

Emergency Preparedness Training Using Virtual Reality Games: Allowing Knowledge Transfer in the Digital Age

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Abstract: When unexpected incidents occur, such as fire outbreaks or floods, individuals who lack knowledge on how to handle such events are often shocked and unable to act efficiently. Virtual Reality (VR) technology promises to compensate for the lack of traditional teaching environments by immersing users in virtual learning environments with real-life relevance for many emergency scenarios. The primary objective of this paper is to provide a better understanding of how to raise awareness of emergencies and learn to manage unforeseen situations using VR games. Based on a theoretical background examining available literature on Knowledge Transfer (KT), VR and learning theories, we illustrate a case depicting how to handle a fire emergency at a school building. The case describes a VR game to inform students about the necessary steps for preparedness and discuss its utilization as an educational module in a course. Based on this, an Inclusive VR for KT (IVR-KT) framework is proposed that contributes to increasing the understanding of planning and assessing emergency preparedness training in education. The games included in IVR-KT will be developed using retrieved real-time and historical data with a special emphasis on inclusivity aspects by addressing a wide range of users regardless of their personal limitations and constraints. By presenting the framework and providing examples of its key components, the paper introduces new ways of considering KT for emergency preparedness training in education for handling unforeseen incidents.

Keywords: Emergency Preparedness, Evaluation, Knowledge Transfer, Virtual Reality, Serious Games, Education.

1. Introduction

With an increasing demand for practice-based learning and Knowledge Transfer (KT), new innovative ways of learning are crucial. Virtual reality (VR) based Serious Games (SG) are games designed for educational purposes rather than just entertainment. They offer a unique opportunity to simulate various scenarios where the participant can interact in a computer-generated environment while experience the consequences of their actions simultaneously. These actions are critical in emergency services, and therefore, hands-on training plays a crucial role in building skills, maintaining expertise, and strengthening readiness for unforeseen circumstances. Besides natural disasters, there are many man-made unexpected situations, such as fire, terrorist attacks, and transport accidents that may occur in our daily lives. These events can also cause injuries and damage, extensive and lasting physical and mental harm (Valcik and Tracy, 2017), as well as economic losses (Shaluf, 2007). According to the European Fire Safety Alliance, cautious estimates suggest that every year, over 5,000 people die from residential fires in Europe (European Fire Safety Alliance, 2024). Economic losses from natural disasters affected 50 million people in the EU between 1980-2020, and caused an economic loss of €12 billion per year (Majdik et al, 2023). Losses at such a large scale may cause unexpected ripple effects, for example, delaying Eurozone membership and enabling democratic backsliding (Arató, Koller and Pelle, 2021).

Emergency preparedness training is essential in conveying the importance of self-help and mutual assistance. Historically, various methods have been used, including videos, posters, and physical disaster exercises. Nowadays, the integration of cutting-edge technologies such as VR and SG presents promising new avenues for effectively training citizens (Hsu et al., 2013, Heldal, 2016). VR technology, widely recognized for its immersive capabilities, offers a versatile tool applicable across various educational contexts (Collins et al., 2021, Goedicke et al., 2018), and it is already gaining presence in training and decision support for first responders and civil defense (Székely, 2015).

Handling an emergency can be difficult for citizens involved, who must act in an organized way under time pressure. People are also more prone to commit errors in stressful conditions. By integrating VR via module into

a training program that teaches how to cope with life-threatening incidents, learners can repeatedly practice mastering the required knowledge and skills without the risk of incurring costs or triggering accidents that often may occur in real-life situations (Hammar Wijkmark et al., 2019, Song et al., 2021). This module is part of a European Union-funded project, B-prepared (see B-prepared, 2024), and the knowledge assessments are tracked via a back-to-back LMS (Learning Management System) solution between the B-prepared LMS and the LMS of the educational institution. This can allow tracking both individual knowledge progression as well as organizational level KT, for example the KT Metrics developed by the European Commission Expert Group (2009, 2022) for public research organizations. In this context, we further investigate the possibilities of VR interaction mediums (voice command, gesture recognition) and dynamic scenario design (e.g. wheelchair users' evacuation process), allowing to consider escape opportunities for people with, e.g., visual and motor impairment.

