Using a Serious Game in public schools for training fire evacuation procedures

Paulo V. Rodrigues de Carvalho[1], Darcio O. Ranauro[1], Gabriel M. S. Abreu Mol[1], Alessandro Jatoba[1], Ana P. Legey de Siqueira[1], Antonio C. de Abreu Mol[1]
[1]*Mestrado Profisional em Novas Tecnologias Digitais na Educação, Centro Universitário Carioca, Rio de Janeiro, Brasil, darcioranauro262@gmail.com, bielmellomol@gmail.com, alessandro.jatoba@fiocruz.br, anapaula.legey@gmail.com, prof.antonio.carlos.mol@gmail.com, paulov195617@gmail.com*

Abstract

Most Brazilian schools do not offer evacuation training from their buildings in the event of a fire. The lack of safety culture among students and teachers, coupled with a lack of knowledge and training on safety protocols to follow when facing fires, have led to unwanted outcomes, including unnecessary injuries and even death. This study describes the development of a prototype of a Serious Game to teach fire evacuation procedures in schools in the case of fire, aiming to help students to learn fire safety procedures, to know how to behave in case of fire, and to start discussions to create a positive fire safety culture. The prototype was used and evaluated by 35 public school students from 12 to 16 years old. The results indicated that students' knowledge on how to behave in case of fire after they played the game was significantly improved, and the discussions triggered by the game contributed to the creation of a positive fire safety culture in school. The game developed proved useful to teach evacuation procedures and is available for use by all public schools in the city.

Keywords: *Serious Games, fire evacuation procedures, evacuation plan.*

1 Introduction

A school needs to be a pleasant and safe place for staff, teachers, and students. When faced with various natural and human threats, preventive plans and projects aimed at safeguarding students are necessary to preserve lives and reduce the damage that may occur to school assets. Proper training is essential for a rapid and efficient response to possible accidents. According to data collected from the National Fire Incident Reporting System in the United States [1], an average of 10,300 fires in school buildings required the presence of fire departments each year in the country. Brazil lacks a national data recording system that tallies the annual number of fires in schools, hotels, concert halls, and other establishments. This deficiency hinders the development of prevention and public management initiatives. A study conducted with hotels in Spain reported the same shortcoming in data collection. The lack of fire safety initiatives resulted in 240 injuries between 2004 and 2008 [2].

Accident prevention in schools is particularly important because children are a vulnerable group. Their perception of danger, experience, and knowledge is inferior compared to that of adults. Therefore, they require guidance and repeated training to prevent threats such as a possible fire in a building. In his study, Proulx [3]reports that children under the age of five years face a 2.5 times higher risk of death in a fire compared to other groups. Hence, in addition to pupils' academic and physical education, schools need to

provide age-appropriate guidance to students, teachers, and staff on how to prevent fires, and promote safety in the event of a possible fire.

In Brazil, current legislation requires numerous safety plans against fire and panic in school buildings. For buildings in general, aspects such as building occupancy classification (e.g., school versus factory), types of activities taking place in the building, number of floors, height, total construction area, and risk of fire, among others, determine specific construction rules and equipment requirements aimed at accident prevention. For a school building to be considered safe, it must have the Firefighters' Corps' endorsement.

However, many public schools in Brazil do not meet the pre-established rules. According to Bottari and colleagues [4], only 7.8% (120) of the 1,539 public schools in the state of Rio de Janeiro have the endorsement of the fire department. In the state of São Paulo, 95% of the 133 schools visited by the State Court of Auditors did not comply with current legislation [5]. In the state of Minas Gerais, 87% of the 565 public schools visited by the State Court of Auditors did not have the endorsement of the fire department [6]. Given this scenario, fire prevention training is especially necessary. Digital tools, such as simulations, can be used to teach protocols that safeguard students.

The main research question that guides this study can be stated as: "To what extent can a Serious Game (SG) be used to improve knowledge on evacuation procedures and, at the same time, trigger discussions and reflections on safety culture within elementary school students?" Therefore, we developed a SG to teach elementary school students the use of protocols for evacuating school buildings in case of fire. In addition to addressing evacuation procedures, the research also aimed to discuss and improve safety culture and risk perception in elementary schools. The study evaluated whether the students who participated in the research improved their knowledge on fire procedures, evacuation protocols, and on how to act in the event of a fire in the school.

2 *Serious Games for emergency and disaster management*

The literature review carried out for this research shows that educational institutions should use digital games as a powerful tool for teaching and learning and attempts to change students' behaviors and improve their knowledge, specifically the knowledge related to safety culture. This is because games have narratives, rules, restrictions, interactions, challenges, competitions, conflicts, results, rewards, and feedback, as pointed out by Prensky [7], [8]. These pieces of software promote intellectual development by requiring that players strategize, communicate, interact, make decisions, and process information to solve problems. Games also elicit emotions and can reinforce either short-term or long-term memory, both of which contribute to learning and cultural change. Previous research shows that educational games facilitate active and more meaningful learning experiences [9], [10].

Papadakis [11]conducted an extensive review on digital games used as learning tools. The findings of the various studies reviewed confirm that games motivate and generate curiosity resulting in "a positive relationship between learning and students' engagement while using digital games". Games cultivate this motivation with a series of challenges and feedback. Challenges arouse students' interest and curiosity, capturing their attention. Games typically advance in stages, where the challenges are easy at the beginning and become increasingly difficult. With each challenge presented, glimpses of success boost the players' confidence, making them feel more secure with each stage completed. The player then receives feedback when they break records, achieve goals, and win trophies, medals, and points, providing satisfaction. Thus, the obstacles ahead and the pleasure of achievement motivate the player, generating a constant cycle of challenges and feedback. The feedback, in turn, guides performance.

