Digital Learning Environments - Constructing Augmented and Virtual Reality in Fire Safety

Brita Somerkoski
University of Turku
Department of Teacher Education, Rauma unit
20014 Turun yliopisto
+358 44 20 900 540
brisom@utu.fi

David Oliva
Turku University of Applied Sciences
Joukahaisenk. 3
20520 Turku
+358 40 080 7594
david.oliva@turkuamk.fi

Kimmo Tarkkanen
Turku University of Applied Sciences
Joukahaisenk. 3
20520 Turku
+358 50 320 4105
Kimmo.tarkkanen@turkuamk.fi.

Mika Luimula
Turku University of Applied Sciences
Joukahaisenk. 3
20520 Turku
+358 40 355 0839
mika.luimula@turkuamk.fi

This article gives examples of how the use of Augmented Reality (AR) and Virtual Reality (VR) environments support the fire prevention training. We present the VR and AR games that we designed for fire safety training. Here, we see the VR environment as a digital learning environment while the AR environment is a mixed learning environment on-site. Combining VR and AR learning environments, physical, psychological, social and pedagogic dimensions are distinguished. We also describe the internal and external learning environment in the context of future technologies. The internal learning environment includes the virtual scenario, whereas the external learning environment is the situation in the room around the player – the authentic learning experience before, during and after the game play. These two layers need to be concerned and further developed when designing serious games. If not, the challenge is that the game, instead of being serious, remains on the level of entertainment.

CCS Concepts

• Human-centered computing→Human computer interaction engines • Information systems → Information systems applications.

Keywords

Learning environment; Virtual reality; Augmented reality

1. INTRODUCTION

Rapid development of future technologies, such as Augmented Reality (AR) and Virtual Reality (VR) has enabled the creation of new and motivating learning methods based on these interactive technologies. The researchers definite Virtual Reality (VR) as an immersive, interactive system based on computable information [1]. Augmented Reality (AR) in turn is a technology that allows computer generated virtual imagery to exactly overlay physical objects in real time [2]. VR learning environments allow the visualization of three-dimensional spaces, where also interactive learning is possible. The number of possible simulated tasks is large, but with special attention are those that in reality would be dangerous, expensive, or even impossible to fulfill. [3] From this point of view, virtual reality serves well for the fire safety education. VR has been used both to simulate dangerous situations and as a tool for helping individuals to learn. [4] AR learning environments in turn allow the visualization of digital content. The aim of this paper is to describe the game development process to establish VR/AR based digital learning environments. There is urgent need for this as the new generation is using their digital devices, whereas the content of fire education has remained somewhat stable and traditional. The future technologies would provide a motivating and interesting learning environment for fire safety. Firstly, as a context description, we present the game design process to satisfy the serious game requirements set by the fire department according to Hevner´s [5] framework of combining behavioral approach and game design. Secondly, we developed fire safety related serious games to understand the limitations and possibilities of such a game design. Finally, we will describe the game characteristics by the social, physical and psychological dimensions of the learning environment (Figure 1).

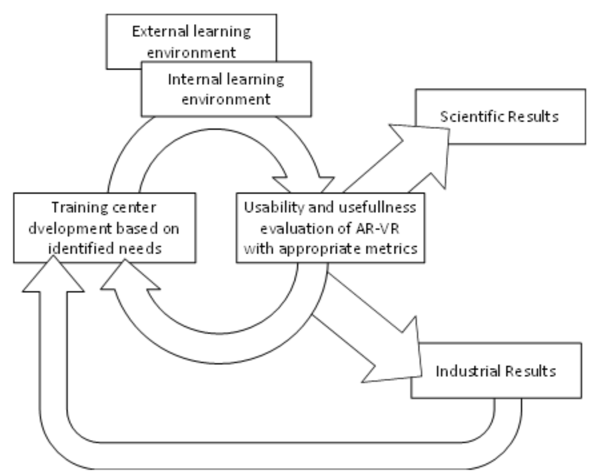

Figure 1. The research design in this study

While VR learning environments offer a safe way to learn safety in classroom setting, AR learning environments can be used for on-site training. Many studies concerning future technologies have focused on the technical details to improve effectiveness or, the game engagement or the gamification [6][7][8]. and the definitions, methods, and learning are studied less.