In such context, this paper presents the Inclusive VR for KT (IVR-KT) framework for achieving the KT within an educational institution of self-help in emergencies. The structure of the article is as follows: Based on existing projects in the field of VR-supported training, we first describe the fundamentals of KT in VR. We then explain how inclusive immersive training may help KT in disaster preparedness and engage students and teachers to learn by using new technologies. A case presenting a pilot VR prototype for a school fire evacuation scenario is sketched. We conclude this paper by discussing the opportunities of utilizing VR for KT and presenting the potential of the framework to teach life-threatening situations in a more engaging way by introducing an elective course module.

2. Background

2.1 Knowledge Transfer and Virtual Reality for Training Emergency Preparedness

Numerous publications have addressed issues related to Knowledge Management (KM), emphasizing the pursuit of efficient KM by seeking optimal methods and approaches (Wiig, 1997). A pivotal aspect of KM involves the dissemination and accessibility of knowledge within and across selected organizations. Schwartz (2006) asserts that knowledge transfer (KT) is a foundational societal process crucial for learning, which, in turn, drives development. While knowledge sharing (KS) and knowledge transfer (KT) are sometimes used interchangeably, the literature suggests that KS is predominantly utilized when focusing on individuals, whereas KT is more commonly employed when examining groups, departments, organizations, or businesses (Argote and Ingram, 2000; Choo and de Alvarenga Neto, 2010).

But how does anyone know whether the knowledge acquired in a VR environment is effectively transferred to the real world, and which basic characteristics will ensure KT from VR training to real world practices? While VR training has many already identified benefits (Xie et al., 2021), virtual simulations offer a significant advantage in terms of cost-effectiveness compared to traditional training methods for, e.g., firefighters on training grounds or in classrooms (Heldal and Hammar, 2017; Lamb et al., 2020; Hammar Wijkmark et al., 2021) or relevance, confidence (Ooi et al., 2019; Pedram et al., 2021).

In the last decades, many research studies have addressed the potential of VR for KT. For instance, Khanal et al. (2022), Grassini and Laumann (2020) report in their literature review that VR training can help prepare individuals for real-life emergency scenarios. VR has also changed how we engage with the type of VR we using, which, in turn, influences experiences and performance (Heldal, 2004). While there are VR technologies running on everyday computers, these are called non-immersive technologies, and others immerse the users in the simulated 3D technologies, e.g., head-mounted displays (HMDs); and these are called immersive technologies (Slater et al., 2018). VR is also useful for training in scenarios that are difficult to simulate in the real world, e.g., large forest fires, incidents in large buildings, or large public places (Williams-Bell et al., 2015; Heldal, 2016; Reis and Neves, 2019).

According to the learning pyramid (The Learning Pyramid, 2024), students remember only 10% of what they read, 20% of what they hear, and 75% when they simulate, model, or experience the material. Since allowing high experiences is one of the main benefits of VR, our proposed (IVR-KT) allows students to experience life-threatening situations in advance, thus VR games can help learners learn more effectively since they allow users to experience the intended scenarios firsthand and respond accordingly.

From the literature, it has been seen that VR continues to serve as a valuable tool for educating individuals on essential knowledge and skills. However, challenges related to the operational aspects of VR seem to introduce unnecessary obstacles, thereby diminishing learning outcomes (Song et al., 2021) and reducing gameplay self-

efficacy (Hong et al., 2023). This disparity is largely attributed to the inadequate and reflexive utilization of VR technology, failing to account for its full spectrum of capabilities, such as permitting errors for learning purposes. Hence, the development of VR applications should adhere to sound educational theories to ensure optimal learning outcomes. It is important to determine how guidance can negatively affect the acceptance of new learning ways (Fomin et al., 2024) or how leaders contribute to the outcome (Danielsson and Sjöstedt-Landén, 2020). If the user does not know how to make progress in the training, frustration can arise, and their willingness to learn may be reduced. Simplified representation of work steps as well as the lack of multimodal stimuli during VR training, can negatively influence the learning effect. In these contexts, human-computer interaction (HCI) guidelines play a significant role in the design of VR applications (Luo et al., 2021).

