How to communicate and educate more effectively on natural risk issues to improve disaster risk management through serious games

Mercedes Vázquez-Vílchez[1*], Rocío Carmona-Molero[1,2], Tania Ouariachi-Peralta[3]

[1]Didactics of Experimental Sciences, University of Granada, Granada, 18011 Granada, Spain.
[2]Department of Analytical Chemistry, University of Granada, Granada, 18071 Granada, Spain.
[3]Professorship Communication, Behaviour & The Sustainable Society, Center of Expertise Energy, Hanze University of Applied Sciences, Groningen, 9747 AS, The Netherlands.

Correspondence to: Mercedes Vázquez-Vílchez (mmvazquez@ugr.es)

Abstract. This study focuses on exploring the potential of serious games for improving disaster risk management. The research involves methodological triangulation, analysing and comparing data from content analysis of serious games (6 digital games: 3 mobile apps and 3 online games), focus groups with experts and literature review. The results show that only online games fulfil the fundamental narrative indicated by the experts, with mobile apps focusing their gameplay more on interaction. Such interaction could enhance the playful aspect of the game and thus increase the desire to play; thus, the educational aspect of online games is much higher. Few online games work on issues of multiculturalism, diversity and gender. This paper provides a list of recommended features of disaster risk management games that we have categorised into three dimensions: a) character, b) information and message tone and c) narrative dynamics, reward systems and feedback. The results can be of great help to teachers and game designers in improving citizens' knowledge of disaster risk management.

1 Introduction

Today's scientific and technological advances allow us to anticipate natural hazards and take early action, both at governmental and civilian levels. However, the occurrence of devastating disasters in countries of any economic and cultural scale shows that these technological and scientific advances in disaster risk management (DRM) do not necessarily correspond to their correct implementation. Examples are the catastrophic floods that occurred in Europe (Germany, Belgium and the Netherlands) in 2021 or the earthquake that affected Turkey and Syria in 2023, where many people died and economic losses were very high. Therefore, there is a huge gap between scientific-technological valuations and their practices and implementation, and this communication is a critical factor in DRM (Solinska-Nowak et al., 2018; Weyrich et al., 2021).

The dynamics of conflict resolution caused by natural hazards are based on centralized processes in which decision-making is linked to governments, scientists and experts (Clerveaux et al., 2008; Tanwattana and Toyoda, 2018) which minimizes the participation of affected communities. In extreme cases, these decisions may even be made without regard to the local cultural, social or economic norms of the affected area. In this context, in the 21st century, there has been a growing interest in changing

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such hierarchical decision-making and converting it into more participatory strategies involving communities (Yamori and Kikkawa, 2005; Yamori, 2007; Yamori, 2008; Suarez, et al., 2014; Tanwattana and Toyoda, 2018). With this point of view, society is not understood as a world where there is a need for only one solution proposed by people such as scientists or politicians, but as a world where dialogue is possible and diverse viable answers coexist (Yamori, 2011). Some authors suggested a mutual learning, in order to promote the democratization of decisions, which combines a diverse learning methodology, such as adaptive management, experiential learning, or transformative learning (e.g. Lavell et al., 2012). Some important approaches in adaptive management incorporate the use of knowledge co-production, where scientists, politicians and other stakeholders work to interexchange, create and implement knowledge (van Kerkhoff and Lebel, 2006). In this sense, participatory mapping, workshop and hackathons highlight (e.g. Sullivan-Wiley et al., 2019; Trejo-Rangel et al., 2023; Macholl et al., 2024). These approaches introduce local knowledge of natural hazards into vulnerability evaluation, showing diverse vulnerabilities to natural hazards that are co-produced at local scales (Sullivan-Wiley et al., 2019). Experiential (Kolb, 1984) and transformative (Mezirow, 1995) learning remark the importance of action oriented to problem-solving, learning by-doing and how these processes originate reflective thinking, theory generation and applications of knowledge, enabling behaviour change for adaptation to natural hazards (Sharpe, 2016; Lavell et al., 2012).

