges faced by training participants. 18 trainees have mentioned they faced navigation issues, which are evident in responses “Controllers are confusing”, “Buttons have issues”, “I was confused about where to go”. An interesting finding was that there was a left-handed participant; the controllers and the virtual realm were designed for a right-handed person. This is evidence for future VR designers to consider this kind of customization and design VR environments more human-centric. Motion sickness was reported by 10 participants, and four trainees mentioned feeling slight vertigo and the beginning. This is evident in the following responses: “Motion Sick” and “I felt vertigo but later felt okay”.

There were reports of external distractions, such as the VR glasses having loose-fitting. They said “It was blurry” and “VR glass was loose”. Another common external distraction was the sound of other trainees while they were talking to the instructors, since the training setup involved multiple computers placed side by side.

4.2.6 Comparison with Traditional Training Methods

Trainees have pointed out that VR training is highly effective compared to classroom or completely theory-based training. It is evident in the following responses: “Better than classroom”, “I prefer VR more”, “It is interesting than classroom”. However, according to most of the student’s practical fire extinguishing training is more engaging compared to VR. One of the interesting feedback was “More engaging than classroom, less than practical”; this feedback represents most of the responses provided by the students. Analysis of this feedback reveals that VR-based training is more preferable than classroom or video training, yet it is missing some factors that participants feel that if they have an option of participating in practical fire extinguishing, they will prefer that over VR training.

4.2.7 Advantages and Limitations of VR Training

There were more mentions of advantages in comparison to the limiting factors of VR training. Some interesting quotes are “It is safer”, “No real danger”, and “No fear or real damage”. This points out that most of the participants think that VR-based safety training provides a safe environment while training for a certain skill. Some have mentioned advantages such as repeatability of the training and ease of interaction with the training equipment’s and less logistical support required. Some limiting factors are that the virtual fire scenario misses the urgency factor, and there were some mentions about the navigation issues, and the internal lag of the virtual simulation.

4.2.8 Suggestions for Improvement

Some of the participants have provided in-depth suggestions for improving the virtual realm. Mostly, they have suggested improving the realism of the fire scenario and adding more urgency factors to the training. A few mentioned having an in-game tutorial to familiarize themselves with the virtual environment and to increase the length of the training session so the participants can participate in multiple rounds of fire extinguishing. As for the navigation, some have mentioned that they would prefer teleportation, while some others pointed out that teleportation has negatively affected the training effectiveness.

4.2.9 Influence of Prior VR Experience

Prior exposure to virtual reality technology had a significant effect. Among the 71 students, 49 of them had previously used VR gear and goggles before participating in the VR training, while others had no experience or interaction with the virtual realm or VR-based technologies. Trainees who have previous exposure have better results compared to the trainees who have no experience with VR. However, these novice VR users mostly faced navigation issues while controlling their avatar inside the virtual realm. Interestingly, two participants were novice users, yet they mentioned that it didn’t take much effort to get used to the VR environment, which is evident in the following quote: “ My first time yet I coped up easily”. As most of the novice VR users have reported some kind of issues, it can be concluded that previous exposure to VR technologies significantly affects the person's overall experience in VR training.

4.2.10 Overview of the Qualitative Results

Table 11 provides a comprehensive view of the results from the qualitative analysis. Mostly, participants thought that the instructions provided before the training were useful, and it was clear and concise. According to them, the realism of the fire scenario needs improvement, which was also very evident in the quantitative analysis results. Participants took the VR experience as highly engaging, and they felt safe while participating in the training.

Table 11. Overview of The Participants' Perceptions

Themes	**Quotes**	**Overall Perception**
Clarity and Usability of Instructions	1. **"The instruction was easy to follow"** 2. **"It could be more clear and easier if we could see some guidance video"**	90% of the participants have given positive feedback regarding the instructions given before the VR fire extinguishing training.
Realism of the Training Environment	1. **"7 out of 10"** 2. **"Basic", "Neutral", "Felt okay"** 3. **"Unrealistic", "Unnatural"**	Participants provided mixed feedback. (For some participants, there was lag inside the virtual environment)
Engagement and Interactivity	1. **"Exciting"** 2. **"Fun"**	The virtual realm was immersive, and the design of the fire extinguisher, water splash, and aiming was interactive.
Skill Preparedness and Knowledge Retention	1. **"I think it is useful before practicing in real life"**	Half of the participants recorded that virtual training has boosted their confidence before handling a real fire scenario.
Usability Challenges	1. **1."Learning controls and VR-set feeling uncomfortable were distracting from the learning experience"**	In total 23 participants faced navigation issue due to button controller and 14 reports of motion sickness in total.