Shernoff and Csikszentmihalyi [12] provide a theoretical framework for understanding how games engage students. They describe how the human mind, when using high concentration to execute a task, can lose track of space and time; thus, they coined the term

"flow" to describe this type of experience. They suggest that games can facilitate these flow experiences, which encourage learning by holding students' attention in a learning environment over a long time. The game choice is essential; if the challenges are too easy or extremely difficult, the game becomes tedious or discouraging.

Currently, SG has been used for a wide variety of practical applications, including emergency and disaster management, risk mitigation and prevention, contributing to the development of a safety culture.

The Tactical Language and Culture Training System [13], is a collection of SGs that use artificial intelligence to assist in military language learning under conflicts. It also teaches about the local culture and provides scenarios that simulate military actions. The game provides students with missions that they – as military – should achieve with constant feedback on student performance, while giving guidance on the protocols the military should follow. For example, the game Tactical Iraq has three modules: the Skill Builder, the Mission Game, and the Arcade game. An initial evaluation study that included 20 marines as participants suggested the game contributed to Arabic language learning at the level needed for the training missions. The game also provides simulated scenarios to teach the social norms of politeness and etiquette when approaching people in Iraq.

The SG Zero Focus [14] aims to teach players how to eliminate larval development sites of the Aedes aegypti mosquito, which transmits the Dengue, Zika, and Chikungunya viruses. An avatar starts a search for larval development sites in places that accumulate water, and the player can eliminate the sites with the help of mosquito-fighting kits. The software provides educational, free, and innovative solutions to healthcare problems faced by Brazilian society daily.

Developed by the United Nations the Stop Disasters game offers scenarios to teach players how to protect against five natural disasters to develop a safety culture and prepare against a future emergency [15]. Designed for children and teenagers, it spans between 10–20 minutes and presents a variety of risks for players to manage. The user can choose to play against tsunamis, hurricanes, forest fires, earthquakes, and floods at different levels of difficulty.

The game "State Civil Defense Agent", developed by the State Defense Agency [16], focuses on rescuing people trapped by floods. The following phases are created: emergency sirens' activation and temporary eviction of a community at risk; distribution of humanitarian material; planting of seedlings and recovery of slopes to avoid landslides; preparation of an emergency backpack; and, finally, escaping from a risky location. The focus on heavy rain disasters is justified because it is the main cause of deaths in natural disasters in Brazil [17].

There are also several studies on SGs for evacuation procedures in case of fire and other safety related events.

Catal and colleagues [18] developed a mobile application based on augmented reality (AR) technology for a game-based evacuation training system. With 36 participants' responses, they concluded that SGs based on AR provide a flexible environment to develop evacuation systems in the university buildings where the game was applied.

Silva and colleagues [19] described a SG called EVA, as a proposal for training health professionals. With 20 participants, the game application enables the evaluation of the evacuation time in case of fire, the indication of which exit was used by the participants, and the rescue time needed to rescue a given person.

Rüppel and Schatz [20] proposed a serious gaming framework based on Building Information Modeling sed in the modern construction industry to explore how building conditions in extreme situations, such as fires, affect human behavior during the evacuation process. They claim that it is impossible to collect data on human behavior during evacuation in real fires, and their basic hypothesis is that human behavior in extreme situations can be explored through SGs.

These related studies guided the basic requirements for the development of our game. Some of these requirements were pedagogical – difficult to learn, knowledge acquisition, challenge, practice, goal setting – and others related to game design itself such as interface

design, motivation, realistic simulation. The fire evacuation procedures previous studies stress the need that the game follow the actual procedures for evacuation in case of fires in a realistic setting. Consequently, we used the procedures already established by the Brazilian Firefighters Corps and the basic layout of Rio de Janeiro's public schools in the game development.

3 Material and methods

This study aimed at developing a SG to teach behaviors that safeguard students during a public school fire. The game was developed to promote practices that are not typically taught in classrooms and can be extended to other environments, such as churches, companies, cultural centers, and non-governmental institutions. The study was carried out with elementary school students from a public school in Rio de Janeiro. Thirty-five students between the ages of 12–16 years participated in the research, with 17 males and 18 females from the seventh and eighth grades. The method for the development of the SG began with a social construction, where the first step was contacting the participating school's manager. One of the authors, who is also a professor at the school, presented the project proposal to the school manager, and analyzed the underlying structural conditions necessary for the research. After clarification with the management team, the researcher fulfilled all steps for approval of the research project by the Ethics Council, Opinion 3,525,383, on August 22, 2019. Figure 1 presents the phases for the SG development.