Following this approach, in which acquiring knowledge about natural hazards should enable citizens to make decisions and implement prevention measures, where there is recognition of active teaching methodologies, such as serious games, which may serve as a participatory and supportive tool for understanding the essential aspects of natural hazards (e.g. Solinska-Nowak et al., 2018, Tanwattana and Toyoda, 2018, Tsai et al., 2020; Schueller et al., 2020; Teague et al., 2021; Altan, et al., 2022; Villagra et al., 2023). Serious games allow users to visualise and explore phenomena that would otherwise be very difficult to experience as they enhance player immersion, and allow them to learn about the consequences of their actions at different points in time during a natural hazard (Solinska-Nowak et al., 2018; Heinzlef et al., 2024). In this way, serious games encourage experiential and transformative learning, as users try to reproduce a context as close to reality as possible that could allow to the players to enable behaviour change for adaptation and resilience to natural hazards (Villagra, 2023). The effectiveness of learning through serious games are also the immediate feedback and the emotional and sensorial experiences they provide, which is essential for learning to mitigate the effects of natural hazards (Solinska-Nowak et al., 2018; Heinzlef et al., 2024). However, while serious games can contribute by giving researchers useful evidence into how people conceive disasters, there is a poor understanding of the representation of catastrophes within popular culture (Gampell and Gaillard, 2016; Safran et al., 2024). Some authors related the characteristics of several disaster games to the disaster risk reduction framework (mitigation, preparedness and recovery), highlight the need for further research into how game characteristics (mechanics, dynamics, narrative and content), player skills, motivations and social interactions contribute towards improving decision-making in the area of disaster risk reduction (DRR) (Gampell and Gaillard, 2016; Safran et al., 2024). Few works address the influence of video games on the tendency of players to prepare for natural hazards (Tanes and Cho, 2013; Tanes, 2017; Safran et al, 2024). Attention is draw to the lack of solid scientific evidence of the potential of serious games, with

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challenges remaining for the development of more detailed studies to test and demonstrate the effectiveness of serious games for DRM education (Weyrich et al., 2021; Safran et al., 2024).

This paper aims to explore the potential of serious games for improving DRM. The main research question it raises is how can we educate and communicate more effectively about natural hazards through serious games? To this end, the following research sub-questions are posed: (a) How do serious games communicate and educate on issues related to natural hazards? and (b) What are the educational and communicative elements or characteristics that serious games should have to improve DRM? This work will follow a methodology consisting of qualitative research based on triangulation. The research method includes a content analysis of selected serious games applied to DRM, a focus group of experts and a literature review (the constructs of the investigation were determined with the help of introductory literature).

The remainder of this paper is organised as follows: an overview of serious games as tools for learning and change, especially those for disaster risk management (Section 2); a description of the qualitative methodological approach used (Section 3); a presentation of qualitative content analysis of serious games and focus group with experts results (Section 4), and finally, a discussion of the results (Section 5) and main conclusions, including the limitations of this study and recommendation for future works (Section 6).

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2. Theoretical framework

2.1 Serious games for learning and change

A large body of research supports the idea that active learning can improve learning performance more than traditional learning strategies, with gamification being one of the more representative examples (e.g. Tolks et al., 2024). Gamification refers to the use of game design elements in non-game contexts, in order to enhance learning and certain behaviour (e.g. Ramírez-Cogollor, 2014). Games awaken, engage and motivate, provide social and civic skills and promote problem-solving capabilities (e.g. Liao et al., 2023; Safran et al., 2024). Today there is an increasing tendency of educational platforms to incorporate game elements (points, badges, difficulty levels, leaderboards) so as to measure and encourage learning outcomes by adding scores and feedback (Hellín et al., 2023).

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Serious games are those that have the purpose not only of entertaining, but also teaching, as well as conveying ideas, values, and influencing the thoughts and actions of players in real-life contexts (e.g. Frasca, 2007; Bylieva and Lobatyuk, 2019; Sáiz-Manzanares et al., 2021). The terms serious games and game-based learning are frequently used synonymously (Corti, 2006), although serious games have been created for the broader intentions of training and behaviour change in various fields, including business, healthcare, NGOs and education (Sawyer and Smith, 2008). Serious games are also referred to as "change games" (Bogost, 2007; Courbet et al., 2016) and "social impact games" (Cremers et al., 2014).

