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Research Study Design for Teaching and Testing Fire Safety Skills with AR and VR Games

Kimmo Tarkkanen
ICT
Turku University of Applied Sciences
Turku, Finland
kimmo.tarkkanen@turkuamk.fi

Anttoni Lehto
RDI Services
Turku University of Applied Sciences
Turku, Finland
anttoni.lehto@turkuamk.fi

David Oliva
ICT
Turku University of Applied Sciences
Turku, Finland
david.oliva@turkuamk.fi

Brita Somerkoski
Department of Teacher Education
University of Turku
Turku, Finland
brita.somerkoski@utu.fi

Timo Haavisto
ICT
Turku University of Applied Sciences
Turku, Finland
timo.haavisto@edu.turkuamk.fi

Mika Luimula
ICT
Turku University of Applied Sciences
Turku, Finland
mika.luimula@turkuamk.fi

***Abstract*—Virtual and augmented reality (VR & AR) games can provide innovative methods for teaching and learning important skills relating to fire safety. However, in an emergency context, testing the acquired knowledge and skills, i.e. verifying the learning, can be challenging. In this paper, we ask how the interplay between AR and VR could support learning verification. We describe two standalone games of both types, which interchangeably teach fire safety skills to children and verify their learning results. In particular, we describe the planned learning paths and research study designs for verification studies within and between these games to answer the above question. By operationalizing the two cases, the paper ends in proposing more generalized study design for AR and VR research in a fire safety context.**

Keywords—virtual reality, augmented reality, fire safety, serious games, research design

I. INTRODUCTION

Fire safety refers to preventive measures in the case of fire and to specific actions limiting the spread of fire and smoke [1]. Fire-related injuries are expensive to treat, and the healing process is long. In Finland, the number of fire-related deaths is relatively high compared with the total population [2,3].

Previous research shows that people tend to ignore fire alarms, dismiss exit signs, and lack awareness of escape routes [1,4,5]. Especially children were observed to notify exit signs less than adults in the virtual fire alarm situation [6]. These facts, and the figures of fire deaths caused by people who could not exit in an emergency [7], have raised interest towards innovative methods for teaching fire safety.

Augmented and virtual reality applications provide a meaningful platform for learning fire safety skills, as these actions are difficult to practice in real life environments. Compared to standard training practices, such as lectures and safety walks, mobile AR and VR games provide immersive and engaging experiences. Children have found virtual experiences fun and intriguing in fire safety skills training [8], and their skills could be significantly improved with the use of virtual reality based training [9].

A serious educational game can be fun, but it also needs to teach something new to the players or strengthen their existing knowledge. Learning by playing can be a result of either a conscious effort or accidental, achieved without awareness of what is really aimed at by the game design and the resulting gaming experience. These aspects must be reflected in the game design, because contrary to learning, teaching via a game is at its most efficient when done with a clear target in mind.

Therefore, an educational game design must answer two questions: *How to ensure learning and how to verify it?* Solutions can be external and internal to the game play itself [10]. For example, one can measure learning results after game play with a questionnaire or one can design a game that simply encourages players to learn more about the topic [6]. Internal, i.e. in-game solutions can be wide-spread, including material such as videos, puzzles and quizzes around the specific topic. However, it is nearly impossible verify one's skills in the case of fire and similar emergency contexts in-game. Virtual reality environments and games are of good use here, as those can be designed to be immersive and realistic enough to verify authentic human behaviour. A more specific design question that shapes both AR and VR environments in this context is *how to utilize virtual reality in verifying learning results of an emergency education game?*

In this paper, we describe two applications, an AR and a VR game, which aim at teaching fire safety skills and verifying learning results among children. The objective of the paper is to describe how these two standalone applications will *interchangeably* teach fire safety and test the acquired skills. We describe the planned learning paths and verification studies *within and between the games* to answer the questions above and to discuss pros and cons of combining AR and VR in a game research setting.

