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Design, Development, and Evaluation of a Virtual Reality Serious Game for School Fire Preparedness Training

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Abstract: Immersive virtual reality (VR) is a technology that can be effective for procedural skills training through game-based simulations such as serious games. The current study describes the instructional design, development, and evaluation of the FSCHOOL fire preparedness serious game in a cave automatic virtual environment (CAVE-VR) for elementary school teachers. The main game mechanics include a storytelling scenario, enhanced realism, freedom of movement, levels, and points corresponding to the learning mechanics of instruction, action, simulation, discovery, repetition, and imitation. The game was developed in Unity 3D with the help of the Fire Dynamics Simulator and a script to emulate and visualize fire propagation. The game featured three levels to respond to school fire safety regulations and was evaluated by elementary school teachers (N = 33) in Greece. A comparative quantitative study was conducted with experimental and control groups. The results indicate that the VR serious game is appropriate for training, providing challenge, enjoyment, and mastery.

Keywords: virtual reality; cave automatic virtual environments; serious games; fire preparedness; computer simulations

1. Introduction

School staff members worldwide need to be prepared to handle a wide range of emergency events, perilous circumstances, safety threats, and unanticipated situations [1]. Fire preparedness is a part of schools' crisis management plan, involving fire prevention measures, handling capacity of minor fires, and school evacuation protocols in major fire incidents [2]. Recent studies have reported low participation and motivation of school staff members to engage in crisis preparedness activities [3]. Game-based solutions such as serious games can increase trainees' engagement and performance in skills training [4]. Immersive virtual reality (VR) is considered to be a suitable medium for procedural skills acquisition [5] and training in simulated hazardous situations that are too dangerous or ethically unacceptable to be replicated in the physical environment [6]. To this end, serious games in VR offer superior engagement, performance, and retention [7]. The current study describes the instructional design, development decisions, and preliminary evaluation of such a game dedicated to the fire response preparedness of elementary school teachers. This research on an active game-based learning curriculum has the potential to transform compliance with fire safety training from a trivial, tedious obligation into realistic and memorable experiences. Improved, in-depth procedural knowledge retention on fire preparedness can literally save lives by being transferred to authentic contexts [8].

2. Literature Review and Theoretical Background

VR is one of the fundamental technologies of the metaverse, the next three-dimensional paradigm of social networks towards the Internet of Place [9,10]. According to the model for meaningful learning in immersive VR environments, designers should provide useful, context-specific information only and in small chunks, and the focal point should be aligned on the conduct of constructive problem-solving activities [11]. These elements of the model have been demonstrated in a serious VR escape room for science education [12]. In the beginning of this epistemic breakout game, four panels with short texts and simultaneous audio narration are unlocked. Next, players are challenged to apply this specific information in practical puzzles with increasing complexity and difficulty. Gamified VR applications can facilitate in-depth, meaningful knowledge construction, both in attendance-based and in distance education settings [13,14]. Immersive VR applications include systems based on head-mounted displays (HMDs) and cave automatic virtual environment (CAVE) systems [15].

A CAVE system is a fully immersive, large-scale, modular system that provides a faithful representation of a variety of situations addressing the needs of diverse sectors (e.g., higher education, scientific research, industry, maritime, law enforcement, military, security) [16,17]. CAVE systems offer users the illusion that they are surrounded by a fictional world, providing a fully interactive, spatial representation. In contrary to HMDs, which suffer from limited field of view, CAVEs provide a larger field of view (ranging from 180°C to 300°C), which facilitates an amplified feeling of presence in the virtual environment without the need for specialized wearable equipment [18], and further allow up to six people to collaborate simultaneously, which in turn breaks the user isolation feeling.

Immersive VR applications have been adopted widely to enhance the conduct of educational activities dedicated to vocational skill (practical/technical) development such as welding [19], vehicle painting [20], renewable energy [21], design [22], safety training [23], computer network threats [24], and security awareness in Industry 4.0 IoT environments [25], as well as for the training of small and medium enterprises' personnel in the new digital era [26]. To this end, game-based learning approaches, mediated by immersive VR systems, have been successfully utilized to teach both primary subjects (e.g., mathematics) and fire safety skills to primary education students [18,27]. CAVE-VR systems have been used to recreate environments and allow users to observe and interact with objects in project screens in various fields such as marine archeology [16] and specialized vehicle safety training [17]. Although learning should prioritize high-end immersion hardware [8], desktop-based VR lab simulation games can be enhanced using motion trackers such as Kinect [28]. Various efforts have been undertaken to develop realistic and accurate simulators that visualize aspects of fire dynamics in VR [29]. A fire training simulator with an integrated smoke visualization and hazard detection plugin was utilized to teach evacuation skills [30]. Serious games have been also utilized extensively for evacuation training [31]. The same literature review revealed a conceptual framework for effective serious game design. VR serious games can be incorporated in various training and learning stages in the pursuit of various cognitive and affective outcomes [12,13].

In line with the previous efforts, in the present work, we sought to evaluate the usefulness of the FSCHOOL game, a highly immersive experience dedicated to fire preparedness in schools. The goal of the evaluation was two-fold: (a) to detect and compare the learning effects of the serious game and (b) to collect and analyze schoolteachers' perceptions about the game.

3. Design of the FSCHOOL Fire Preparedness Serious Game

3.1. Serious Game Design

To address the above-stated need, the FSCHOOL fire preparedness serious game entitled "A fiery first day at school" was developed. The purpose of the FSCHOOL serious game is to facilitate the capacity development and preparedness skills of schoolteachers to prevent fires and maintain personnel safety in case of fire. Upon completion of the experience, participants are expected to have developed a multitude of cognitive skills around three key fire safety areas: (a) fire prevention, (b) fire extinguishment, and (c) school evacuation. The key educational objectives emerged from the regulation-specified intended learning outcomes and are illustrated in Table 1.