3. Methods

We propose the IVR KT framework based on literature from Knowledge Management (KT and KS), VR-based learning, e.g., investigating learning theories and cognitive learning models. It is inspired by the Trifecta model suggested by de Vaujany and his colleagues (De Vaujany et al., 2018), further developed for identifying patterns for VR for training for emergency professionals (Heldal et al., 2018).

The framework identifies aspects of how to teach emergency preparedness in a course module utilizing VR game via B-prepared created LMS API (Application Programming Interface) integration to educational institutions' own LMS, and the knowledge assessments are tracked via a back-to-back LMS solution between those two LMSs. B-prepared LMS has developed in such a way that it can automatically detect knowledge transfer metrics where players can see their individual progress (Majdik et al., 2023). Students can also learn relevant disaster-related knowledge by getting access to 'Disastropedia', a knowledge-sharing platform (see Disastropedia, 2024). In a course module, students receive all the available resources that fit this concept. To allow VR training to be handled via a solution between two LMS systems in a course module, the B-prepared LMS has a built-in player knowledge assessment tracking feature, and the educational institution provides all other resources, IT tools, and rules.

The defined IVR KT framework (see Figure 1) has five layers: a) the technology and other resources utilized, e.g. databases, repositories, resources for games (as the "IT technology" from Trifecta) together with b) influencing rules from the organization (as the "Rules" from Trifecta), c) information on managing VR training (this is a new layer, but necessary to be designed separately), d) involving practices for utilizing VR game based learning (as the "Practices" from Trifecta) and e) for the participants (this is a new layer, for teachers and students). Considering a new training module (a layer a) may influence some or each other layers since they have different mechanisms. Accordingly, we can use the same framework for different training situations. For example, if students want to learn how to handle a school fire systematically, the specific steps they need to take will depend highly on the scenario. The scenario depends on many circumstances, such as accessible buildings, people around, or the exact place of the incidents. This framework can potentially be used for various courses and students, but it is essential to consider issues that may vary. This should possibly be used for various courses and students, one needs to consider issues that may vary. For example, a and b) the technical resources, the current rules needed to be considered (how emergency training needs to be planned at a school) c) considering an existing scenario that needs to be used and further developed for a specific training situation, d) providing examples of applied practices, e.g. who needs to do what for finding escape routes, helping others, or reporting to emergency professionals, and e) considering the participants and their abilities (e.g. with or without functional problems). Through this, we intend to provide a better understanding of important parts of a situation necessary for KT for trainees.

4. Emergency Training

4.1 The Proposed Framework

For VR training in an educational institution as part of the course curriculum, teachers and students will have access to current VR resources and can also update the framework with information continuously. The aim is that teachers could get support for setting up VR training, and students will form teams and thoroughly brainstorm in order to learn about various emergency preparedness in immersive environment. They can experience VR games with the aid of API integration to existing game code repositories as well as design their own scenarios or new design ideas. Accordingly, new features and scenarios may be developed, which will make

learning more interesting and rewarding. For the architecture of the IVR KT framework, inspired by the Trifecta model) see Figure 1.