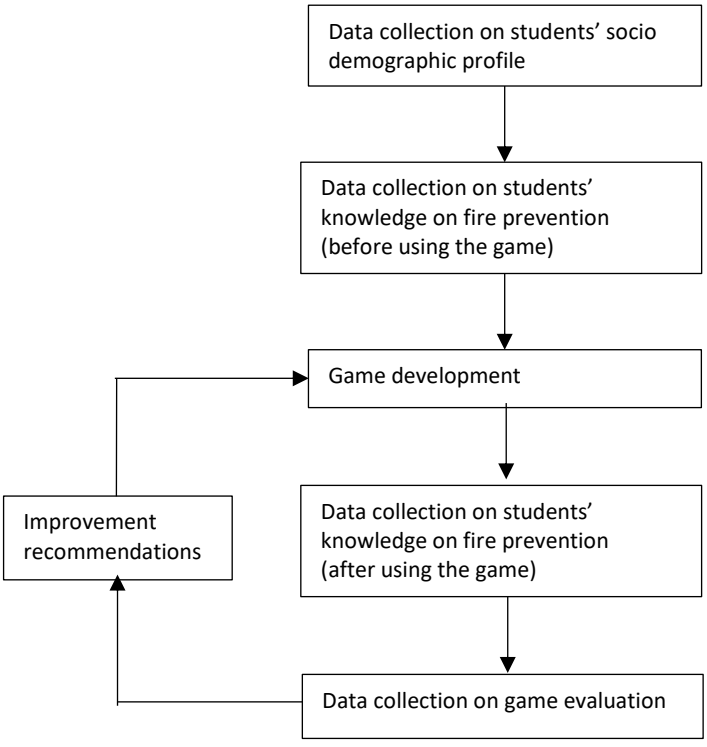

Figure 1. *The method for SG development.*

Three different questionnaires were used to collect the data as shown in Figure 1. The first questionnaire was used to collect data on the socio demographic profile of the students. It consisted of open questions to collect information about each participant's name, age, and level of education, the neighborhood of residence, and other activities outside of school hours.

The second questionnaire consisted of closed multiple-choice affirmations containing five possible answers on a Likert scale, ranging from strongly disagree (SD) to strongly agree (SA). This questionnaire was about "knowledge about escape from school in case of a fire" and it was applied twice – before and after using the game – to analyze the learning results. It aimed to assess whether students knew the necessary protocols for safe and organized evacuation in the event of a fire and the roles of each actor in the process. The first application aimed to understand the students' knowledge about existing fire prevention at school and determine whether students had any experience with the school's evacuation plan before using the game. When designing the questionnaire, we followed guidelines provided by Machado [21], who states there are risks whose symbolic burden is more significant than the probability of the event materializing, making them especially feared.

For the development of this questionnaire, preliminary tests were carried out with a small group of students to adjust the questions suggested by the Machado framework for the school context, students' comprehension of question terms, and the research objectives. Six students responded to the questionnaire without help and debriefing sections were carried out to discuss and clarify students' doubts and problems in answering the questions. After the implementation of these tests, the final version of the questionnaire was validated by the research group. It is important to note that terms used in the questions on the evacuation protocols and on the main roles and names of the different actors were the same as used for the game development.

The SG was developed after the first application of the second questionnaire (on the "knowledge about existing fire prevention"). Therefore, it was possible to outline the content needed to teach students the procedures and protocols of school evacuation in case of a fire. The proposed procedures were translated into a digital tool, a SG.

Then, the 35 students played the game in groups of five students sharing seven different computers and after that, each student again answered the questionnaire individually.

The third questionnaire was used to evaluate the game itself and was applied once, after using the game. The game evaluation questionnaire was based on the four main categories – Attention, Relevance, Confidence, and Satisfaction – of the ARCS model [22], a model to evaluate educational games, with phases related to motivation, user experience, and acquired knowledge [23]. The model uses a Likert scale and 35 students answered this questionnaire individually after playing the SG.

4 *Game development*

The overall analysis of questionnaire responses on *Knowledge about escape from school in case of a fire* and observations in the school environment indicated that there are many problems related to risk perception, prevention plans, and safety culture such as:

- A lack of projects in the school building focused on fire prevention plans;
- Students' lack of knowledge of the necessary protocols for safe evacuation from the building in an emergency;
- A lack of safety plans necessary for fire department endorsement in place at the educational institution, further increasing the need for quick and efficient evacuation in the event of an accident;
- A lack of an overall safety culture at the school among students and teachers.

A preliminary version of the game was applied beforehand with six students. Each student used a computer to play the game and after that, they answered the third questionnaire, about game evaluation. After the debriefing section and the evaluation questionnaire responses analysis, the following improvements were made to the game:

- Adequacy of the language used in the texts for the target audience – less far-fetched language;
- Improvement in the design of some game elements (e.g., the telephone and agenda with larger numbers and colors to draw more attention);
- An arrow was made available indicating the position that the line the leader should assume;
- Text was included for guiding the roles of the line leader and the line closing actor;
- An arrow was added indicating that the player should walk to the right side of the corridor.

Furthermore, during the development of the final version of the game, the research team had the collaboration of a Civil Defense agent.

4.1 Game elements

The main game elements are references, target audience, scenario, game engine, game history, and forms of validating the game developed:

- References: The proper evacuation strategies used in the SG software were based on projects developed in Brazil by the Civil Defense State Agency of Paraná [24], [25] ;
- Target audience: Elementary school students between the ages of 12 and 16 years;
- Scenario: The scenario was inspired by Centros Integrados de Educação Pública (Public Education Integrated Centers), simulating the architectural structure of a project carried out in the state of Rio de Janeiro by then-Governor Leonel Brizola, in the early 1980s, as shown in Figure 2;
- Game Engine: The game used Unity 3D, a game engine designed by Unity Technologies, and widely used to create virtual reality and AR rograms. The game was designed for Windows 7, Windows 8.1, and Windows 10 64-bit Operating Systems;
- Actors involved: Students, teachers, and employees of public schools.