Table 1. Connection of the intended learning objectives with the instructional design decisions.

Bloom's Taxonomy	Intended Learning Objectives	Instructional Design	Intended Learning Outcomes
Comprehend	Identify common fire hazards.	Gamified quest activity	Maintain a fire-free, safe school environment.
Comprehend	Accurately assess the danger magnitude of a fire.	Simulation activity	Decide whether to evacuate or extinguish a fire.
Know	Identify the main types of fire extinguishers.	Experiential puzzle	Select proper media to extinguish a fire.
Apply	Correctly utilize an extinguisher to combat a fire.	Gamified activity	Apply proper skills to extinguish a fire.
Apply	Initiate and execute school evacuation procedures.	Simulation activity	Evacuate school safely.

The learning outcomes were formulated based on the school fire safety regulations and frequent briefings of the Ministry of Education of Greece using Bloom's revised taxonomy [32]. This popular model distinguishes six categories of educational activity and achievement: remembering, understanding, applying, analyzing, evaluating, and creating. For the FSCHOOL, the outcomes were formulated collaboratively with the participation of an instructional designer, a subject-matter expert, and a game designer. For fire prevention, the main objective is the accurate identification of potential threats in school environments. Fire extinguishing entails assessing correctly whether a fire can be put out with available fire extinguishers. This in turn involves (i) the accurate knowledge of different fire extinguisher types and against which fires they should be used, and (ii) activating the fire extinguisher effectively and safely. In the final game stage, the prime objective is the execution of the school evacuation protocol by performing all predefined tasks in the proper order under time pressure and audiovisual distractions.

3.1.1. Game Structure

The game is structured in three levels (story episodes) that users can experience sequentially or independently from each other. The overall game narrative and progression is as follows. The user assumes the role of a new teacher who has accepted an offer to work in a notorious school. One colleague shared some worrisome rumors about that particular school. However, these warnings were dismissed. After all, the school principal promised to provide "ample opportunities for professional development." On the first workday, the user meets the goofy principal, who informs the player that s/he has also been appointed as the school's fire prevention officer and gives her/him access to all school rooms and facilities. The user's duties include the inspection of preventive fire measures and the duty to orchestrate appropriate actions in case of a fire. Right after the principal is gone, a teacher invites the user to her classroom to inspect and ensure that everything is OK. There, the player has to locate potential threats (episode 1: Prevention). Later that day, the janitor asks for help to correctly classify the recently purchased fire extinguishers. Right after this, a student enters and asks for help, as she has seen smoke coming out of a room. The user enters and has to assess and eventually extinguish a fire (episode 2: Extinguishment). After that, the fire alarm rings, as there is another fire outbreak. The user has to assess the situation again and decide whether to extinguish the fire or apply the proper school evacuation protocol (episode 3: Evacuation).

3.1.2. Learning and Game Mechanics Alignment

The FSCHOOL game employs a pedagogically driven design approach based on the Learning Mechanics–Game Mechanics (LM-GM) model [33]. The LM-GM model supports the design of experiential learning activities in serious games by joining pedagogy and game features (such as game mechanics, dynamics, and aesthetics) together [34]. Using the LM-GM model, we carefully identified and selected the GMs that can facilitate and enhance learning outcomes through appropriate LMs. The analysis of the FSCHOOL serious game is illustrated in Table 2.

Table 2. LM-GM analysis of the FSCHOOL fire preparedness serious game.

Game Mechanic	Learning Mechanic	Implementation
Story	Instructional	Rendered dialogs
Cascading information	Guidance	Non-player characters
Selecting	Action/task	Choice of equipment, action
Movement	Discovery	Navigation, position
Realism	Simulation	FDS plugin
Action points	Imitation	Extinguishing accuracy, execution speed
Levels	Repetition	Guided and unaided practice
Feedback	Feedback	Prompts
Status	Competition	Leaderboard

The storyline and the instructional content are delivered through cut scenes with rendered dialogs. In each level, non-player characters (NPCs—autonomously programmed avatars) guide the user and provide helpful, cascading information and hints that ensure smooth gameplay development. Another vital game mechanic is selection. The user can make meaningful choices across game time and space to complete tasks and achieve the set objectives. In any case, the user can move freely in the virtual environment, including visits to different rooms and engagement with NPCs. The freedom of movement and choice enable learning discovery and agency. The procedural skills transfer is ensured through the LMs of simulation and imitation. The realism of the VR experience is based on an accurate fire simulation plugin that will be described next. Whenever a player performs a task, feedback is provided by the system to convey the degree of success. User actions are translated into points according to their accuracy and visualized in global and contextual leaderboards. Each game level features an extensive list of editable scenarios. Hence, each user can replay each game level (repetition) and receive a different assignment each time.

4. Development and Technical Aspects of the FSCHOOL Game

4.1. Serious Game Development

CAVE VR System

The employed CAVE-VR system has a hexagonal structure that consists of a five-wall room with simultaneous full-HD projection on every wall, totaling a resolution of 8000 × 1200—a 9.6 Mpixel real-time graphic. In such virtual environments, tracking quality is fundamental (Figure 1). Participants and objects need to be tracked in order to interact with the synthetic world, but till now have had modest outcomes, restricting interactive VR applications to certain less-demanding areas. The employed CAVE system can achieve a tracking accuracy of up to 0.5 mm per axis, allowing it to be used in new, never-before-assigned tasks, like shooting and fire-extinguishing simulations. The heart of the system is a series of specialized autonomous laser tracking devices that are both small and lightweight enough that they can be fitted onto a variety of objects like guns, clothes, or fire extinguishers, but also have exceptional data-processing abilities so they can perform all the complex calculations needed to calculate their six degrees of freedom (horizontal, vertical, depth, pitch, yaw, and roll) coordinates in real time [9].