II. LEARNING DESIGN IN THE VIRPA2 AR GAME

The aim of the AR game called 'Virpa2' is to teach kids, in the age range of 7–14 years old, fire safety, especially fire safety signs as well as related knowledge and practices. The mobile game environment represents a typical school, including three floors with numerous rooms to unlock and discover (Fig. 1).

The player can move freely within the three floors of the school. The school has specific rooms where the teaching implemented in the game design occurs. To get inside those rooms, the player needs to scan safety signs in real-world buildings. Thus, the virtual world integrates into the real world with an augmented reality (AR) function.

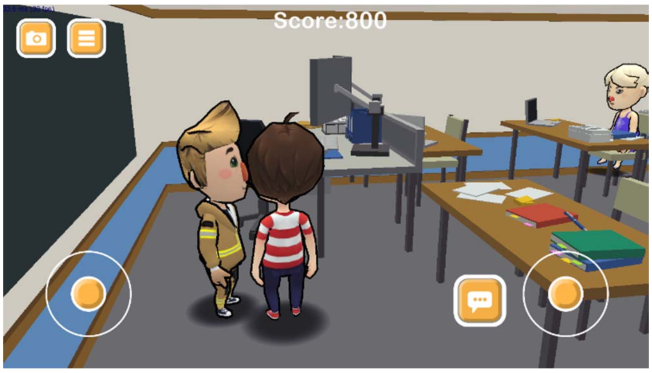

Fig. 1. The game environment for Virpa2 AR game is a school containing rooms with fire safety activities.

With their mobile phone camera, players scan real fire safety signs in real spaces, for instance, in their own school or near-by shopping centres, in order to proceed in the virtual world (Fig. 2). The sign is recognized by a machine vision algorithm, which, together with a dedicated database, informs the game of the scanned sign. The Virpa2 AR game is divided into two intermeshing playing modes, *School Mode* and *Roam Mode*, which differ in their teaching methods.

Fig. 2. The player, not a 11-year old though, scans the fire alarm button sign with his own mobile phone in order to get access to one of the rooms in the virtual game environment.

A. Learning Objectives and Methods

The game has two objectives: 1) to change and support players' everyday practices and habits in a way that they would notify and observe fire safety signs wherever they visit and 2) to improve players' factual knowledge and practical skills related to fire safety, and especially fire safety signs. In this way, the game would tackle for example the problem of unnotified exit-signs among kids [6] and improve their awareness of the local escape routes, floor maps, fire alarm buttons and extinguishers.

School Mode refers to unlocking rooms in the virtual game environment by scanning signs in real world, answering questions, and reading teaching material. The School Mode consists of seven Primary Learning Topics (PLT), which are 1 = Fire extinguisher, 2 = Exit and Escape, 3 = Fire Alarm Push Button, 4 = Meeting Point, 5 = Defibrillator, 6 = Fire Hose Reel, 112 = 112 Service. Each PLT is associated with one room number, i.e. rooms 1, 2, 3, 4, 5, 6 and 112. Each PLT is also presented at three pedagogical levels: Knowledge, Skills, and Attitude (marked with letters A, B and C respectively). These rooms prepare the player for the Final Exam, the culmination of the School Mode.

In all rooms associated with PLTs, the player is posed a multiple-choice question. For example, the room 1B introduces a question like:

How to use a fire extinguisher?

a. Press the handle before detaching it from the wall.

b. Point the hose to the fire and press the handle.

c. Remove the cotter pin before pressing the handle.

d. Shake the extinguisher before pressing the handle.

The teaching material presented to the player after the earlier question 1A (Knowledge) provides an answer to the question 1B (Skills). The question 1C has no correct answer (Attitude), and therefore the teaching material after the question 1B prepares the player to the Final Exam. Other PLTs are taught respectively. Notable is that the question will not immediately follow its corresponding teaching material as the rooms become accessible in a partly non-linear fashion.

Roam Mode is a set of challenges regarding finding fire safety signs in public buildings in the real world. All PLTs are reinforced by the Roam Mode through repetition of scanning challenges. The Roam Mode enables incidental learning by giving the player attractive and interesting AR scanning challenges based on e.g. location, time frame, or current sign collections. The challenges could be, for example:

- Scan 5 different signs in less than three minutes.
- Scan 5 exit-signs from 5 different buildings.
- Scan the greatest number of signs in the location X.