The concept of learning environment is not totally clear, but the term generally refers to educational approaches, cultures, and

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physical settings for all types of learners. The concept describes the goals for teaching and learning [9] as well as activities, places, spaces, communities, or modes of action that support and promote learning and whose use is carefully and pedagogically well planned. The concept of learning environment is sharpened with dimensions, for instance physical [9], social [10] and psychological [11]. Sometimes also pedagogic [12] dimension is distinguished. As a rough grouping, physical learning environment refers to concrete spaces, materials, technical solutions or tools; the social learning environment is focused on interaction between individuals and on the group dynamics, and the pedagogic learning environment gets its shape form the pedagogical phenomena, such as the learner-based approach or the problem based learning [13]. Whatever learning environment we are talking about, the teacher, with multiple roles in the multiple learning environments, is a key factor [14] [15]. In addition, in the research literature, also concepts, such as digital learning environment, virtual (versus authentic) learning environment or e-learning environment are used [16]. The use of these concepts are not exactly determined, but the basic principle is that an on-line technical device, often PC, mobile phone or tablet, support this kind of learning. [17] [18] Already early, 1970, Abt stated, that serious games are synonymous with games for learning that are deliberately developed for more than pure entertainment [19].

2. LEARNING FIRE SAFETY

When determining the learning environment, we can´t avoid the concept of constructivism or constructivist learning. The definition of constructivism is widely presented in an educational context. John Dewey has created this thought of a learner as an active participant already 1916. He stated that learners should not just absorb information, but also to connect it with the previously learned issues. The principle is that the environment affects the learner and there is a constant interplay between the learner and the information. According to Dewey, education should be both experimental and experiential. [20] In addition, construction in learning means that adopting new ideas are actively processed on the surface that exists prior to learning, for instance knowledge, beliefs, individual development and culture. [17] [21] Discussing learning means integrating and implementing knowledge, skills, and attitudes. Because of gaining knowledge, skills, and attitudes, the competence is achieved. [22]

The context of this analysis is fire safety. The term safety refers to the situations, where physical, psychological or moral dangers and threads are missing; or being in a shelter. The origin of the word safety refers to word < solwos (health) [23]. The tactical and strategic actions people take to manage fire spread and maintain safety culture is defined fire safety actions. [24] Fire safety policies show peoples´ thoughts the way in which people think about this issue. [22] Human behavior in the fire plays an important role in terms of survival from fires. It concerns the actions and decisions people make upon their perception of the situation and their intentions to act in the situation. Decision making in the emergencies is one of the major issues when making conceptual remarks on fire safety. Since fire response performance is dependent upon the physical surroundings, we need to take the interaction between human behavior and the characteristics of a building into account. [25] [26] [27].

One of the most international symbols is green escape route marking, the so called exit signs. They are an expressive example of symbolic fire safety, yet these signs we might not see during the fire, or people don´t notice them. Incident evaluations show that people usually ail to either notice or ignore the exit signs. Sometimes the green signs are located in such a way that spreading smoke makes them invisible. Some researches show that in the fire, the survivors are not aware of the escape routes and if they do, they normally use familiar exits in case of fire. In addition, people tend to ignore the fire alarm bell or wait for the verbal cues. [25] [28]

The challenges described here and the fire statistics [29] with the figures of fire deaths caused by people, who could not exit in an emergency, have raised the concern about the innovative methods of teaching fire safety. In addition, in many countries fire prevention activities, public education in fire safety is mandatory for the fire departments [e.g. 30]. The task of the fire department is to prevent fires, decrease the loss caused by fires and minimize the number of fire deaths.

The pedagogic dimension and serious games development are connected: to ensure successful learning through serious games, five themes require intertwining with pedagogical content: 1) back story and production 2) interaction 3) realism 4) artificial intelligence and adaptivity 5) feedback and debriefing [28]. At the beginning of the development, artificial intelligence was not developed into the game in the extent presented by Ravyse et al. [31], yet for example, the fire environment should adapt to players' different actions during the gameplay.

3. VR AS A LEARNING ENVIRONMENT

Earlier in this paper we stated that as an outcome of learning, fire safety competence is achieved. In the pedagogical research, competence is about knowledge, skills and attitudes [22]. In the context of digital learning Pan [32], who states that the learners are "not simple knowledge accepters, agrees this. The learners are information providers, question askers, question answerers and concept analyzers."