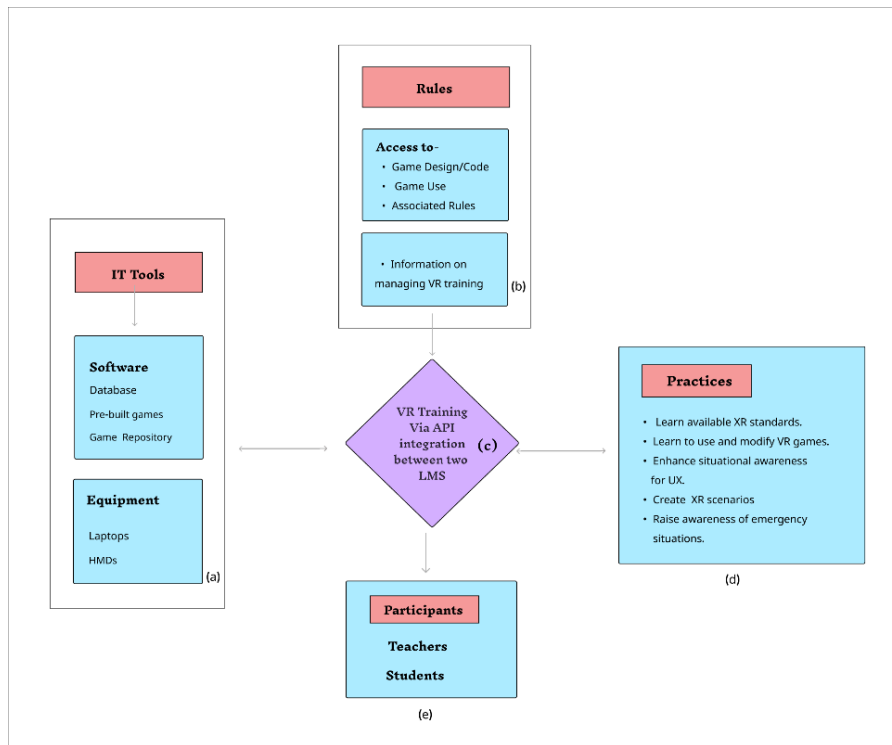


Figure 1: IVR-KT Framework. It has a total of five layers where layers a and b may vary depending on necessity. Layer c is the VR training that will be done via B-prepared LMS API integration into the educational institution’s LMS.

We are using the terminology introduced by De Vaujany et al. (2018) for considering digital technologies in organizations. This terminology focused separately on IT technology (a), Rules (b) and Practices (c), but additionally accentuates the main participants due to their different roles and enhances the necessary integration between the two LMS for the actual training (c). Every module can be modified, e.g., the software extended by new games, equipment with new technologies, or the used game with new storylines for different educational modules.

4.2 The Proposed Architecture for VR Games Framework

Since existing games play a central role in the framework, we discuss here some basics that can be included in most of the VR training situations. The proposed VR application is a 3D game environment designed to familiarize students with emergency situations as well as teaching about new technology and XR standards. The design aims to produce an engaging game to increase public awareness and support decision-making in emergencies. The main parts of the architecture (Figure 2) include a data layer, VR game models, and user interface (UI). The game utilizes gamification techniques based on historical data to trigger engagement and learning. The design follows specific learning goals related to situational emergency incidents and general safety knowledge on that field (e.g. fire, flood) and consists of various learning elements. Time-constrained tasks require players to make prompt decisions under stress and provide a unique opportunity to study user behavior. Players will be able to choose from existing locations for scenarios (e.g., Norway school fire incidents) or create a custom scene by setting various parameters. Voice input and gesture recognition are also planned to be used to analyze players' reactions to game-related incidents and detect emotional and psychological states.