It is important to note that enabling these challenges to continue indefinitely would most likely result in more consistent and permanent behavioural change, as it would require many repetitive AR scanning actions to reach such a change. The number and the type of scanned fire safety signs is stored for each player. Performing real-world challenges grants points and unlocks minigames in the virtual School Mode game environment. The point system can be used for local leaderboards and arranging competitions within the player community. The back-end solution of the game stores the personal learning path as questions, answers and collected signs with timestamps as well as locations. Scanning unique variations of the signs not yet found in the database grants the player especially significant rewards. Each scan event functions as training data for machine learning that eventually leads to more accurate sign recognition and responses in the game.

One of the most crucial aspects of the game design of the Virpa2 AR game is to enable *incidental learning*. Incidental learning refers to players learning by accident, in other words without being actively aware of the learning process at the time of playing. Incidental learning becomes relevant in this case when the potentially learned substance goes beyond the ludic system of the game mechanics, the endogenous meanings stemming from the virtual game world and especially the evident taught material available during the game.

Both modes support players' behavioural change through incidental learning i.e. continuous observations of fire safety signs even outside game play. However, only the School Mode includes informational teaching material while the Roam Mode emphasizes more repetitive observations and thus potentially a more constant real-world behavioural change, where the players instinctively look for fire safety signs in their surroundings.

B. Study Design for Internal Learning Verification

In-game verification of learning exploits a repeated measures research design (Fig. 3). Twelve questions related to knowledge and practical skills (A and B) in the School Mode form a baseline, a comparison point, to each player's learning. Six questions (1A-6A) describe each player's starting level in understanding fire safety signs, since questions are asked before any treatment of that specific topic. The same twelve questions are repeated in the Final Exam, which allows the comparison of answers in the beginning and at the end of the game play. The assumption is that the treatment – i.e. the teaching material the player is exposed to during the game play – will increase the number of correct answers in the Final Exam compared to the first answers. In addition, the Final Exam consists of six new questions about the same PLT themes, which can be utilised to confirm the correctness of the learning measurement (i.e. to avoid confirmation bias). These questions are more holistic by nature, also integrating elements from the C questions (Attitude).

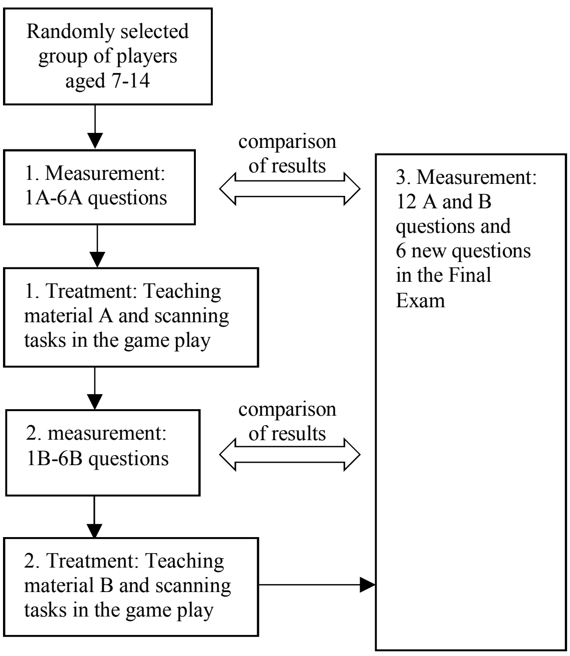

Fig. 3. Internal learning verification with repeated measures.