When analyzing digital learning environments, there are physical, psychological and social dimensions present in the scene that the player sees and experiences. The virtual learning environment provides many possibilities for the pedagogic point of view. First, the learning in the virtual reality environment is learner-based. The person who plays the game has an active role and is constructing his or her learning by the facts that s/he knows or is memorizing, and taking responsibility of his or her behavior. Also, awareness raising about misconceptions in fire safety is emphasized in the virtual learning environment. The virtual reality environment provides a learning by doing experience and that would enhance to learn the fire safety skills. In some occasions, it is also possible to learn with co-operative learning if the player is teaching other players or is interacting with other players.

3.1 Physical Learning Environment

There are limitations concerning the space. The digital learning environment may not provide enough possibilities to feel the structure of the room and it is impossible to create the smell and sound of the real fire scene in the game. When developing the physical VR learning environment [16] the focus is to describe how the smoke will spread in the fire compartments. There seems to be a stereotypic picture of gestures or heroes moving around in the building after inhaling smoke. In the real situation, they would be unconscious in some minutes, or even faster.

3.2 Psychological Learning Environment

The psychological learning environment [13] is connected with cognitive and emotional processes such as knowing, remembering, avoiding and decision-making. In the context of future technologies, for instance this means that the player takes the game seriously, remembers the layout of the building, seeks new routes or decides what would be the most decent act in the situation. The focus on the fire safety games is in the decision-making and in the situational thinking. Virtual reality provides a controlled and simulated situation for emergencies and especially the attitudes towards it. Thinking schemas prioritize the tasks and controlled environment gives possibilities for action in a stressful situation. Furthermore, emotions, such as fear, surprise or joy during the game are part of the psychological learning environment. The player needs to remember the geography of the building; s/he needs to memorize where the corridor and rooms are or how to open doors and to act accordingly. The use of VR/AR provides possibilities to motivate players by the curiosity and problem-based learning.

There are limitations concerning the psychological dimension and the learning outcome, as in the fire, panic may prevent any decent actions or decisions that need to be made in seconds.

3.3 Social Learning Environment

The social dimension [16] of the learning environment contains interaction with the supervisor, other players or non-player characters (NCPs) in the game. The social dimension of the learning environment cannot be totally distinguished from the psychological dimension, as these schemes are acting together.

In one of our VR solutions presented later in this paper, a person in the scenery is working alone and s/he cannot negotiate with anyone. There are NCPs in the building, but they are only information providers and interaction is not possible, so the player makes the decisions individually with no help from outside. The goal is that the player shows responsible behavior to care and warn and decides to escape from the building that filled with smoke whereas AR lets players interact and discuss freely.

3.4 Two Layers of Virtual Learning Environments

To be able to further analyze the serious games and virtual learning environments [13] [16}, we found out that in the serious game design process, in addition to the scenes, events, solutions in the game, we should also focus on the external learning environment, outside of the view of the glasses. The tasks performed in the external virtual environment include interaction before the game starts, for instance taking turns, competing with others, comparing the experiences, listening to the presentation before the game starts, trying on the devices, learning how the devices are activated, listening to the comments after the game, providing solutions or conducting discussions after the whole game performance. Combining the behavioral science and design science paradigms according to Hevner´s [5] theory for the Information System discipline we developed a matrix (Figure 2) as a draft for analyzing the two-fold digital learning environment in the context of VR/AR. This led us to create a short comparative analysis how VR and AR can complete and support each other while developing the next generation learning environments for fire safety education.

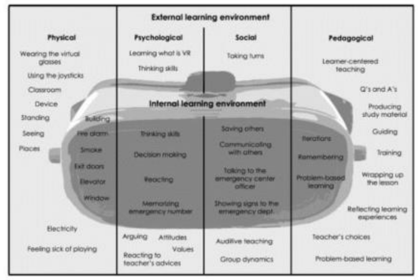

Figure 2. Designing and developing two-fold digital learning environment

4. VR AND AR IN FIRE SAFETY EDUCATION

We divide the utilization possibilities of VR and AR in fire safety in three educational sections. VR can be used in the very beginning while students have not at all or less than enough experiences to work in this particular fire safety context. AR in turn is used in physical environment as an on-site training tool. This brings fire safety training from classrooms to the field and enables fire safety education whenever needed. VR can later again be used in an updated education or homework context. The learners can use both VR and AR countless repetitions to ensure that their training is complete.