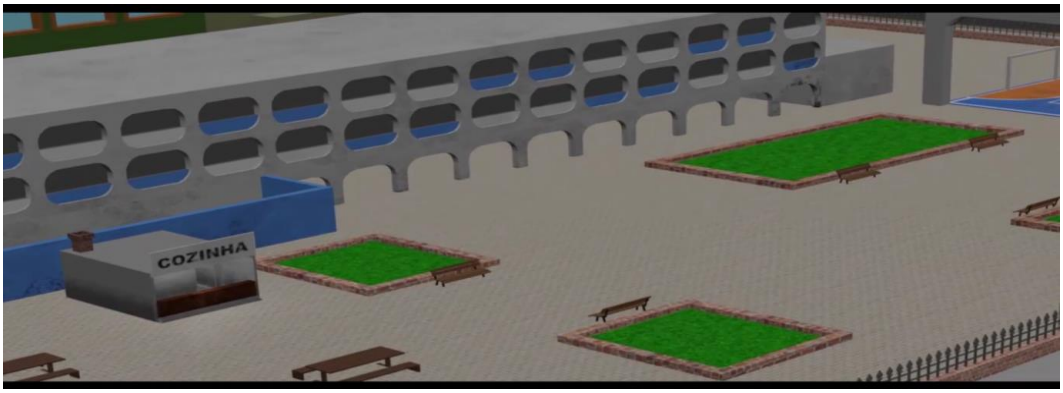

Figure 2. *The game scenario: a simulation of the integrated education centers.*

4.2 Game design

The game design considered existing guidelines regarding the procedures and protocols that the students must follow, and the typical terminology to be used by each actor. The single-player game was divided into four stages, and only one escape route was implemented.

In Stage 1, a video shows a fire in the educational institution. Soon after, the player is faced with a phone on the computer screen. To clear the stage, the player must dial the emergency number of the Military Firefighters' Corps, 193. If the player fails, a new opportunity will be given with the help of a phone book on the right side of the screen, as shown in Figure 3.

Stage 2 takes place in the schoolyard. With the mouse's aid, the player must ring the fire alarm, close the gas valve, and guide the students toward the pre-established meeting point. Stage 3 takes place inside a classroom. After hearing the fire alarm and having been warned by an employee about evacuating the building, the player must organize a single queue at the exit door of the room, as shown in Figure 4. Meanwhile, the teacher must close the doors and windows before leaving. After the successful organization of the queue, the teacher automatically assumes the rear-guard role. After the player completes these steps, the game provides a button for opening the exit door, and the game moves on to the next stage.

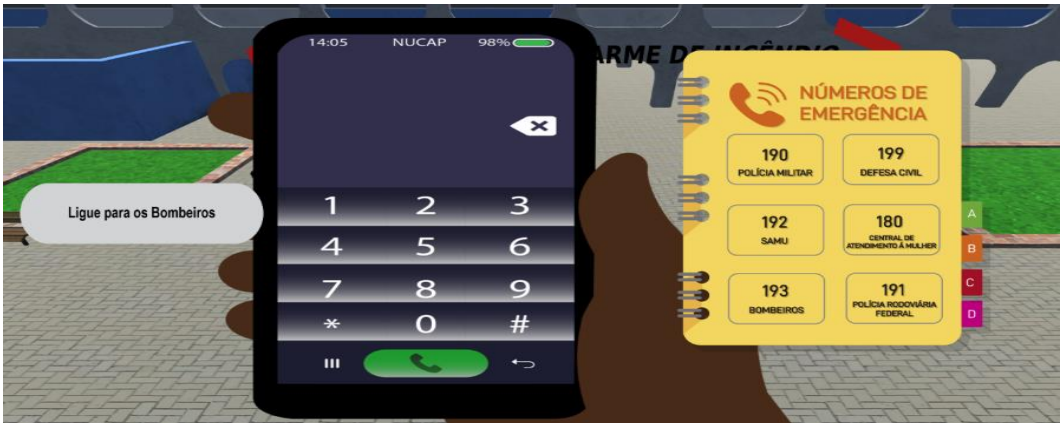

Figure 3. *Dialing the fire department emergency number.*

Figure 4. *The inside classroom stage with students in a single row inside the classroom.*

The scenario in Stage 4 is a corridor of the building. The player must divert students from obstacles and lead them along the right side of the corridor, as shown in Figure 5. In order to stress the importance of following evacuation procedures, the game introduces some points of doubt to the player. At a particular moment, the player is faced with an arrow indicating a possible escape alternative. Then, the player must choose between following the instructions of the person in charge of the corridor, or entering the location indicated by the arrow, as shown in Figure 5. If he/she does not follow the guidelines of the person in charge of the corridor, the player loses the match, and the game restarts this stage.

When the player reaches the end of the route, the game provides two exit options: the first is through the elevator, and the second by stairs. Following guidelines developed by Civil Defense Agencies worldwide, the player must walk down the stairs and continue to the meeting point, reaching the end of the game, as shown in Figure 6.

Figure 5. *Students walking through the school corridor.*

Figure 6. *Students at the meeting point.*

5 Results and discussion

Study participants were comprised of 35 students aged 12 to 16 years, in seventh and eighth grades. The group was 48.6% male and 51.4% female. All students were born in Brazil and lived in the school neighborhood. They did not engage in any professional activities outside of school.