Like informational learning above, the behavioural change should be measured as a difference between two points in time. However, the Roam Mode, where the player performs challenges and collects signs, lacks a similar, in-game defined baseline for measuring the behavioural change. Thus, the internal verification of learning primarily assumes that the player has not observed any fire safety signs before the gaming experience. Then, the hypothesis is that each scanned sign is a positive signal towards a behavioural change, and the larger the personal sign collection is, the more the player has changed their behaviour. The C questions presented in the School Mode could potentially form a subjective baseline by asking players' previous behaviour and experience in observing fire safety signs. Be that as it may, an objective assessment of individual behaviour requires an external evaluation, for example with a mobile eye tracker or virtual reality environment, which are discussed next in connection to the Virpa1 VR game.

III. Virpa1 VR Game in External Learning Verification

Virtual reality environments, and especially games, are a highly used educational technology [11], which allow performing dangerous and even impossible activities [12, 13]. In the fire safety domain, VR has been applied in many ways: in training general public in evacuation and rescue in fire situations at road tunnels [14] or at university buildings [15]; in improving fire safety skills of children and their evacuation behaviour in residential buildings [9, 8]; in training firefighters [16] especially for an optimal rescue path selection with complex simulations of smoke spreading [17], or in estimating the behaviour of endangered people with detailed 3D models of a building [18]. In addition to training and education purposes, virtual reality environments are valuable in analysing human behaviour in fire evacuation research [13].

A. The Developed Virtual Reality Environment

The VR game called 'Virpa1' was developed by Turku Game Lab in 2019. The game is played with commercial VR glasses. The virtual environment represents an office being engulfed in smoke while the player's task is to escape the building. To ensure as realistic response as possible, however, the player is not made aware of this goal before the fire alarm is triggered in the game environment. This results both in a radical shift in game dynamics as well as in an authentic representation of the unexpected nature of an actual fire alarm. From the player's point of view, the main learning objective for the player is to understand and remember how important fire safety skills are.

In the beginning of the game, the player is instructed and persuaded by a non-playable character (NPC) to follow herself to the third floor of an office building where some psychological tests would take place (Fig. 4). After arriving to the third floor, and while waiting the test to begin, the player is exposed to a fire alarm, to which they need to react (Fig. 5). The VR environment includes exit and other fire safety signs, floor maps as well as emergency exit doors, of which the player can take advantage. In addition, the player can interact with NPCs, make an emergency call, open and close windows and doors, and use a tape to seal a door.

The game was designed to track down and record players' actions for analysing them as representations of human behaviour in a real fire situation. In other words, the game is primarily meant to enable collecting information on players' current knowledge and detailed reactions related to fire safety rather than being a tool for providing them with optimal operational models in the emergency. This way it is possible to achieve practical and empirical research contributions [19] where players' natural responses to the emergency could be exploited in identifying possible gaps and fire safety training needs at individual and group levels. From the design-driven point of view [19], collecting player experiences supports the evaluation of the effectiveness of VR in the fire safety context, and contributes to future systems designs, i.e. identifies game-related issues that are worth taking into account when designing data recording or a narrative continuum for a serious game.

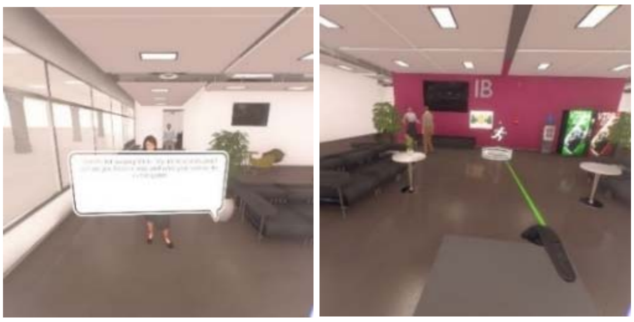

Fig. 4. NPC explaining the initial gaming situation to the player (on the left) and the view of the lobby and the use of teleporting (on the right).

Fig. 5. A cognitive test called Hanoi Towers is designed to catch the attention of the player before fire alarm (on the left) and the floorplan of the building as seen in the game (on the right).

A study by Oliva et al. [6] with 169 test subjects confirms that the Virpa1 VR game was considered effective in teaching the importance of fire safety (83% of the respondents agreed in 5-point Likert scale), its virtual environment was realistic (71%), and the game play was immersive (67%). Based on these results, we assume that the Virpa1 VR game adequately represents a real environment for studying human behaviour in a fire emergency.