	2. **2.“Blurry vision”** 3. **3.“With the joysticks and turning my head**	
Comparison with Traditional Training Methods	1. **“Better than classroom”** 2. **“I prefer real life situation/ environment”** 3. **“More engaging than classroom, less than practical”**	Most of the participants preferred VR training over classroom or theory-based training.
Advantages and Limitations of VR Training	1. **“Safe environment to learn”** 2. **“Safe way to show what to do can do it without a safety expert”** 3. **“Risk feels less real”**	Participants pointed out more advantages than limitations regarding the VR training environment.
Suggestions for Improvement	1. **"UX needs tweaking”** 2. **“Could be more realistic scene”** 3. **“Teleporting”**	Enhancing the realism of the fire scenario so that urgency can be felt and providing a game tutorial.
Influence of Prior VR Experience	1. **“It is effective if the trainee knows how to use VR glasses”** 2. **“Slightly confused due to my inexperience with VR”** 3. **“The VR needed some getting used to”**	Novice users had navigation difficulties compared to experienced VR users.

Key findings from the qualitative analysis are displayed in Table 12. According to the participants, the knowledge retention rate is quite high in VR training, and it is more interesting compared to the traditional training methods. However, VR training is not preferred as a standalone training method, as some prefer practical training over VR training. So, according to this perception, VR can be used as a complementary training method, but to develop VR as a more complete way of fire safety training inclusion of the urgency factor is very crucial. In order to eradicate navigation issues, participants should be provided with adequate time to participate in an in-game tutorial so they get used to controlling and navigating. Factors like motion sickness, vertigo, and no prior experience with affect the VR training effectiveness negatively.

Table 12. Overview of Qualitative Analysis Results (Hossain et al., 2025)

Themes	Key Findings
Knowledge retention	Knowledge retention rate is higher in VR training
Skill preparedness	Participants are confident about transferring the skills learned in the virtual realm into a real-life scenario
Realism	Perceived realism among trainees is neutral
Usability	75% of the trainees had no usability issues
Engagement	The virtual environment was very engaging and immersive
Usability challenges	Button-controlled navigation, motion sickness, virtual and physical distraction
Limitations	Lack of urgency factor
Prior VR experience	Prior VR exposure makes it easy to get used to the virtual realm
Enhancements required	Amplification of realism, real time feedback, tutorial for practicing in the virtual realm before the original training

4.3 Kirkpatrick's Model Data Integration

The basis of this study is mixed mixed-methods approach; the findings from the quantitative and qualitative study have to be merged. Kirkpatrick's model is used as a framework to compare the findings form both of the datasets. This model has four levels, which measures the training effectiveness across reaction, learning, behaviour and perceived outcomes. Table 13 displays the merged result which is generated using Kirkpatrick's model.

In level 1, responses from three themes are analysed, which are deeply related to participants' reactions. Engagement and usability themes have received mostly positive feedback, which is pretty evident from the quantitative results, and it is also complemented by qualitative findings. Both analyses have outlined that participants were neutral regarding the realism, and they demanded significant improvement in this factor would improve overall training effectiveness. However, the second level, which deals with the knowledge acquisition among the participants, based on both feedback and knowledge retention rate, is average. This indicates half of the participants had successfully acquired the knowledge, and they were able to learn a new skill during the training session.

Table 13. Kirkpatrick's Model Joint Display for Mixed Method Result

Level	**Evaluation Criteria**	**Quantitative Findings**	**Qualitative Findings**
Level 1: **(Reaction)**	Engagement	Positive feedback-60% Neutral feedback-30% Negative feedbcks-10%	Most of the participants think the virtual environment was engaging.
	Realism	Positive feedback-30% Neutral feedback-48% Negative feedbcks-22%	Participants were neutral about the realism with some mentions of improving the urgency of the fire scenario.
	Usability	Positive feedback-80% Neutral feedback-17% Negative feedbcks-3%	The instructions provided before the training was clear and understandable.
Level 2: **(Learning)**	Knowledge Retention	Knowledge retention rate is around 45%	Half of the participants expressed positive feelings.
Level 3: **(Behaviour)**	Skill Preparedness	60% of the participants feel confident after the VR training.	Participants mentioned that virtual training has boosted their confidence.
Level 4: **(Results)**	Improvements Required	To make the experience more immersive urgency factor and realism of the fire scenario must be improved.	

According to the merged results of level 3, VR training was quite successful in boosting the confidence among participants. Numerically 60% participants feel more confident regarding the emergency fire scenario after completion of VR training. In the qualitative analysis data was collected for the suggestions for improvement and it also evident from quantitative data analysis that the immersivity experience of VR training has to be improved to increase the effectiveness of VR fire safety training.

Finally, it can be concluded that this VR training was successful to prepare the trainees for real life fire scenarios. It also indicates that clear instructions and highly interactive training environments positively impact the effectiveness of training.