Figure 1. Overview of the hexagonal CAVE VR environment.

Based entirely on interactive three-dimensional computer-generated imagery, the system enables the execution of massive, complex simulated scenarios for various use cases: From close-quarters combat to industrial firefighting, the outcome is realistic and authentic (Figure 2). Lighting conditions not only vary with the time of day, but also play an active role in the outcome of the exercise, creating new training opportunities. Similarly, varying weather conditions can accumulate experience to the trainees in novel ways.

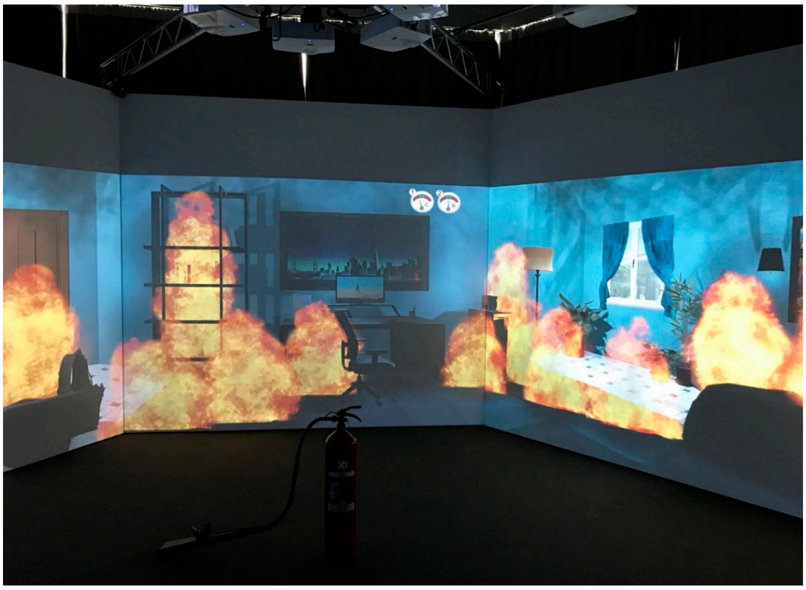

Figure 2. Indoor fire simulation in the CAVE environment.

4.2. Interaction and Gameplay

All interactions in the CAVE environments are mediated through a hand-held VR controller. User movement is tracked by embedded sensors. In the FSCHOOL game's episodes 2 and 3, fires occur in a classroom and the alarm sounds, ringing to create an additional auditory level of experience realism. After the rendered dialog in the opening sequence, the user locates where the gameplay starts in the corridor. There are three classes of extinguishers available to pick up to subdue the fire—the ones that are placed in schools. Users have to assess whether they can extinguish the fire by themselves or whether the fire is out of control. If they decide to stop the fire, they can pick any unit, move, and start extinguishing the fire (Figure 3). Alternatively, they can evacuate the school through the stairs (Figure 4) leading to the playground, the designated evacuation area according to the fire emergency evacuation plan.

Figure 3. Corridor with extinguishers (**left**); extinguishing the fire (**right**).

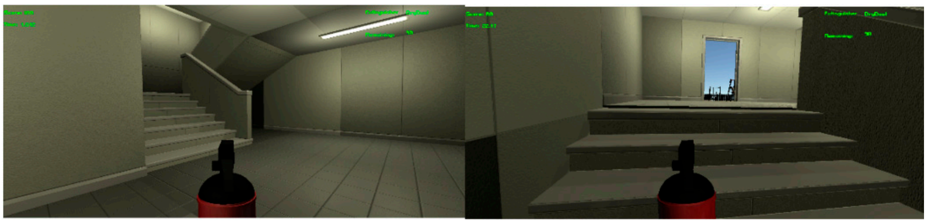

Figure 4. Evacuation staircase (**left**); exit to the evacuation assembly area—the playground (**right**).

4.3. Fire Simulation

The serious game development was based on a complete fire-training plugin. To deliver high learning quality, a realistic simulation was implemented while maintaining an attractive end-user game feel. The simulation is based on the Fire Dynamics Simulator (FDS) model. We used data from the FDS to validate the fire propagation and used them as an input to the Unity 3D engine.

The FDS is a powerful computational fluid dynamics model developed at the USA's National Institute of Standards and Technology [35]. It is written in Fortran 90, which has been used to model various phenomena, such as pyrolysis, combustion products by fire, and the spread of fire and smoke. As its creators mentioned, "the model solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally driven flows with an emphasis on smoke and heat transport from fires" [35].

The FDS provides the capability to model the geometry of an object or a collection of geometries. Every object in the environment is modeled independently. A Fortran script was written to describe the object′s properties, such as density, dimensions, the heat of reaction, and more [35].

All flammable objects' geometries were imported into the FDS to calculate the impact of fire on them. After running the simulation, the FDS exported multiple files with the model results. These results described the fire spread on the specific geometry based on several factors, such as material, size, volume of the geometry, and more. Based on this set of data, we focused on the mass loss rate values and the time it takes for the fire to burn the geometry. Figure 5 represents the general implementation flow of the fire-training environment.