B. Study Design for the Virpa2 AR Game External Testing

To verify players' learning in the Virpa2 AR game, in other words the game's effectiveness, we apply the Virpa1 VR game as an external evaluating tool. As discussed in the previous chapter, the Virpa1 VR game represents reality in this study, meaning that the player's success in the simulated environment is interpreted as success in the real-world environment. The research follows a between-subjects design where two groups of target users receive different treatments, i.e. only one group plays the mobile AR game, while the VR game acts as the measurement for both groups (Fig. 6).

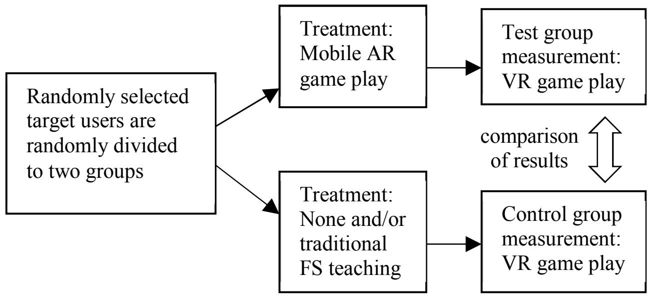

Fig. 6. An external, between-subjects design for verifying learning in the Virpa2 AR game.

In the measurement phase, we are interested in whether the players of the Virpa2 AR game observe, i.e. look at fire safety signs (exit signs and floor maps) more than people with other treatments (e.g. none and/or traditional FS teaching content). The developed Virpa1 VR game records the number of times and the length of the eye fixation to signs. These variables are compared between the test and the control groups. Other treatments could include more traditional fire safety teaching methods such as readings, lectures, and videos whereas at least one group has not any specific treatment at all. To analyse the possible cause-effect relation in more detail, the AR game players' group can be divided into separate groups as well; the division of the test group can be based on e.g. previous experience (C questions), the length of the AR game play, or the number of collected signs.

C. Study design for the Virpa1 VR External Testing

In the previous chapter, a model for studying the effectiveness of the AR game with the VR game was presented. While the model answers whether the AR game players observe signs more than non-players, it does not describe the degree or the volume of the behavioural change among the players that we earlier referred to as the baseline of the Roam Mode. The baseline can be determined in a similar comparison study for the Virpa1 VR game's effectiveness (Fig. 7). With a mobile eye tracker, one can catch the most natural behaviour of people accessing a new office building. We calculate how many times and which fire safety signs participants observe (without any previous treatment). This number is a baseline to which the data of the Roam mode will be compared having either an increasing or decreasing effect. Measured variables, the number and length of eye fixations to exit and floor map signs, are the same as in the Virpa1 VR game. In this case, first measurements with the eye tracker and the second measurement for the control group can act as a baseline for the Roam Mode of the AR game whereas the repeated measures design tests the VR game accuracy and the effect on fire safety sign observations (Fig. 7).

IV. Interplay between the AR and VR Games

Previous chapters show how two standalone fire safety games support each other to verify players' learning. On the other hand, these games are also a continuum for training and learning fire safety skills. Both rely on *incidental learning* discussed earlier, in which the Virpa1 VR game is an 'eye-opener' to fire safety learning and the Virpa2 AR game continues keeping the player's 'eyes open' and focused on fire safety signs while on the move. By nature, the VR game is a single-use experience as its effect is based on the unexpectedness of fire alarm. Thus, the VR game experience should take place in the beginning or in the middle of the player's learning continuum (Fig. 8). For the operational testing according to the represented models, we plan to recruit children from local schools together with their teachers.