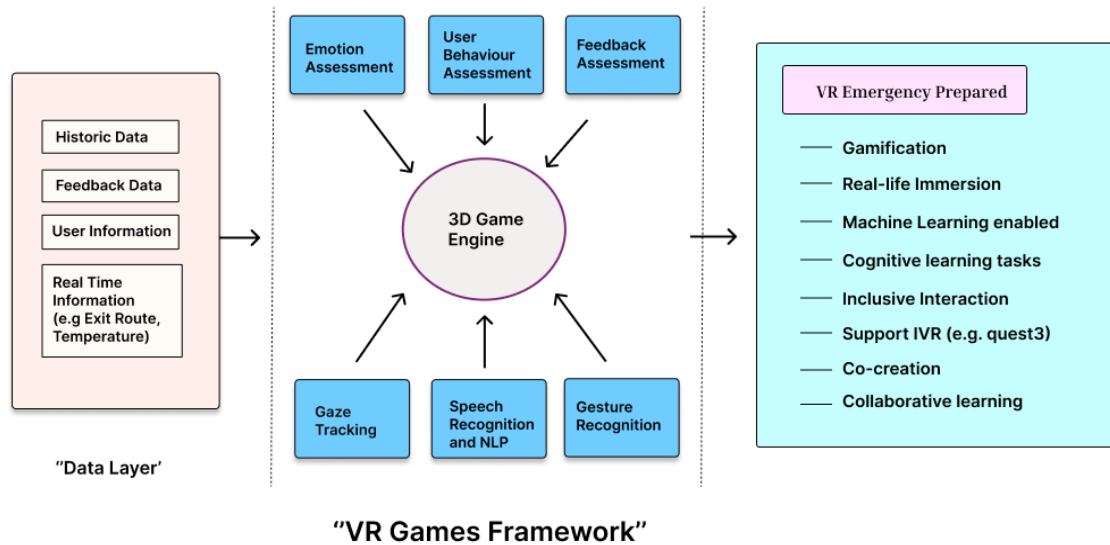


Figure 2: Main architecture for supporting KT via VR games for training. The game architecture includes a 3D game engine with different interaction mediums. Data Layer consists of different types of data which plays a significant role in the VR game framework.

The increasing interest students have in technology and VR provides an opportunity to improve the effectiveness of teaching environmental sciences and social responsibility by implementing this framework. The application incorporates retrieved real-time drill data to generate the environmental conditions necessary for simulating scenarios accurately. The temperature, visibility, smoke detection, length, and intensity of the precipitation, as well as the observation location and time, are all included in the retrieved real-time and historical drill data. Players will be able to wear a haptic suit to feel the temperature of specific scenarios (e.g. feeling warm when fire breaks) to increase the presence of the application as well as user experience and realism. Users will be able to select places and interact with accessible scenarios if data is stored in those specific locations. Different drill data from various locations are stored following the FLAIM framework to protect individual privacy while facilitating collaborative data exchange (Slagell et al., 2006). The game requires players to complete a variety of activities in a timed round to keep it interesting and effective. One of the important aspects of the framework is that users themselves can create scenarios in the game engine and provide feedback for improvement. Those feedback and user behavioural analysis data will work as a base for continuous improvements. From user behaviour patterns, it is possible to detect the most common patterns, e.g., mistakes, navigation, orientation, manipulation, data can help to design more user-centric tasks.

Under the United Nations' social inclusion principle, the Convention on the Rights of Persons with Disabilities (CRPD) requires all UN member countries to ensure that disaster awareness, preparedness, and response efforts are inclusive and accessible to individuals with disabilities (Inclusion Made Easy, 2012). Therefore, emergency preparedness training should follow Universal Design Principles (European Disability Forum, 2010). Our suggested system provides gaze tracking, gesture recognition, and voice interaction with natural language commands. These features increase accessibility and create an inclusive learning environment for everyone, regardless of their personal limitations. Additionally, Machine Learning algorithms will be used to evaluate behavioral analysis, feedback, and student learning patterns to adjust VR content in real-time scenarios. This will support the creation of more user-centric tasks design to ensure learning outcomes, which are necessary for KT. VR interaction can be difficult for untrained and disabled users, therefore our framework offers a variety of interaction methods, including voice command, gesture detection, controllers, and touchpads, in addition to language change possibilities, to provide an inclusive learning environment for diverse users. This ensures that a wide range of users, irrespective of their requirements and constraints, will be able to access our systems.

4.3 A Case: Considerations for a VR Game for Classroom Training

Under the guidance of our IVR KT framework, this experiment uses VR technology to build a Fire safety learning application for school scenarios. We split the fire safety education content into two categories: fire safety knowledge and practical application. The knowledge segment covers topics such as fire alarms, fire protection,

and fire hazards. First students are taught the safety information of the domain, and then they are exposed to the second category where players navigate through different fire safety scenarios. They receive interactive feedback to rectify mistakes and enhance their understanding. Essential guidelines and quizzes are pre-established to ensure students grasp the fundamental concepts. For example: What should you do if you encounter smoke while evacuating during a fire?