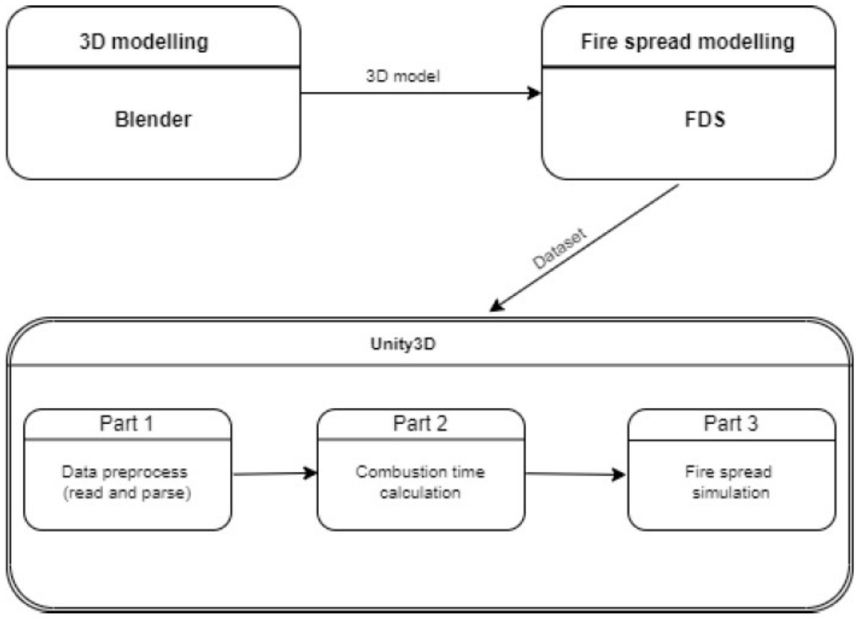

Figure 5. Implementation flow of the fire-training environment.

Specifically, every flammable object has the DataAndMassController script attached. When the game starts, the script searches—in the resources folder—for the dataset with the same name as the objects. After finding the dataset, we assign the two needed columns to two lists: the timeStampsList and the massLossRateList. By iterating through these lists, we extract some essential data, such as the total mass, the simulation step, the massTriggerFraction, and the fullBurnIndex.

- FullBurnIndex: We iterate through the massLossRateList and find the index where the object's mass zeros out. This index is used in the timestampsList in order to determine the time that an object takes to get fully burnt.
- totalMass–massTriggerFraction: We iterate through the massLossrateList until the point where the mass zeroes out, and we add up all the mass fractions that are being subtracted in every step. We assign this sum to the totalMass variable, and furthermore, the massTriggerFraction—10% of the totalMass variable—is calculated, which will be the trigger for the fire movement.
- Simulation step: The simulation step is calculated by subtracting each step from the previous one.

When the fire touches a piece of furniture in the VR environment, the mass starts reducing. When the totalMass reaches 10%, the fire starts moving to the neighboring objects—based on other inputs, like speed and direction—as long as it touches flammable objects. For example, if there are two pieces of furniture at a distance and no carpet existing on the floor, the fire cannot transfer from one piece of furniture to another.

4.3.1. Mass Loss Rate

The FDS's heat release rate dataset was utilized to calculate the mass-loss rate. The dataset provides the simulation's timestamps and the mass-reducing quantities in each timestamp. The simulation step is calculated as the difference between each timestamp, and it is calculated dynamically by subtracting each timestamp from its previous one. These timestamps and mass-loss rate sequences were assigned in lists to be more accessible from the script's methods. According to the dataset, when an object is on fire, the algorithm activates the ReduceMass method, subtracting a specific quantity in every simulation step. This method works while the object's mass is not zero. When the mass turns to zero, the fire disappears and only the smoke object remains active.

4.3.2. Fire Propagation

The fire propagation system was designed and developed in Unity as a grid system, where the FDS calculates and monitors every flaming object's temperature. This concept was challenging because it requires reading different datasets in each time frame and collecting data for all the scene's collisions. More specifically, the fds2ascii provides the core of the object's temperature fire. The simulation was separated into five windows, and we developed a method that changes the datasets parsing every 10 s. For example, if we want to read the desk data, the procedure is as follows:

0″–10″: Desk_Temp_0_10.csv,
11″–20″: Desk _Temp_11_20.csv,
21″–30″: Desk _Temp_21_30.csv,
31″–40″: Desk _Temp_31_40.csv,
41″–50″: Desk _Temp_41_50.csv

This data was used in order to transfer fire to adjacent flammable objects. With Unity mesh, we identified the corner of the scene's floor, and we generated a grid with 1 × 1 cells in all scenes (Figure 6) [35].

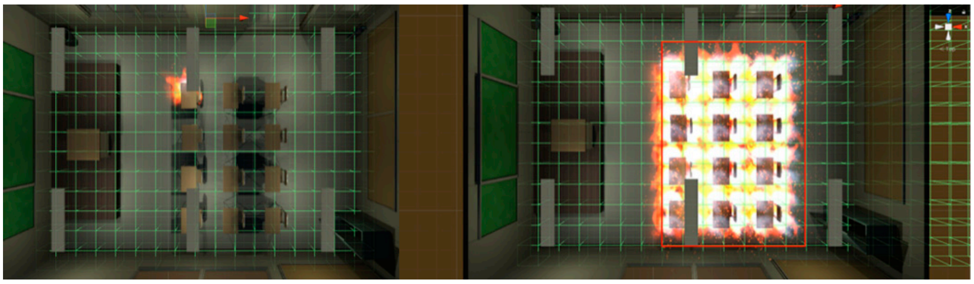

Figure 6. Scene grid (**left**); fire propagation in the grid (**right**).