4.1 First Fire Safety Demonstrations

We developed the first fire safety VR and AR demonstrations for Turku Machine Technology Center in 2017 (Figure 3) to find out whether we could teach fire safety with the future technologies. One student group developed for HTC Vive VR glasses a VR learning environment consisting of a tutorial and a learning episode where the player had two tasks: finding the closest exit, and pressing the alarm button. Another student group created an AR learning environment for ODG R7 AR glasses. In this game, the player used the real fire extinguisher by Alku. We showed the instructions how to use the fire extinguisher as textual information with 2D animations. A fire safety questionnaire followed the game play.

Another VR fire safety demonstration was developed by the third student group in a close cooperation with an industrial partner who had already years of experience in VR solutions. In this

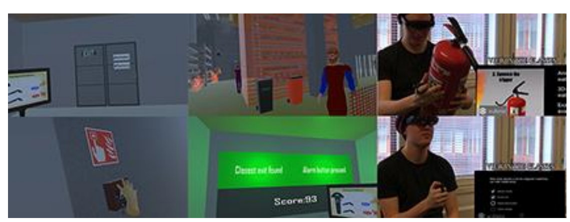

Figure 3. VR and AR solutions developed for Machine Technology Center.

demonstration, we asked players to follow fire safety instructions visualized in a process diagram. Players´ tasks were to set alarm manually, to notify the shift supervisor, to follow safety instructions, and to use the fire extinguisher in the turbine hall (Figure 4).

These three demonstrations showed the potential of VR and AR in fire safety. Yet no specific usability or user experience experiments had not been conducted. In this phase, especially ODG R7 device was not robust enough (e.g. limited operation time).

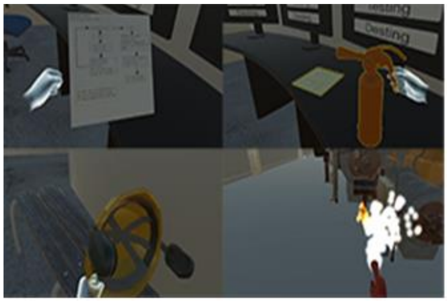

Figure 4. VR fire safety in turbine hall.

4.2 Testing Fire Safety Applications

As continuation, we implemented a fire safety application called Virpa (Figure 5). In this serious game, the player is in VR building environment, in a three floor office building. The building has three wings A, B and C. The game starts when the player is performing a task as a part of a work interview. This task is provided by NPC Ines, who wants the player to follow her to the third floor, wing C in the building. With this intro part of the manuscript part, Ines teaches the player how to use the joysticks.

The player starts to play the game and Ines disappears. The fire alarm is triggered on the lower floor of the same wing. The player will not see any sign of smoke until s/he has left the room and reached one of the lowest two floors. Based on the earlier games, the metrics contain fifteen tasks such as reacting to the fire alarm, taking the right exit door, making an emergency call and avoiding areas with smoke. The right decision will get +1 value, whereas the wrong decision would be 1. If the player did not interact with the object or the task, the result would be 0. One of the research focus areas was to visualize the smoke flow (Figure 5, left) as realistic as possible [33]. In total 169 players (n=169) participated in Virpa experiment. The results are reported on [34]. One of the main findings for further studies was that only about four percent (two out of 51) the youth made eye contact with escape signs and only 28 percent (14 out of 51) of the youth who played the game looked building floor plan on the wall.

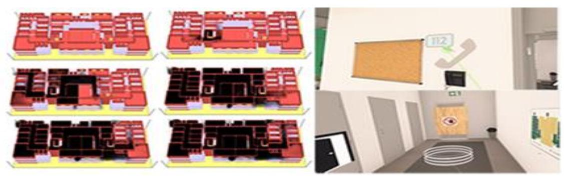

Figure 5. Smoke flow (left) and two of the tasks to be completed (right) in Virpa game.