5.1 Answers before gaming related to the student's perception of the school preparedness for fire events

The responses to the second questionnaire, before gaming were:

- My school has a fire alarm: 52.9% of males and 77.8% of females reported that the school dis not have a fire alarm. Adding the groups, the survey found that more than half (65.7%) realized the school did not have a fire alarm. According to the school manager, it did not have a specific fire alarm. For Almeida [26], identifying the fire alarm's sound is of paramount importance in an emergency so that occupants can react appropriately, increasing the likelihood of survival, and decreasing the number of victims;

- My school has an emergency plan indicating the escape route that must be followed in the event of a fire: all of the students identified that the school did not have an emergency plan, a fact confirmed by the school manager;

- My school has fire extinguishers: the study found that, out of the three school floors, only two had fire extinguishers. Furthermore, these were in inappropriate locations and did not have proper identification. Overall, 38.9% of female students reported a lack of safety equipment, compared to 29.4% of male students;

- My school has a fire brigade: all students stated the educational institution did not have a fire brigade, a fact confirmed by the management team. Notably, this shortcoming violates the specifications of NT 2-11 / 2019 of CBMERJ [27];

- I can identify that a fire has started: 51.4% of students said they could identify when a fire had started;

- At my school, staff and teachers are prepared to guide students in the event of a fire: the school manager did not consider teachers and staff to be prepared to work in an emergency. However, 57.1% of students trusted the training of professionals. For 44.4% of females, the professionals who worked at the school were prepared. This number increased to 70.6% when only the male group was analyzed;

- The school has projects aimed at fire prevention: for 71.4% of participants, the institution did not promote projects in the area of prevention;

- The school has a fire evacuation plan: almost all participants, 97.2%, stated that the school unit did not have an evacuation plan;

- This year, the school provided fire evacuation training: consistent with the responses to the previous question, 97.1% of students reported that they did not undergo evacuation training in 2019;

- I know how to proceed to help a disabled person if there is a fire in my school unit: 40% of respondents reported that they knew how to proceed to help a disabled person in case of a fire. According to the Emergency Evacuation Planning Guide for People with Disabilities, prepared by the National Fire Protection Association [28], the disabled person should have a designated helper in the evacuation plan. The evacuation plan coordinator must make a second person available as a backup if the designated employee is sick or on vacation.

5.2 Knowledge about escape from the school unit in case of a fire – prior and acquired knowledge

The answers regarding students' knowledge on evacuation procedures in case of a fire, both before and after playing the SG were:

- I know how to proceed in case of a fire in my school: before the game, 45.7% reported that they knew how to proceed in case of fire. With the educational game's aid, this percentage increased to 94.3%, a significant gain for the study;

- I can hear the fire alarm: before playing the game, 62.9% could identify/distinguish the sound of the fire alarm. After playing the game, the percentage increased to 94.3%;

- I don't stay in line if there is a fire: before playing, 76% of the students said it is correct – which would lead to an uncontrolled escape process with possible injuries – but after playing the game only 8.6% maintained the same inadequate behavior. The same pattern change – common sense versus following procedures – appeared in many other responses;

- I don't depend on anyone to escape the fire: the game helped students to better understand the importance of following established guidelines and protocols. Before playing the SG, 54.3% agreed they did not depend on others during evacuation. However, after using the software, this number decreased to 11.4%;

- I know what a "meeting place" means in case of a fire: The percentage of students who strongly agreed that they knew what a "meeting place" means increased from 51.4% to 97.1%;

- I am aware of the role that the "lead partner" plays during an evacuation from the school in case of a fire: "Lead partner" refers to the student responsible for organizing the queue in the classroom during the evacuation procedures. With the aid of the game, 80% of students were aware of this role, a considerable gain from 0% before students played the game;

- I will leave the door open if I escape the classroom during a fire: the research discarded this statement because it confused the students when they were responding to the questionnaire. The authors' initial idea was to evaluate whether the students understood that after leaving a specific location, all doors and windows should be closed to avoid or minimize the spread of fire and fumes. After playing the game, 60% reported that they would leave the door open with the following consensus: "I will leave the door open for my friends to leave as well." The authors suggest that for future studies the sentence should be modified to: "After the departure of all occupants of the classroom, doors and windows will remain open." The discussion on the need to close the doors to avoid fire-spreading versus leaving them open to enable evacuation, shows that gaming triggers discussions on the rationale of evacuation procedure statements, as already shown in other SG settings [29]. Figure 7 summarizes these knowledge evaluation results.

5.3 Game evaluation

The overall experience of using the game was evaluated by the 35 participants. The evaluation model used [22], [23] seeks to assess whether a game: (i) can motivate students to use the resource as learning material; (ii) provides a good experience for users (e.g., if it's fun); and (iii) a perception of educational utility is generated among its users (i.e., whether students feel they are learning from the game). An important requirement considered in the evaluation was the low time consumption for its application, and systematization to allow repeated evaluations to enable comparisons between different versions of the game. The evaluation questionnaires have items about various aspects of the parameters of the evaluation model and are presented in the form of statements for students to indicate how much they agree with them according to a five-point Likert scale ranging from "strongly disagree" to "strongly agree". The affirmations used for evaluation and answers are displayed in Table 1.