These cells have a collider attached that informs the system about which objects collide with the cells and vice versa. Hence, when a fire starts on an object, the algorithm starts checking whether adjacent cells contain a flammable object. If so, the algorithm checks the cell's ignition temperature of its adjacent cell. The cell inherits the ignition temperature from the contained object.

Every object has an ignition temperature based on its material. Thus, if the flaming object's temperature exceeds the adjacent cells' ignition temperature, a fire clone is generated in this cell, and the method is repeated until all the flammable cells have a fire clone (Figure 4). Furthermore, every object has a fireClass property assigned to it when the material is selected (Figure 7).

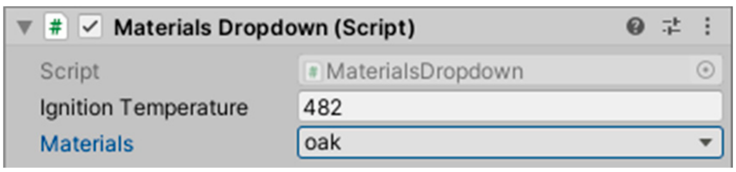

Figure 7. FireClass property: ignition temperature of oak wood measured in °C.

4.3.3. Extinguishment

In order to provide an integrated fire-training simulation environment, an extinguishing system had to be developed. Unity's particle system was utilized to create the extinguishing agent of the extinguisher. The fire objects also consist of the particle system, so a particle system interaction solution was developed. Colliders were defined for all objects. The trainee can choose an extinguisher among four choices: Water, Foam, Dry Dust, and CO_2. Every extinguisher has its specifications, and according to these, the extinguishing logic is handled. When the user presses the handle in VR and the extinguishing agent collides with a fire object, the fire loses mass quantity based on the extinguisher's size for every second the collision occurs. For example, in the case of a Dry Dust/27A-0.77, every second the extinguishing agent collides with the fire, the fire loses 0.77 of its total mass and the extinguisher quantity is reduced by 0.2 of its total 30. Experienced fire-training specialists validated the aspects of the fire simulation.

5. Evaluation

For the needs of the study, a comparative mixed-method evaluation approach was deployed, combining quantitative and qualitative data featuring an equivalent group pretest and delayed post-test design [36]. The pre-post knowledge test was prepared in collaboration with a subject-matter expert, and it consisted of 13 multiple-choice questions (MCQs). The MCQs were formulated to assess participants' knowledge and skills in accordance with the stage in Bloom's taxonomy of each objective, as described in Table 1. One indicative MCQ on fire prevention was, "To avoid a fire outbreak and to put it out what elements should be prevented from coexisting?" (correct answer: fuel, heat, and oxygen) and on fire extinguishing, "In a fire with electric equipment (e.g., computer, socket) what types of extinguishers should be used?" (correct answer: CO_2 and dry powder). Each correct item was awarded 10 points, with 130 being the perfect score. To facilitate the comparison process, the same evaluation content was used across both testing stages in random order as a safeguard against the same-set response effect [37]. The knowledge test and the fire preparedness manual were based on official fire safety documents and validated by two certified subject-matter experts.

For the evaluation of the learning experience, we adopted the scales of a validated psychometric instrument for VR applications [38]. In total, 67 items distributed across 13 constructs (C1-C13) were included in the present study (Appendix A). The questionnaire was translated into the participants' native language by the authors and its language accuracy was examined and improved by two professional language translators.

The experimental procedure was as follows (Figure 8): the evaluation took place in two sessions arranged in the Laboratory of Knowledge and Intelligent Computing. In the first session, all participants took the pre-test and were separated into two cohorts: an experimental group and a control group based on their pre-test scores to ensure group equivalence in terms of pre-existing knowledge. Next, the experimental group played the FSCHOOL game, while the control group read a fire preparedness manual that contained all fire-related information contained in the game. After a short introduction of the study goals, means, and preparation, the experimental group members played the game in the CAVE environment for 15 to 20 min. The second session took place one week later in the same space. At the beginning of the second meeting, all participants took the post-test. This time, the control group members played the FSCHOOL game. Finally, all except four participants evaluated their FSCHOOL game experience by answering the aforementioned questionnaire. During each session, all laboratory equipment and spaces were cleaned and disinfected according to the latest health and sanitation guidelines to avoid the spread of COVID-19 [39]. Qualitative data were collected through gameplay observation and feedback discussions during the second session, wherein participants elaborated on their experience and provided additional comments.