Serious games have experienced a rapid increase over the last decade, with extensive research supporting empirical evidence of cognitive benefits (Vogel et al., 2006; Bellotti et al., 2013), along with the identification of the impact on affective and motivational outcomes (Connolly et al., 2012; Wilson et al., 2009; Pineda-Martinez et al., 2023). Serious games allow users

to visualize and explore phenomena that would otherwise be very difficult to experience, and see the consequences of their actions at different times (Wiek and Iwaniec, 2014). One of the great reasons for the effectiveness of learning through serious games is the immediate feedback they provide. These kinds of games allow learning through problem solving in an active way, where students focus solely on their learning (Medina, 2012). In addition, serious games favour personal autonomy, and social and cultural engagement (Magnuszewski et al., 2018).

A special case is that of serious games based on computer technologies, which have experienced a rapid increase in the last decade, increasingly replacing traditional games. Computer games take advantage of young people's interest in social networks and video or online games, and can cover diverse learning objectives, multiple fields and target different age groups (Mouaheb et al., 2012). Playing computer games is related to a variety of cognitive, affective, behavioural and motivational impacts and outcomes, the most frequent of these being knowledge acquisition and content comprehension (Connolly et al., 2012). Attending to their characteristics, there are a wide variety of genres and formats such as simulations, which simulate aspects of a real or fictional reality, and adventures, where users solve challenges by interacting with people or the environment in a non-confrontational manner (Lamb et al., 2018; Heintz and Law, 2015; De Freitas, 2018; Heintz and Law, 2018).

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2.2 Serious games for disaster risk management

Most disaster-related serious games involve social simulations and role-plays (Solinska-Nowak et al., 2018; Cremers et al., 2014). These types of games are intended for a high number of people, from different contexts, providing them with face-to-face discussion and negotiation about a given problem. Players have the opportunity to share different values and perspectives, engaging stakeholders with conflicting interests to cooperate towards a common goal (Akhtar et al., 2020).

Floods (e.g. Teague et al., 2021; Tsai et al., 2020; Gordon and Yiannakoulias, 2020), earthquakes (e.g. Safran et al., 2024; Feng et al., 2020; Whaley, 2019) and droughts (e.g. Podêbradská et al., 2020; Wang and Davies, 2015) dominate the subject of the different natural hazard games (Solinska-Nowak et al., 2018). This is in line with actual occurrence statistics, as, at least until 2015, floods have been the most common natural hazards globally over the last 20 years (43% of all events), followed by storms, (34% of sum total) with earthquakes in third place (8% of sum total) (CRED, 2015). On the other hand, the three dominant themes correspond to those causing the highest number of deaths (IFRC, 2020), and it is reasonable that they are the most represented in serious games.

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Most serious games aim to strengthen the preparation capacity for natural hazards (Solinska-Nowak et al., 2018). These games provide instructions through appropriate activities in relation to buildings, preparing emergency kits, stockpiling equipment and supplies and how to recognise the first signs of disasters (e.g. Tanwattana and Toyoda, 2018; Teague et al., 2021 Mossoux et al., 2016). In contrast, there are fewer games that focus on the post-disaster phase, which takes into account evacuation management (e.g. Feng et al., 2020) or how to save people (e.g. Whaley, 2019).

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According to Solinska-Nowak et al. (2018), serious games achieve a broad range of public. Most serious games are focused mainly on adults, and to a lesser extent on younger people. This audience diversification constitutes a powerful tool for communication and education about DRM.

Serious games provide a satisfying learning and training experience of disaster management (e.g. Safran et al., 2024; Zhao et al., 2023). However, some limitations have been described that can potentially limit their effectiveness. Firstly, although serious games are destined to a wide audience, few examples consider cultural diversity, gender equality and learning from past events (Solinska-Nowak et al., 2018). This limitation is important because adequate risk management demands participatory strategies involving communities (Tanwattana and Toyoda, 2018). Instead, few studies have addressed the development of diverse resiliency skills through serious games (Villagra et al., 2023; Teague et al., 2021; Neset et al., 2020), with the biggest research gap in serious games related to DRR is the lack of empirical evidence about their effectiveness, with a scarcity of quantitative and qualitative surveys (Solinska-Nowak et al., 2018; Safran et al., 2024).