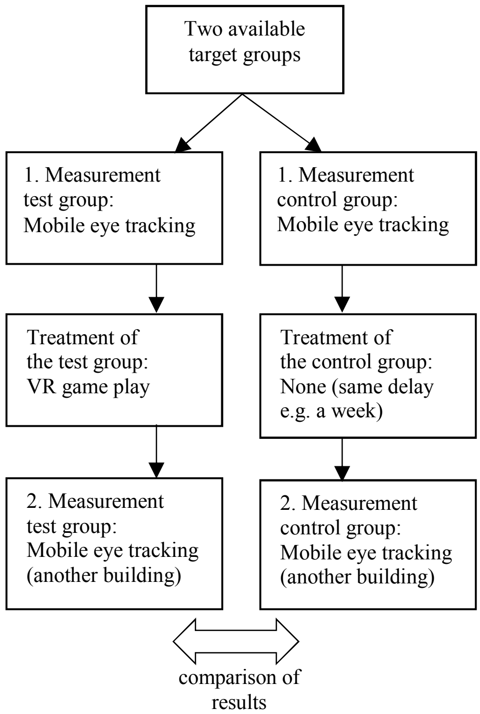

Fig. 7. External learning verification with repeated measures for the Virpa1 VR game that supports defining the baseline for the Roam Mode in the Virpa2 AR game.

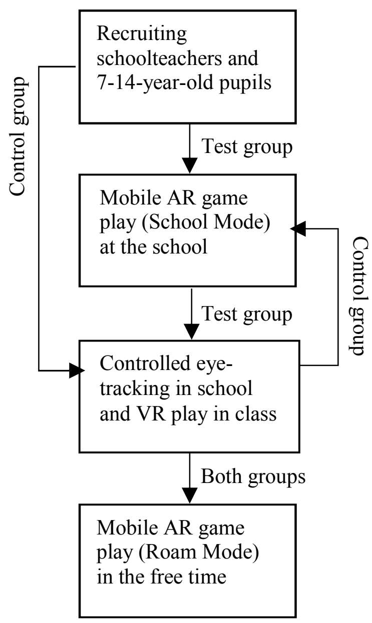

Fig. 8. Operational interplay between the AR and VR games in the research study considering the optimal learning path and the practical study context.

A. *Proposed Research Study Design*

The proposed model for the research study is a combination of the individual studies of the effectiveness with case-specific operational and contextual realities (Fig. 9). After grouping the children, we offer the groups either the VR game or the AR game as a starting point. The latter group plays the AR game as the test group and the other group is the control group. The AR game in its School Mode lasts approximately 2-4 hours, which is ideal for one or two classroom sessions. The control group of the AR game acts as the test group for the VR game as well, thus beginning the research intervention with the mobile eye tracking test (This group needs to be further split in two, in case the external verification for the Virpa1 VR game is performed as in Fig 7.)