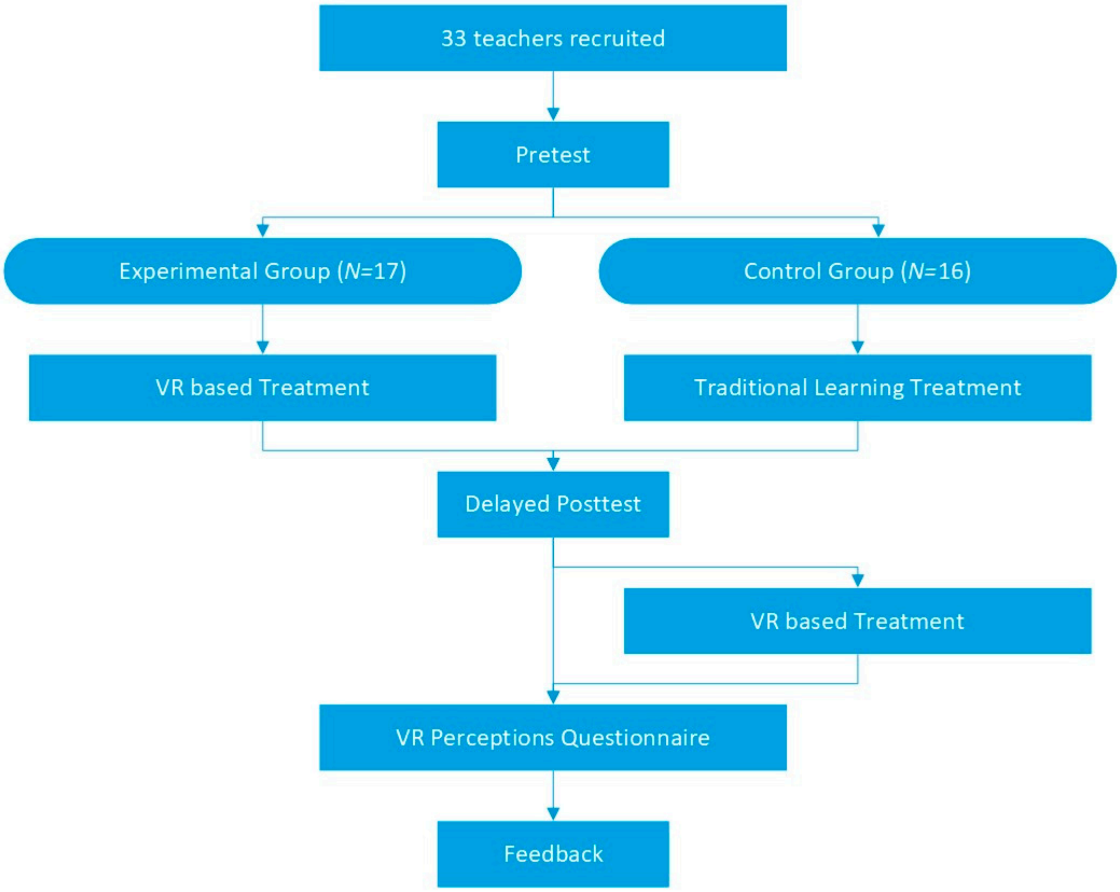

Figure 8. Experimental research procedure.

6. Results and Discussion

In total, 33 (N = 33) schoolteachers from elementary schools in Arta, Greece, participated in the evaluation (Table 3). The sample was fairly equally distributed in terms of gender, with most participants being in the middle-age group.

Table 3. Descriptive statistics for the demographic data.

Statistic		Control Group		Experimental Group	
		N	**Percent**	***N***	**Percent**
Gender	Males	9	56.25	10	58.82
	Females	7	43.75	7	41.18
Age group	20–30	2	12.50	4	23.53
	31–40	7	43.75	4	23.53
	41–50	4	25.00	5	29.41
	51 or above	3	18.75	4	23.53

The custom-made knowledge evaluation test demonstrated an acceptable internal consistency (Cronbach's $\alpha > 0.7$) for each group across both testing stages (Table 4). Based on the initial exploration of the dataset, the distribution of the scores seemed fairly symmetrical, an outcome that was also confirmed from the Shapiro–Wilk test of normality. Nevertheless, despite the normal distribution of the score results, the adoption of non-parametric tests was considered more appropriate due to the small sample size.

Table 4. Descriptive statistics of the academic performance.

	Control Group		Experimental Group	
Statistic	**Pre-Test**	**Post-Test**	**Pre-Test**	**Post-Test**
Min	0.31	0.46	0.38	0.46
Max	0.92	1.00	0.92	1.00
M	0.66	0.76	0.65	0.81
Mdn	0.65	0.77	0.69	0.85
Std. dev.	0.15	0.13	0.18	0.17
Skewness	−0.30	−0.45	−0.15	−0.52
Kurtosis	0.51	1.22	−1.47	−0.56
Cronbach's *a*	0.73	0.74	0.72	0.75
Shapiro–Wilk	$W = 0.953$ $p = 0.546$	$W = 0.95$ $p = 0.494$	$W = 0.893$ $p = 0.0524$	$W = 0.918$ $p = 0.135$

To ease the presentation of the results, the scores have been scaled (min = 0, max = 1).

As already mentioned, the participants were intentionally split in accordance with their prior knowledge (pre-test performance assessment) in an evenly distributed way. To verify that both cohorts were on the same level, a Mann–Whitney *U* test was performed ($U = 134.00$, $Z = -0.07$, $p = 0.94$). Following the conduct of the post-test knowledge assessment, changes in performance (pre-post-test) were examined. To achieve this goal, a Wilcoxon signed-rank test was performed for each group. In both cases, participants demonstrated significant improvements (control group: $Z = -2.9003$, $p = 0.004$; experimental group: $Z = -3.2958$, $p < 0.001$). In view of these statistically significant outcomes, we opted to further gauge the effect size (Cohen's *d*). The results indicate that the instructional approach (VR) adopted by the experimental group had greater effect (large effect, $d = 0.91$) than the traditional method that was utilized for the training of the control group (medium effect, $d = 0.71$); an outcome that is also in agreement with a similar study that was conducted with relatively younger individuals [5]. Nevertheless, no statistically significant differences were identified when compared to the overall performance improvement across both groups ($U = 110$, $Z = -0.95$, $p = 0.34$).

Beyond the summative analysis, we also performed correlation tests to explore the impact that the participants' gender or age group may have had on the observed performance improvement in view of the adopted training method. In both cases, the participants' age was found to be an influential factor (control group: Spearman's *rho* = 0.56, $p = 0.02$; experimental group: Spearman's *rho* = 0.67, $p = 0.004$) but no impact was identified as far as their gender was concerned (control group: $U = 21.000$, $Z = -1.137$, $p = 0.256$; experimental group: $U = 32.5$, $Z = -0.25$, $p = 0.8$), an observation that is in partial agreement with the findings reported from a systematic review [40].