Table 1. An external-internal digital learning environment analysis in the context of VR and AR

Learning Environment	Virtual Reality	Augmented Reality
Physical External	wearing glasses (robust, relatively cheap), controllers for interactions, classroom with limited physical space	
Physical Internal	building fire scenario, single person acting,	does not exist, or highly connected with the external
sychological External	players' behavior (e.g. arguing, attitudes) can be fully monitored	monitoring players´ behavior more challenging
Psychological Internal	controlled gaming experiment, possibility to measure metrics¸ pre-experiences: even hazardous scenarios for novices	on-site training: before or after the VR training or class room activities. These can be location, context, or situation aware
Social External	multiplayer feature for group dynamics challenging, auditive teaching possibilities needed e.g.training centers	group working, immediate feedback from teachers' more challenging
Social Internal	auditive teaching possible especially in training centers, utilization of advanced AIs for Natural Language Understanding (auditive teaching)	immediate feedback to learner more challenging, wearing headsets for auditive teaching or Natural Language Understanding (auditive teaching)
Pedagogical External	guiding possible especially in training centers, possibility for iterations possible	guiding based on pre-defined pedagogical procedure, iterations not meaningfuld
Pedagogical Internal	problem based learning, controlled design¸ post-experiences: repetitions, updated education	learner based learning, problem based learning; on-site experiences: just in time information (e.g. silent information available)

Figure 6. Electric Cabin Fire Simulation

Another fire safety application called Electric Cabin Fire Simulation is reported on [35]. We tested this application in a different cultural context in Oman with 16 trainees from National Training Center (NTI) in Muscat. The preliminary results in this small-scale experiment seems to be quite promising. Trainees reported that they were able to learn and understand fire safety issues. In addition, it seems that they would prefer to use virtual rather than traditional training methods. Compared with the Virpa game, this application has more hands-on training tasks and we state this type of application would fit well in professional certification training programs (Figure 6).

4.3 Towards two-fold Learning Environments

Based on the experiences collected from previous projects we present a two-fold learning environment comparative analysis. This is presented in Table 1. VR as a technology is already available for the educators and for the software developers. New glasses are introduced frequently and those who are considering invest intensively in these VR technologies can be found challenging to minimize risks in investments. That is to say investing in VR technologies is up-to-date only after the following years. Therefore organizations should be able to share costs while developing enough learning episodes for 24/7 use. One of the future trends seems to be the establishment of VR training centers. In this type of environment, teacher and trainees can work together in multiplayer training scenarios from pre-experience to post experience context. In addition, training center can have AR training scenarios for an on-site context. Therefore, the combination of VR and AR training can offer education institutes new ways to train new professionals from the very beginning in realistic learning environments and offer updated education services also for professionals.

5. DISCUSSION

This paper has researched VR learning environment in the context of fire safety. In the analysis, the idea of twofold learning environment was presented. This was done to provide ideas for the serious game developers using VR in the educational context.

Virtual reality for fire safety provided thought provoking experiences, experiential experiences and the utmost feelings, which will continue player's learning experience long after the actual play session. When designing games for learning, it is important to consider that learning means absorbing knowledge, skills and attitudes. We described the characteristics of the physical, psychological and social learning environment to provide game developers a context for game design. Further on, the learning environment was divided here in two. The internal learning environment, the scenes and the experiences in the game, can never be fully distinguished from the external learning environment, the interior and environment outside the game. This two-fold structure of the game creates new possibilities for game research and the layer model provides untouched possibilities for the game designers, such as focusing on motivational factors, attitude development and interaction in the game as well as outside the game in the external learning environment.

All [36] has stated that researchers should focus on the pedagogical content of serious games. This could be for instance the back story and production, interaction, realism, artificial intelligence and adaptivity or feedback and debriefing. To be able to design a training center for serious games, it is essential to understand the basic principles of the game metrics, such as how long is one game, player characteristics, and the other limitations of a digital learning environment. In addition, when designing a game for fire safety, based on the primary results of the Virpa-game, we can conclude that the VR environment provides a relatively realistic game environment for players. AR solution provides a possibility for more exact learning experience. It is important to have a usability study of this VR/AR combination. We are expecting this to continue, as the Virpa 2 game project will start.

The virtual learning environments provide new possibilities for the fire service. However, the game design should continue in the external learning environment with the help of pedagogical experts. In addition, researchers should consider learning outcome analysis. Without this, it is possible, that the gaming remains at the level of entertainment and the primary goal, learning, is not achieved. In that case, we will question, whether using VR is a learning environment at all.

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