- A. Keep running to exit quickly
- B. Hold your breath and continue evacuating
- C. Go back and find an alternate route
- D. Stay low and crawl to the nearest exit

The game play part includes simple fire evacuation scenarios based on situational learning theory (see Figure 3). Situational learning theory ensures that learning should be placed in meaningful and complex situations so that users can take the initiative to learn and improve their ability to solve problems while making stories or, based on the available models, build up new stories within the VR app. In a game scene, a flame suddenly erupts from a cabinet in a classroom, causing the students to flee. The scenario unfolds with detailed descriptions, and users must select the correct actions. Currently there are two scenarios: the fire starts in a classroom (first floor) with all emergency exits available (Scenario 1), and the fire starts in a classroom (first floor) and only the right emergency exit is available (Scenario 2). Incorrect responses result in a potential "death," accompanied by alerts highlighting mistakes. For example, if the user is running towards the left emergency exit for scenario 2, an alert will pop up showing that the left emergency exit is closed. The simulations also feature students with disabilities to increase awareness. In one scenario, a wheelchair-using student tries to use the lift when smoke bursts. A pop-up alert shows 'wrong' choice, and help is coming within the scenarios. When the player will click "continue," it will show that help with evacuation chairs is on the way to ensure the student's safe and prompt evacuation. This situation not only teaches wheelchair users to wait for assistance and not panic, but it also raises awareness that special equipment is essential to kept in every fire safety department. The fire rescue department is not responsible for such a scenario. Thus, the organization's general evacuation plan and personal evacuation plan should include those special needs.

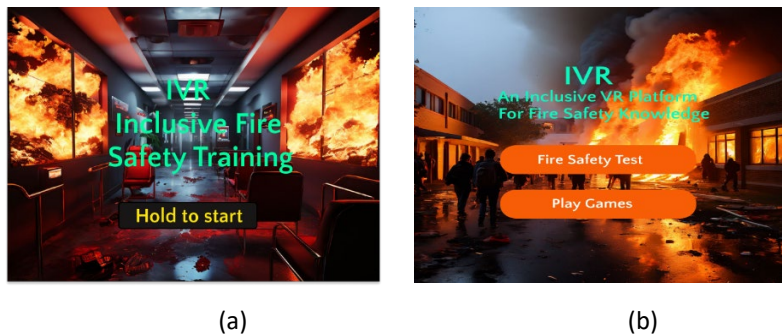


Figure 3: Interface of the IVR KT, showing (a) the start screen, and (b) the entrance of two modules for our case.

4.4 Connection to Actual, Real Incidents and Real-life Implications

Around the world, occurrences involving school fires or residential fires are not uncommon. There's a good probability that the newspaper that contains details on a residential fire. There were twice-weekly arson attacks at schools in the small Norwegian village of 'Nordkjosbotn.' Luckily no injuries were recorded from this incident, but the damage was significant. What if the same incidents happened during school hours? Are the students ready for unforeseen circumstances? And how can we implement prevention measures? For this case VR can work as a great medium for KT on how to be prepared by themselves and increase awareness in emergency situations (Luo et al., 2021), we can implement alike situations and use the questions for discussions.



Figure 4: Before the Arson Attack at Nordkjosbotn school and town hall (a) and after the attack (b).

An additional example from the beginning of the year, a deadly fire incident at a primary school in China took 13 students' lives (BBC (2024)). VR training can play a great role in preparing individuals for emergency situations not only at the physical level but also at the psychological level. To provide students with a close-to-real-life experience, our framework supports haptic devices. The scenarios are built using real-life incidents, so trainees can feel the heat, smell the smoke, and have a limited time to choose the correct exit route whenever a fire breaks out (Eilaki et al., 2022). If they go through the training multiple times, they will gain more self-assurance and be more mentally and physically equipped to deal with these situations when they arise.