4.4 Technology Acceptance Model (TAM) Data Integration

The Technology Acceptance Model provides a comprehensive preview of participants' conception about the usability and usefulness of the developed VR module. PU is measured using the rate of knowledge acquisition and retention, which is average according to quantitative findings and higher according to qualitative findings among the participants based on both datasets. According to Table 14, 22% of the participants the developed VR module was not realistic, while in the qualitative findings, there are mentions about navigation issues inside the virtual realm as well as reporting of motion sickness while participating in the training.

Table 14. Data Integration Using Technology Acceptance Model

TAM Constructs	**Quantitative Findings**	**Qualitative Findings**
Perceived usefulness **(PU)**	Knowledge retention and Knowledge acquisition rates are average.	Most of the participants felt more confident in handling the real-world training after participating in VR fire extinguisher training.
Perceived ease of use **(PEOU)**	22% of the students felt the VR environment was not realistic.	Participants had issues while navigating inside the virtual realm, and a few of them felt motion sickness, and some had control issues due to no exposure to VR before.
Attitude towards use **(ATU)**	60% of participants believe the VR environment was engaging	Most of the trainees felt that immersion in VR was quite easy, and it was interactive.
Behavioral Intention **(BI)**	45 trainees are positive about recommending this training to others.	Not measured.

The TAM model indicated that approximately 60% of the participants had positive feelings regarding the engaging factor of VR training, which is further supported by qualitative findings in which they mentioned it was easy to interact with the virtual elements.

In the BI section, the rate of recommending this technology to others is measured, and it was found to be quite high. Approximately 64% of the students indicated that they would recommend this VR fire extinguisher training to others. This is directly measured in the quantitative analysis, whereas it was not assessed in the qualitative analysis.

The TAM model concludes that VR training was engaging and showed a higher preference among the participants; however, similar to the previous analysis, it highlighted the importance of an immersive virtual environment.

4.5 Revisiting Research Questions

The research questions that form the basis of this mixed-method are answered in this section based on the results discussed previously. Table 15 highlights the key factors that affect the effectiveness of VR training.

Table 15. Overall Findings from Mixed Method Approach

Research Questions (RQs)	**Key Aspects**	**Analysis Result**
RQ1.	Knowledge Retention	The knowledge retention rate is average, as half of the participants felt confident in transferring the fire extinguishing skills applicable to real situations world.
	Skill Preparedness	VR training can significantly boost confidence among the trainees.
RQ2.	Realism	The virtual realm's ability to resemble the real world needs improvement.
	Engagement	VR training demonstrated higher engagement levels.
RQ3.	Usability Challenges	Several reports highlight navigation issues and motion sickness.
RQ4.	Prior VR Experience	Experienced VR users outperform novice ones.
RQ5.	Improvements Required	Enhancing immersion and resolving navigation issues encountered in the virtual realm.

4.6 Discussion and future implications

This section will briefly discuss the findings from the mixed methods approach. Results of quantitative studies highlight the importance of providing clear instructions before training, which is also evident in qualitative studies. It is essential to consider factors such as voice instructions in the virtual realm and the inclusion of a video tutorial before training, as these

can significantly enhance the learning experience. The developed VR modules have interactive components, such as fire extinguishers; therefore, in both analyses, participants reported a high engagement rate with the VR training. VR is capable of building confidence among participants, boosting their confidence, and they reported it as a fun activity. Therefore, it can be concluded that VR-based training has the potential for higher knowledge retention rates and improves the overall learning experience by making it more engaging. This is also evident from students' responses, where they preferred VR training over traditional training methods.

In contrast, the issues reported by participants were related to realism and usability challenges. Realism is a crucial factor for any kind of virtual training as it affects the overall experience and defines the rate of immersion for a participant. As a result, if the training environment, such as the fire scenario or emergency scenes, is not realistic, it significantly alters the overall attitude toward the learning experience. Realism does not always mean having a very well-designed scenario; it also refers to a person's ability to fully immerse themselves in the VR experience. Inclusion of haptic feedback can be a good choice in that case, as it provides participants with a sense of reality and can enhance the immersive experience. Gani et al. (2022), Lorenz et al. (2023), and Patel (2025) have highlighted that the incorporation of tactile, sense-based haptic feedback can dramatically increase the quality of VR-based learning experiences. In the case of fire safety training, the inclusion of a heat suit can create the sensation of heat when a participant approaches the virtual fire. Modified physical fire extinguishing gear can be used to give participants the feeling of the weight of a real extinguisher. This type of haptic feedback is crucial for improving immersion during safety training. Navigation challenges were quite common among novice VR users; these can be addressed by providing a tutorial session before the actual training for new trainees. However, to resolve navigation challenges within the virtual realm, it would be better to use a room-scale VR environment where participants' movements depend on their real-life movements. Button-controlled VR makes it confusing to control the VR avatar while participating in the training. According to Y. M. Kim & Rhiu (2021) walk-in-place VR navigation provides easier navigation compared to joystick or button-controlled movement.