In addition to the performance evaluation, we also explored participants' views of the integrated VR-based training experience (Table 5). The educators' responses in the distributed psychometric instrument were overly positive and consistent (Cronbach's $\alpha = 0.91$) across all the examined constructs. Nevertheless, some aspects were rated slightly higher than others, thus justifying a more elaborate presentation and discussion. In greater detail, the participants acknowledged the high representational realism of the graphics as the factor that influenced the overall user experience the most. In the same vein, the freedom offered to them to control and interact with the virtual content, without spatiotemporal constraints, increased the so-called sense of presence and positively impacted their overall attitude toward this alternative instructional approach. The aforementioned elements individually and collectively influenced the participants' perception of the learning experience, which was deemed to be meaningful, interesting, and enjoyable. To this end, the educators also acknowledged the cognitive benefits that the integrated training approach offered, with particular emphasis on the opportunities provided for reflective practice and critical reflection. On the other hand, the participants highlighted the steep learning curve that is required to familiarize themselves with and develop understanding on the operational procedures (e.g., use of the hardware equipment), which naturally impacted their overall motivation to utilize the proposed tool and satisfaction with the training experience. Such obstacles are generally reported in studies that utilize immersive learning technologies, thus making the conduct of extended orientation activities—prior to the actual engagement with the learning tasks—essential [41].

Table 5. Descriptive statistics for the immersive VR training experience survey (n = 29).

Construct	Min	Max	Mdn	Mean	Std. Dev.	Cronbach's α
C1. Representational fidelity	2	5	5	4.41	0.66	0.88
C2. Immediacy of control	2	5	4	4.34	0.74	0.93
C3. Perceived usefulness	1	5	4	4.09	1.66	0.95
C4. Perceived case of use	1	5	4	3.72	0.96	0.75
C5. Motivation	1	5	4	3.42	0.78	0.95
C6. Perceived enjoyment	1	5	4	4.15	0.86	0.94
C7. Cognitive benefits	1	5	4	4.06	0.77	0.91
C8. Control and active learning	1	5	4	3.96	0.75	0.97
C9. Reflective thinking	1	5	4	4.00	0.82	0.95
C10. Presence	1	5	4	3.93	0.75	0.90
C11. Perceived learning	1	5	4	3.92	0.75	0.95
C12. Satisfaction	1	5	4	3.69	0.76	0.93
C13. Behavioral intention to use	1	5	4	3.95	0.86	0.96

The qualitative results indicate that the users immediately assumed an active role thanks to the instant feedback system, which enabled them to monitor the consequences of their choices and actions. As a result, they experienced positive emotions of enjoyment that motivated them to explore the game environments further. This observation may lead to include surprises or gifts in the form of fun facts or relevant resources such as movie posters in the following editions of the game [42]. This reaffirms the notion that players adopt different priorities and goals when playing a game. Some users strived for excellence, getting everything right as soon as possible, thus achieving perfect scores, whereas others appreciated free roaming in the virtual school spaces. Other users opted to make deliberate mistakes in the game to test the system and monitor the results visually [43]. This underlines another essential advantage of games that is relatively uncommon in most formal educational settings: the enhancement of learning through repeated cycles of problem identification, critical analysis, formulation of hypothesis, experimentation for hypothesis testing, and reflection of results associated with productive failure [44]. The results corroborate findings from previous VR serious games [18] that VR is suitable for fire preparedness and safety-training purposes for children and adults.

Participants in the feedback discussions were encouraged to elaborate on their experience. Moreover, they were asked to assess whether the game activities were appropriate for the attainment of the learning outcomes. The consensus was positive, with simulated activities (e.g., extinguishing a virtual fire) being the most satisfying aspect due to their realism. Some participants reported that they felt afraid and hesitated to walk close to the fire. During the feedback session, three users (n = 3) with more extensive prior experience with entertainment games in 3D environments compared the FSCHOOL game with commercial games. In their comments, they expressed the desire for educational serious games to achieve levels of visual fidelity and interaction sophistication similar to commercial games. However, this is often not feasible due to budgetary or technical restrictions, especially in teacher-developed VR serious games [10]. Therefore, VR serious game designers and developers need to take extra care to locate other areas of excellence in their product to compensate users for lower levels of technical ingenuity or artistic representation. Some of these areas of strength that emerged from the discussion in the follow-up sessions could be the smart use of playful design and humor with linguistic and visual metaphors, sound effects, and appealing character development in the world-building and cut-scenes [45]. The importance of VR serious games is further magnified due to the COVID-19-induced social distancing and the prevalence of remote teaching. Recent evidence from Bulgaria from the pro-pandemic era have confirmed that both trainers and trainees are highly receptive to adopting and using VR and serious games in distance online education [46].

7. Conclusions and Future Work Recommendations

This study illustrated the instructional design, development, and comparative evaluation of the FSCHOOL fire preparedness serious game in VR for elementary school teachers. Its development was based on a Fire Dynamics Simulator, a plugin based on a Fortran script to emulate and visualize fire propagation in a realistic manner. The game's evaluation results indicate that it is fit for its purpose and suitable for adult learners. The main contribution of this work is the elaborated design of a complex, adaptable VR serious game, in a convergence of learning and game mechanics. This pattern can be helpful to practitioners, educators, researchers, developers, and system administrators to create effective immersive VR serious games to attain complex conceptual and procedural knowledge and skills in spatial contexts. Its findings challenge practitioners in adjacent domains to transform obligatory compliance training and e-learning into active game experiences with meaningful tasks that lead to the transfer of learning. Besides, while considering the educational evaluation of such interactive systems, additional insights can be provided by gathering and interpreting objective data (e.g., digital traces) under the aid of data analytics techniques [47].