4.5 The Possibilities of IVR KT Framework

As previously stated, the proposed games in the framework are based on actual events that have occurred. The tasks and scenarios are developed using detailed information from the local rescue agency. For example, the arson attack that occurred in Norway is still being investigated, and it was a pre-planned attack. Although the school has a fire alarm and the incident happened in the middle of the night, such an attack cannot be prevented by just placing a fire alarm because it takes the firefighters approximately fifteen minutes to arrive. In addition, the fire alarms identify when a fire has already started, but intruder alarms identify when someone has entered without authorization. This way, if someone is planning to create a fire from within the school building, they can be caught in the act before they even try. CCTV and automatic security lighting outside the school building can lower the likelihood of these events. By utilizing contemporary technologies, educational institutions can improve fire safety plans. VR game framework consists of two parts: 1) Educational content 2) Gameplay. The educational contents are created with a wide range of safety information, including how to prevent them, how to evacuate, and what to do if an incident occurs. This content can raise awareness among educators, students, and other authorities to take more action. Even a tiny error could potentially lead to an accident. Educational institutions may be reluctant to spend enough money on fire safety and installing all the needed equipment for night safety.

Thus, in that regard, the game scenario could look into whether all the windows and doors are properly locked at night so that no one can enter, how by installing an intruder alarm, the suspect can be caught, how not wanting to invest in fire safety led to an arson attack and what happened to recover from it, as well as presenting financial loss to give a real-life example. Everyone related to educational institutes can get all those resources, which can inspire them to be more be-prepared, in addition, for task design and improve user experience, they can also come up with new ideas to improve games design. By working together, IVR KT can contribute to a more conscious society within educational institutions, with implications for other areas.

5. Challenges for Utilizing VR for KT for Emergency Preparedness

Emergency training can be complex and challenging. While having individuals read procedures and ensuring their understanding is a good initial step, it is often insufficient. Based on the literature, we can infer that VR holds significant promise for emergency training due to its risk-free immersive experiences. Despite the great potential of VR, implementing successful VR applications can be challenging due to various social and technical factors, including task design, realism, hardware and software requirements. Since it can be challenging to evaluate and enhance the impact and value of VR training, this paper made a first approach by suggested IVR KT framework. It is based on already-existing resources e.g., data, source code, and considering existing hardware (e.g. HMDs),

but also on enabling students to gain familiarity with common XR applications and critical emergency knowledge (e.g., fire safety information). VR training should be also accessible, inclusive, and respectful of the users' preferences, needs, and rights. For example, the proposed framework can be supported by voice & gesture recognition and gaze tracking to make the system inclusive for everyone, including people with disabilities. Having a simulation that is as realistic as feasible is a desirable quality. However, users may experience psychological distress from an intensely realistic disaster simulation, and certainly, they would not like to be burned in a simulation. In VR and safety science research, there may be a trade-off between mental safety and realism in a disaster-related simulation where more research, new design ideas, and technological advancement in emergency preparedness through virtual reality training is necessary. Therefore, we think the IVR KT framework may play a significant role in imparting relevant knowledge to students and teachers so they can create new, practical ideas through a collaborative approach and the provision of already-existing materials. Since public awareness plays an important role in the effective mitigation of a disaster by arousing community interest and educating society to reduce risk from potential threats (Davis, 1989). In that regard, IVR KT can monitor and assess the learners' performance, progress, and feedback and also provides them with timely and constructive support and guidance.

6. Conclusions

This paper argues for the possibility of offering an immersive and interactive setting for training and teaching emergency planning in education. To this end, it proposes the IVR-KT framework, with the goal of addressing the challenges of making learning more engaging and increasing effectiveness by helping students create collaborative strategies for resolving real-world, life-threatening problems using VR games.

The framework uses historical data as a basis to support the creation of an inclusive VR learning environment where users have various interaction options and can collaborate in a realistic and immersive experience. We extended the Trifecta model to fit emergency training at schools and provide a seamless solution between two LMS for tracking KT. We have illustrated the basic elements of a framework that can be used for developing inclusive immersive games with a focus on accessibility, scalability, and adaptation to use cases, to enhance students' understanding of critical issues in handling emergencies. Future work includes using the IVR-KT framework and adding examples of VR games we recently developed based on the presented principles, utilizing it as a data hub for future students to achieve our goal of KT in emergencies using VR games within an educational institution.

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