It is quite common for participants to feel motion sickness or vertigo while participating in VR training. One of the common reasons for this motion sickness is the type of navigation, which is evident in the research work of Nasiri et al. (2023), where it was claimed that the use of room-scale VR can improve VR-related motion sickness due to the navigation inside the virtual realm. Low frame rates and a loose fit of VR goggles are also possible reasons for motion

sickness. Using room-scale VR can alleviate the motion sickness issue and also make navigation inside the virtual environment quite easy for the participants. According to the data integration models, VR-based training has an average rate of knowledge retention and is able to boost the confidence of most of the training participants. In this research work, a hybrid experimentation approach was taken; the participants experienced both virtual and real fire extinguishing. It was also mentioned by participants that they prefer practical training more compared to VR training. The inclusion of haptic feedback and addressing the navigation issues can lead to a drastic improvement in the training experience.

4.7 Limitation of the Study

This study serves as a valuable empirical contributor to the growing body of on-going research regarding VR related training development. Though this study provides valuable insight yet it has some limitations and constraints. The study is conducted among the students who provided the response based on their own experience. Inclusion of industrial experts, fire safety experts and training developers would have increased depth of the insights of this study. The sample size is relatively low having more participants would have definitely provide concrete evidence and interesting findings. Another limitation was that it was not possible to conduct both the VR and practical training on the same day due to the scheduling of the research participants. TAM model and Kirkpatrick's model provide a brief overview by combining the quantitative and qualitative analysis which is a generalized preview. Specific factors or issues cannot be determined from these models. TAM model only provides information on how the participants feel about a particular technology it doesn't provide any specific recommendations on how a technology should be developed.

This study is solely based on user reported data, no in game data or performance score was integrated in this study. Inclusion of participants performance would make this study more reliable and it would serve as evidence for the knowledge acquisition rate.

5 Conclusion

This study assesses the effectiveness of VR fire extinguisher training based on user-reported numerical ratings and open-ended qualitative feedback. A mixed-methods approach was adopted, and research findings are further verified by the established Kirkpatrick's four-level training evaluation model and technology acceptance model. Key indicators of effectiveness include realism, engagement, usability, knowledge acquisition, and knowledge retention. Qualitative findings revealed that VR training successfully developed situational awareness among students, preparing participants for real-life emergencies. The learning experience was engaging, and the instructions provided were clear. These aspects influenced the participants to prefer VR training over traditional methods. This is reinforced by quantitative findings, where all statistical analyses showed that the knowledge retention rate is average and the knowledge acquisition rate is higher. Engagement is the strongest predictor of effectiveness. However, both analyses indicated that participants were neutral and, in some cases, had negative feelings towards the realism of the developed virtual realm. Qualitative findings further revealed that the fire scenario lacked an urgency factor and requires significant improvement.

The first level of Kirkpatrick's model shows that participants appreciated the engagement and interactivity of the developed VR module. Level 2 highlights that the knowledge retention rate is 45%, but in Level 3, it is clear that VR training effectively boosts confidence and increases skill preparedness. Finally, Level 4 points out the importance of developing a highly immersive VR environment, which can ensure 100% immersion in VR. The TAM model results align with the combined findings of Kirkpatrick's model. According to TAM, enhancing realism is very effective in increasing the efficiency of VR training. On the other hand, VR is preferred by most trainees; therefore, close to 64% of trainees intend to recommend this training further.

In conclusion, the developed training module was very engaging and was able to increase emergency preparedness among trainees. The best part of the training is its ability to offer a risk-free, highly engaging environment for developing firefighting skills. The inclusion of an urgency factor is important for improving realism. Incorporating haptic feedback and modified VR tools, such as a heat suit and an extinguisher, will add another dimension to the realism of the fire scenario. Tactile responses enhance the quality of immersion and make interaction with the virtual realm more engaging. To sum up, this study establishes a framework for future VR developers to evaluate the effectiveness of their developed VR modules. The strength of this

study lies in its use of a mixed-methods approach, with both datasets further analyzed using established models recognized worldwide.

5.1 Future Work

This research covers a wider scope for the evaluation of VR effectiveness, and it provides insights regarding the factors that influence the learning experience. However, future research is required to gain deeper insights regarding the following issues:

- Future research work should dive deep into specific factors that can increase the realism of fire scenarios. Two or three virtual modules should be developed with different levels of urgency factors. Participants' reactions should be measured to compare the learning experience.
- Further investigation is required to include more and more haptic feedback to increase the interactivity of the training. The sense of weight and heat is important for fire safety training. Future analysis should revolve around how subjects react to different kinds of feedback.
- This research work is purely based on user experience and self-survey; performance data should be collected directly from the simulation itself. Comparisons of this user-reported data in game performance could be crucial to increase the knowledge retention rate of future VR training.

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