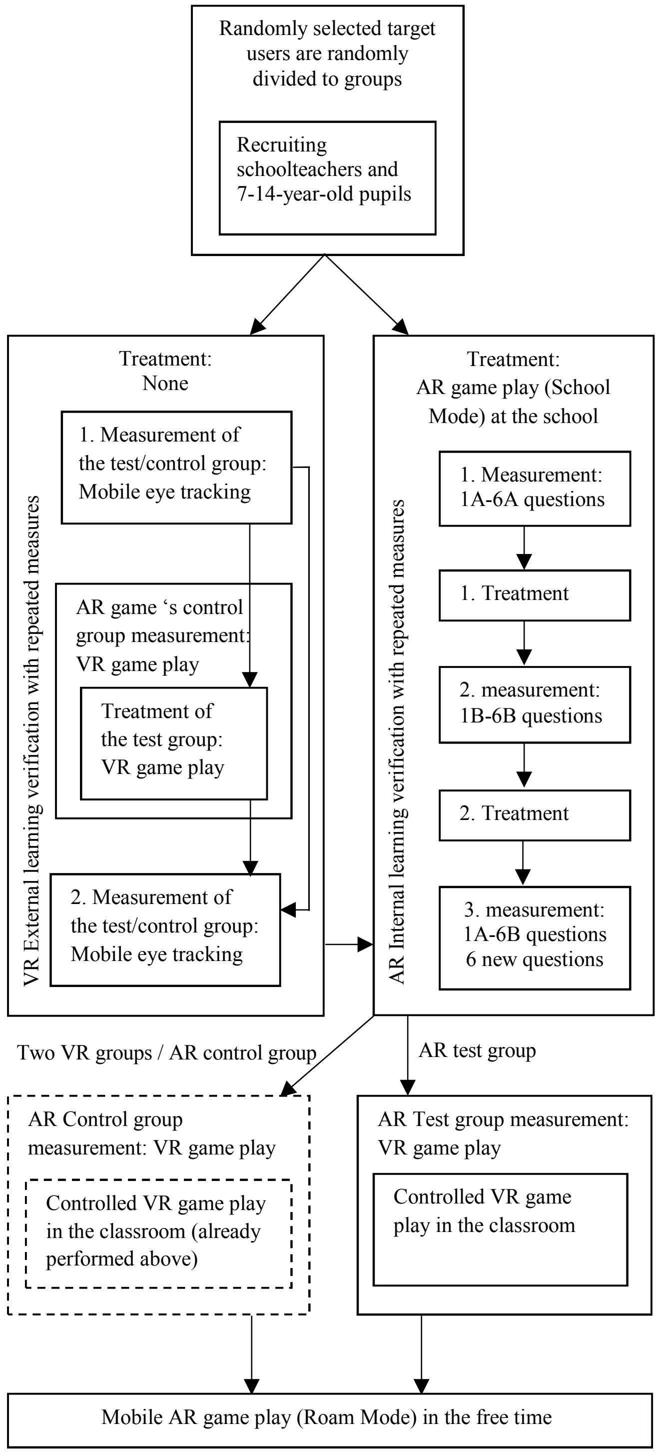

Fig. 9. Proposed model for studying learning in the case.

Eventually, both groups can play the AR game: the control group shall play the VR game before the AR game and the AR test group must not be aware about the VR game content. The control group measurement does not need to be repeated as the VR game play takes place early in the beginning of the research intervention. The consequence is that the test administrator must carefully plan and control timing for each test and each group.

A generalized version of the proposed research model for learning verification with AR and VR applications in an emergency context is introduced in Fig. 10. The represented model describes the learning verification for the AR game with the VR game simulating the real-world context, but the roles could be interchanged depending on the case.

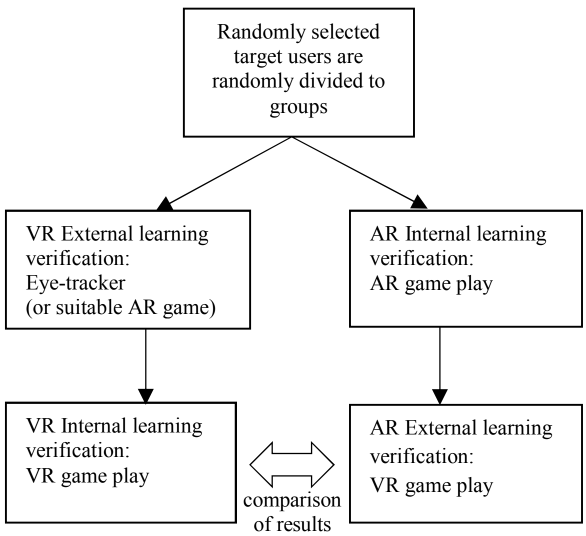

Fig. 10. A generalized research model and interplay of AR and VR to verify players learning in a serious game (AR game) in an emergency context (VR game).

V. CONCLUSIONS

This paper has described two standalone AR and VR games, which interchangeably teach fire safety skills to children and verify their learning results, which is still a relatively rare approach. These studies are in line with the cognitive infocommunication principles, which focus on the challenges of making the communication of information more natural for users [20]. Specifically, we concentrated on the planned learning paths and research study designs for verification studies within and between the games to describe the benefit of the interplay of these applications. Based on the abstract analysis of the research designs, AR and VR technologies can support each other in terms of learning and its verification. The future data collection will show how well this is true in practice.

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