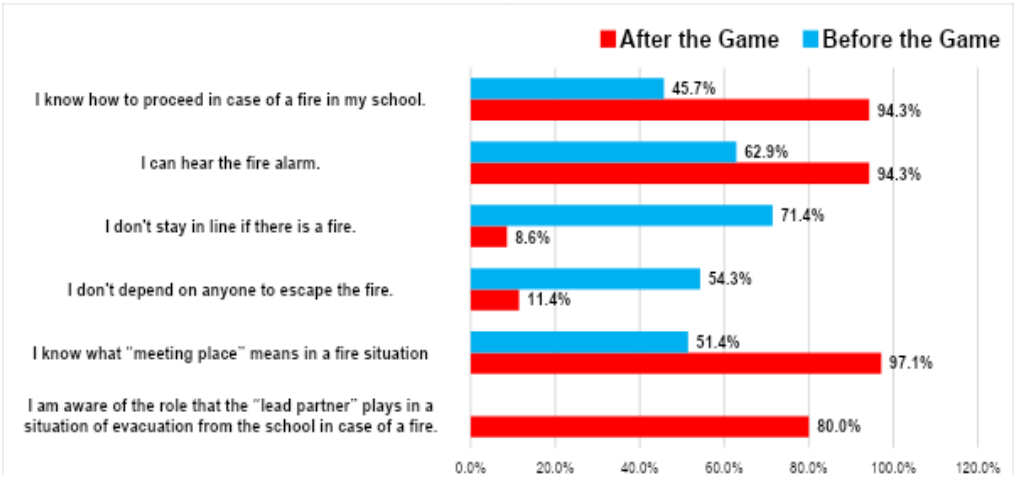

Figure 7. *Comparing knowledge on evacuation protocols begore and after playing the game.*

Table 1. *Game evaluation results: SD: I strongly disagree, PD: I partially disagree, NAD: I neither agree nor disagree, PA: I partially agree, SA: I strongly agree.*

MOTIVATION					
	SD	PD	NAD	PA	SA
The game is attractive and well designed	0.0%	0.0%	0.0%	11.4%	88.6%
The subject presented is important to my life	5.7%	0.0%	0.0%	0.0%	94.3%
The game activities were very difficult	71.4%	5.7%	5.7%	14.3	2.9%
The game had so much information that it was hard to remember the important points	85.7%	0.0%	2.9%	2.9%	8.6%
Completing the game's stages gave me a feeling of accomplishment	5.7%	0.0%	8.6%	11.4%	74.3%
USER EXPERIENCE					
I finished the game successfully	0.0%	0.0%	2.9%	2.9%	94.2%
I didn't notice time passing while playing	8.6%	0.0%	0.0%	2.9%	88.6%
The game offers new challenges at an appropriate pace	2.9%	2.9%	0.0%	0.0%	94.3%
The game had so much information that it was difficult to identify and remember the important points	85.7%	0.0%	2.9%	2.9%	8.6%
I would play this game again	8.6%	2.9%	2.9%	0.0%	85.7%
I found the game kind of boring	77.1%	5.7%	0.0%	11.4%	5.7%
KNOWLEDGE					
The game helped me to understand the evacuation procedures in case of a fire	0.0%	0.0%	2.9%	8.6%	88.5%

The motivation evaluation follows the guidelines of John Keller's ARCS [23]. The questionnaire evaluated the students' motivation to learn the proposed content related to attention, relevance, confidence, and satisfaction that the game provides. From Table 1 the majority of students found the game attractive and well designed. During the game, the researcher noticed that the students were focused on the game, not even realizing what was happening around them. Almost all considered the subject relevant to their lives and 71%

of respondents did not find the game difficult to play. Upon completing the game, 74.3% expressed a feeling of accomplishment.

The user experience evaluation shows that the participants enjoyed playing the game, as most of them did not notice the time passing when playing. Confirming this result, most (80%) said that, at no time, they thought about giving up, indicating that a significant number of students were interested in playing the game. For Takatalo et al. [30], many people spend nights and weekends playing games and do not notice time passing. Therefore, the motivation to play games can be a great ally to introduce knowledge on boring content to students, such as evacuation plans. According to 94.3% of the participants, the game offered new challenges at an appropriate pace, and they reported that they were successful at the end of the game because they got to the meeting point with all the members of the class. Students reported that they would play the game again, with 85.7% in agreement, and most of the students (82.8%) did not find the game boring (monotonous) but rather fun.

For 97% of the students, the game helped them to better understand the procedures for evacuating the school building in case of fire, achieving the main objective of the SG – knowledge development. The research indicated that before playing the game the students did not know how to follow evacuation procedures, and even basic behaviors to protect their lives, such as to proceed in an orderly evacuation, follow evacuation leaders, reaching meeting points, and so forth. Bearing in mind that the city of Rio de Janeiro features many other risky situations, many other games have already been developed to deal with different risk situations such as epidemics

[14], floods due to heavy rain [15], [16] and all these studies suggested that SGs bring possibilities to discuss and reflect about safety culture with children that cannot be neglected. Considering the small number of participants, this study indicated that playing the game significantly changed students' perceptions of the risks and responses they faced in case of fire, indicating that the use of SGs can be an important ally to raise awareness of risk situations.

In open questions, some students reported that the game needed some upgrades in order to make it more attractive. They suggested the following improvements:

- The physical appearance of the characters: characters should look more similar to human beings;
- The number of players: the game should allow many competitors to play the game simultaneously;
- The number of stages: there should be more stages, with new scenarios and challenges.