The convenience-sampling approach limits the representativeness of the study, but the primary evaluation results are promising and should encourage the conduct of similar efforts with participants emerging from diverse professions and contexts. Future works can also explore the conduct of such interventions with participation from upper or possibly lower secondary school students.

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Appendix A

Table A1. Questionnaire items regarding participants' perceptions.

Description
C1. Representational Fidelity
1. The realism of the 3D images motivates me to learn.
2. The 3D images make learning more interesting.
3. The realism of the 3D helps enhance my understanding.

Table A1. *Cont.*

Description
C2. Immediacy of Control
4. The ability to change the view position of the 3D objects allows me to learn better.
5. The ability to change the view position of the 3D objects makes learning more motivating and interesting.
6. The ability to manipulate the objects within the virtual environment makes learning more motivating and interesting.
7. The ability to manipulate the objects in real time helps to enhance my understanding.
C3. Perceived Usefulness
8. Using this type of virtual reality/computer simulation as a tool for learning will increase my learning and academic performance.
9. Using this type of virtual reality/computer simulation will enhance the effectiveness on my learning.
10. This type of virtual reality/computer simulation will allow me to progress at my own pace.
11. This type of virtual reality/computer simulation is useful in supporting my learning.
C4. Perceived Case of Use
12. Learning to operate this type of virtual reality/computer program is easy for me.
13. Learning how to use this type of virtual reality/computer program is too complicated and difficult for me (R) [1].
14. It is easy for mc to find information with the virtual reality/computer program.
15. Overall, I think this type of virtual reality/computer program is easy to use.
C5. Motivation
16. I enjoy working with the virtual reality serious game very much.
17. Virtual reality activities are fun to do.
18. The virtual reality serious game was boring.
19. The virtual reality serious game did not hold my attention at all (R).
20. I would describe virtual reality serious games as very interesting.
21. I thought that the virtual reality serious game was quite enjoyable.
22. While I was doing the virtual reality serious game, I was thinking about how much I enjoyed it.
C6. Perceived Enjoyment
23. I find using virtual reality/computer simulations enjoyable.
24. Using virtual reality/computer simulations is pleasant.
25. I have fun using virtual reality/computer simulations.
C7. Cognitive Benefits
26. This type of virtual reality/computer program makes comprehension easier.
27. This type of virtual reality/computer program makes memorization easier.
28. This type of virtual reality/computer program helps me to better apply what was learned.
29. This type of virtual reality/computer program helps me to better analyze the problems.
C8. Control and Active Learning
30. This type of virtual reality/computer program helps me to have a better overview of the content learned.

Table A1. *Cont.*

Description
31. This type of virtual reality/computer program allows me to be more responsive and active in the learning process.
32. This type of virtual reality/computer program allows me to have more control over my own learning.
33. This type of virtual reality/computer program promotes self-paced learning.
34. This type of virtual reality/computer program helps to get me engaged in the learning activity.
C9. Reflective Thinking
35. Virtual reality/computer simulations enable me to reflect on how I learn.
36. Virtual reality/computer simulations enable me to link new knowledge with previous knowledge and experiences.
37. Virtual reality/computer simulations enable me to become a better learner.
38. Virtual reality/computer simulations enable me to reflect on my own understanding.
C10. Presence
39. My interaction with the simulation environment seemed natural.
40. I was aware of events occurring in the physical/real world around me while using the simulation.
41. I was aware of the display and control devices.
42. My experiences in the virtual environment seemed consistent with real-world experiences.
43. My sense of moving around in the virtual environment was compelling.
44. I was involved in the virtual environment experience.
45. I adjusted quickly to the virtual environment experience.
46. I felt proficient in moving and interacting with the virtual environment at the end of the experience.
47. I was involved in the experimental task to the extent that I lost track of time.
48. My sense of perspective (depth of field) was efficient.
C11. Perceived Learning
49. I was more interested in learning the topics.
50. I learned a lot of factual information on the topics.
51. I gained a good understanding of the basic concepts of the materials.
52. I learned to identify the main and important issues of the topics.
53. I was interested and stimulated to learn more.
54. I was able to summarize and conclude what I learned.
55. The learning activities were meaningful.
56. What I learned, I can apply in a real context.
C12. Satisfaction
57. I was satisfied with this type of virtual reality/computer-based learning experience.
58. A wide variety of learning materials was provided in this type of virtual reality/computer-based learning environment.
59. I do not think this type of virtual reality/computer-based learning environment would benefit my learning achievement (R).

Table A1. *Cont.*

Description
60. I was satisfied with the immediate information gained in this type of virtual reality/computer-based learning environment.
61. I was satisfied with the teaching methods in this type of virtual reality/computer-based learning environment.
62. I was satisfied with this type of virtual reality/computer-based learning environment.
63. I was satisfied with the overall learning effectiveness.
C13. Behavioral Intention to Use
64. I intend to use virtual reality/computer simulations, assuming I have access to them for a relevant subject.
65. I would use virtual reality/computer simulations frequently in the future.
66. I would like to participate in educational activities that use virtual reality/computer simulations.
67. I would study more if I had access to virtual reality/computer simulations in my field of study.

[1] Reverse-coded items.

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