The main research question was "To what extent can a SG be used to improve knowledge on evacuation procedures and at the same time trigger discussions and reflections on safety culture within elementary school students?" and the hypothesis that the "studied SG improved knowledge on evacuation procedures and at the same time triggered discussions and reflections on safety culture within elementary school students" was in part validated in this research. The results on knowledge comparison of Figure 7 show that the game increased the knowledge on how to proceed in case of fire from 45.7% to 94.3%. Furthermore, it changed preconceived unwanted behaviors, such as staying in line and the need for help. Before the game 71.4% did not stay inline in case of fire, against 8.6% after playing the game, and 8.6% believed that they did not need help, against 71.4% after. The mean satisfaction agreement on motivation issues of 82.8% (the sum of SA on affirmative and SD on negative questions) and the good results on user experience indicate that the study was able to respond to the research question in this limited setting, confirming the hypothesis that SGs can be used to improve knowledge on evacuation procedures. Regarding discussions and reflections on safety culture, there were some discussions on that; however, further studies and continuous application of such training are needed to validate the second part of the hypothesis.

6 Conclusions

The lack of safety plans in public schools, and the lack of projects aimed at improving fire safety presents a worrying scenario in Brazil. This issue is challenging for school managers and the entire school community. Unfortunately, fire in schools is impossible to avoid. Thus, the entire school community needs to know how to respond and how to minimize the risks of being injured in case of fires.

In this study, we described the steps for the development of a low-cost SG to be used for fire evacuation training in schools. The prototype of the SG was developed according to basic requirements of evacuation procedures and the layout of schools. It was applied and tested with students aged from 12 to 16 years at a Brazilian public school, a different context from the other studies available in the literature. Our findings indicated that it is possible to provide a better response to fires, improving students' behaviors to avoid losses through the application of simulations to learn evacuation procedures, which is consistent with other SGs that have focused on disaster situations.

The results indicated that students' knowledge on how to behave in case of fire after they played the game was significantly improved, and the discussions triggered by the game contributed to the creation of a positive fire safety culture at school. The game developed proved to be useful to teach evacuation procedures and is available for use by all public schools in the city.

Notwithstanding our small sample size, this qualitative study points to significant results that can be used in new research and relates further improvements in this SG. The initial questionnaires have shown that the students did not know the essential protocols that must be followed in case of a fire. With the software's aid, students reported a considerable gain in knowledge about protocols, as shown in the difference in the responses to questions before and after gaming.

Students also reported that the SG was attractive and easy to use, suggesting that the game could be widely accepted by new students. The game met the established objectives, responding to the research question that SGs can be used to improve knowledge on evacuation procedures and at the same time trigger discussions and reflections on safety culture. However, the study also indicated that for older age students the game needs to be more attractive, with better graphics, missions (variabilities in escape routes), better control mechanisms, and hardware issues such as better sound, graphics, and interaction response time. Future developments will include levels to advance, earn points, and multiplayer possibilities, improved feedback and competitive profile among the gamers.

The study's main limitation is regarding a more compelling approach on the statistical analysis of the results. Being an initial study to validate the idea of this game, our focus was on the mean values of the students' responses to questionnaires, without further considerations on how the profile of subjects (e.g., male/female, age distribution, distribution by school year, school location near vulnerable areas) influenced the responses using a discriminant analysis. Therefore, after this preliminary validation, the game will be used in many schools and such statistical analysis will be undertaken.

This research project foresees, as future actions, the organization of escape drills with students from the public school system of a large city and the evaluation of the contribution of SGs to the development of protocols and improvement actions for training. Based on the results obtained so far, a partnership to transfer the software for use in public schools in a city of 919,596 inhabitants and 74,353 students has already been made. The game will be available to all students, teachers, and staff and will serve as a seed for a change in safety culture in schools, as well to raise awareness among educational institutions and government agencies about the importance of preparing our students for fire evacuation in educational institutions.

References

[1] NFIRS, "School Building Fires (2009-2011)", vol. 14, nº 14, p. 16, 2014.

[2] J. C. Rubio-Romero, F. Márquez-Sierra, e M. Suárez-Cebador, "Can fire safety in hotels be improved? Results from the survey of a panel of experts in Spain", *Work*, vol. 54, nº 2, p. 461–471, jan. 2016, doi: 10.3233/WOR-162332.

[3] G. Proulx, "Occupant behaviour and evacuation", p. 14, 2001.

[4] E. Bottari, G. Ouchana, e L. E. Magalhães, "Ilegal e daí: Mais de 90% das escolas do Rio não oferecem segurança contra incêndio - Jornal O Globo", 2019. https://oglobo.globo.com/rio/ilegal-dai-mais-de-90-das-escolas-do-rio-nao-oferecem-seguranca-contra-incendio-23459186 (acessado 6 de setembro de 2022).

[5] São Paulo, "Relatório das Contas do Governador do Estado", 2018. [Online]. Disponível em: https://www.tce.sp.gov.br/sites/default/files/noticias/AuditoriaTCESP_UnidadesEscolares.pdf

[6] "Escolas de Minas correm contra o tempo para adotar medidas de combate a incêndio - Gerais - Estado de Minas". https://www.em.com.br/app/noticia/gerais/2018/09/29/interna_gerais,992740/escolas-correm-contra-tempo-para-adotar-medidas-de-combate-a-incendio.shtml (acessado 27 de julho de 2020).

[7] M. Prensky, *Don't Bother Me Mom—I'm Learning*. Paragon House, 2011.

[8] M. Prensky e M. Prensky, "Digital game-based learning (Vol. 1)", *St. Paul, MN: Paragon House*, 2007.

[9] R. W. Wagner, "Edgar Dale: Professional", *Theory Into Practice*, vol. 9, nº 2, p. 89–95, abr. 1970, doi: 10.1080/00405847009542259.

[10] C. C. Bonwell e J. A. Eison, *Active Learning: Creating Excitement in the Classroom*, Edição: 1. Washington, DC: Jossey Bass, 1991.

[11] S. Papadakis, "The use of computer games in classroom environment", *International Journal of Teaching and Case Studies*, vol. 9, nº 1, p. 1–25, 2018.

[12] M. Csikszentmihalyi, D. Shernoff, R. Gilman, E. Huebner, e M. Furlong, "Flow in schools: Cultivating engaged learners and optimal learning environments", *Handbook of Positive Psychology in schools*, p. 131–145, 2009.

[13] W. Lewis e Johnson, "Serious Use of a Serious Game for Language Learning", *International Journal of Artificial Intelligence in Education*, vol. 20, nº 2, p. 175–195, jan. 2010, doi: 10.3233/JAI-2010-0006.

[14] *Jogo Foco Zero - NUCAP/UNICARIOCA*, (26 de outubro de 2017). Acessado: 27 de julho de 2020. [Online Video]. Disponível em: https://www.youtube.com/watch?v=C6n4hxFCtLU&t=15s

[15] S. Felicio *et al.*, "Stop disasters game experiment with elementary school students in Rio de Janeiro: Building safety culture.", 2014.

[16] S. Defesa Civil do Estado do Rio de Janeiro, "Defesa Civil O jogo", 2020. http://www.defesacivil.rj.gov.br/index.php/para-o-cidadao/jogo (acessado 27 de julho de 2020).

[17] G. Dolif *et al.*, "Resilience and brittleness in the ALERTA RIO system: a field study about the decision-making of forecasters", *Natural Hazards*, vol. 65, nº 3, p. 1831–1847, fev. 2013, doi: 10.1007/s11069-012-0448-2.

[18] C. Catal, A. Akbulut, B. Tunali, E. Ulug, e E. Ozturk, "Evaluation of augmented reality technology for the design of an evacuation training game", *Virtual Reality*, vol. 24, nº 3, p. 359–368, set. 2020, doi: 10.1007/s10055-019-00410-z.

[19] J. F. Silva, J. E. Almeida, R. J. F. Rossetti, e A. L. Coelho, "A serious game for EVAcuation training", em *2013 IEEE 2nd International Conference on Serious Games and Applications for Health (SeGAH)*, maio 2013, p. 1–6. doi: 10.1109/SeGAH.2013.6665302.

[20] U. Rüppel e K. Schatz, "Designing a BIM-based serious game for fire safety evacuation simulations", *Advanced Engineering Informatics*, vol. 25, nº 4, p. 600–611, out. 2011, doi: 10.1016/j.aei.2011.08.001.

[21] A. B. M. L. M. Machado, "Percepção do risco e implementação de uma cultura de segurança: construindo comunidades educativas resilientes", PhD Thesis, 2012.

[22] J. M. Keller, "Development and use of the ARCS model of instructional design", *Journal of Instructional Development*, vol. 10, nº 3, p. 2, set. 1987, doi: 10.1007/BF02905780.

[23] J. M. Keller, "Motivational design of instruction", *Instructional design theories and models: An overview of their current status*, vol. 1, nº 1983, p. 383–434, 1983.
[24] M. Rotondo e J. C. Saldanha, "Programa Brigadas Escolares: Plano de Abandono Escolar", 2019. [Online]. Disponível em: http://www.defesacivil.pr.gov.br/sites/defesa-civil/arquivos_restritos/files/documento/2019-05/texto_modulo_2_plano_abandono_1.pdf
[25] G. A. de Lima, "Curso de Capacitação para Professores em Proteção e Defesa Civil".", Petrópolis, 2015. [Online]. Disponível em: http://www.defesacivil.rj.gov.br/images/biblioteca/CURSO DE CAPACITA%C3%87%C3%83O PARA PROFESSORES EM PROTE%C3%87%C3%83O E DEFESA CIVIL.pdf
[26] J. E. S. C. de Almeida, "Serious games as a behaviour elicitation tool: applications to evacuation scenarios", 2016.
[27] Rio de Janeiro, "Nota Técnica do Corpo de Bombeiros Militar no 2-11, de 04 de setembro de 2019. Brigadas de incêndio", 2019. [Online]. Disponível em: http://www.cbmerj.rj.gov.br/pdfs/notas-tecnicas/NT%202-11%20-%20Brigadas%20de%20inc%C3%AAndio.pdf
[28] N. F. P. Association e others, *Emergency evacuation planning guide for people with disabilities*. National Fire Protection Association, 1979.
[29] C. Passos, M. H. da Silva, A. C. A. Mol, e P. V. R. Carvalho, "Design of a collaborative virtual environment for training security agents in big events", *Cogn Tech Work*, vol. 19, nº 2, p. 315–328, set. 2017, doi: 10.1007/s10111-017-0407-5.
[30] J. Takatalo, J. Häkkinen, J. Kaistinen, e G. Nyman, "Presence, Involvement, and Flow in Digital Games", em *Evaluating User Experience in Games: Concepts and Methods*, R. Bernhaupt, Org. London: Springer, 2010, p. 23–46. doi: 10.1007/978-1-84882-963-3_3.