3 Materials and methods

The approach to this study is qualitative, implies methodological triangulation and consists of primary research, supported by secondary research. The methodological triangulation employed in this paper permits an issue to be studied from more than one standpoint, thus creating a stronger and more complete account. The research methods include a content analysis of selected serious games, a focus group with experts and a literature review (which enabled the research constructs to be determined).

3.1 Qualitative content analysis of serious games

In order to answer the first research sub-question ("How do serious games communicate and educate on issues related to natural hazards?"), a qualitative content analysis was carried out on serious games for DRM.

We have selected digital games from the wide range of existing examples available. Firstly, we conducted a web search using common search engines including Yahoo, Google, YouTube, Vimeo and the Apple iTunes store, using different combinations of the following keywords: serious games, positive communication, simulation, role play, DRM, DRR, crisis management, emergency, disaster prevention and disaster mitigation. This search allowed us to find a total of 11 mobile apps, 6 online games and 20 board games with material available for download from the web (Table S1). Among the apps and online games we found 4 dedicated to volcanoes, 6 to earthquakes, and 7 related to floods.

Subsequently, in order to limit the scope of this study, we selected only non-commercial games with freely accessible content available in English or Spanish, with the necessary requirement of having a DRM focus in different situations, aimed at young people and adults (age 12 and upwards), with the disasters considered limited to those caused by human interactions with natural hazards (such as volcanic eruptions, earthquakes, floods, droughts, tsunamis, etc.). According to the criteria explained above, a total of 6 examples were selected in this phase from 17 digital games: 3 mobile apps (Earthquake Relief Rescue, Geostorm and Disaster Rescue Service) and 3 online games (Build a kit, Disaster Master and Stop Disasters). Among the former, we found two flooding apps (Geostorm and Disaster Rescue Service) and one focusing on earthquakes (Earthquake Relief Rescue). Regarding the latter, two of the online games considered various natural hazards in a detailed way at different

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levels (Disaster Master and Stop Disasters), while Build a Kit deals with emergencies due to natural hazards in a more generic way.

A content analysis of the selected games was then carried out, which is a research tool used for the quantifying and analysis of the presence, meaning and relationship between specific words, themes or concepts, and thus inferences to be made about the messages within the different analysis unit (e.g. webs sites, journals, games, etc). The type of content analysis in this research is conceptual analysis. In conceptual content analysis a concept is chosen for examination and the analysis involves quantifying and counting its presence. It is able to identify the intentions or communicative tendencies in the games; in turn, it describes the attitudes or behaviours that result from those communications, revealing patterns in communication content. The dimensions analysed in this study were those proposed by Ouariachi et al. (2017a). These authors adapted the theoretical of Social Discourse of Video Games Analysis Model (Pérez-Latorre, 2010) in an analysis instrument for games about climate change through the Delphi method. The instrument presents 51 criteria or variables, which are analysed in regards to the messages within the texts, audio, static and dynamic images of games. These criteria were classified into five dimensions: identification (features that help identify and locate the game), gameplay (set of properties that describe the player's experience within a given game system), narrative (discursive construction around a complex phenomenon), contents (analysis of the information and messages transmitted), and educational aspects (referring to competencies, skills and learning). These criteria are described in further detail in Table 1. The analysis of the games was carried out by the authors, who played the games and filled out a form containing the criteria mentioned above.

Table 1. Dimensions and indicators of qualitative content analysis.

Dimension	Indicators
Identification	– Name of game – URL/App – Type of creator (author and type of institution): *name and type of institution involved in the game's creation, and placement of the URL within an independent website or in a section of the producer/author's webpage or another webpage.* – Language – Communicative Objective: *communicative intentions and goals.* – Brief Description: *summary according to genre, objectives, and story.*
Narrative	– Narrative Relevance: *importance or irrelevance of narrative elements.* – Global Story: *description of the game's narrative as a whole, based on the logical or causal succession of events over a specific period.* – Character Representation: *role and characteristics of the character.* – Environment Representation: *the setting in which the character operates.* – Dimension / Space / Scale: *general context and scale of the scenarios.* – Dimension / Time: *period covered by the story.*
Contents	– Terminology used to describe natural hazards. – Presence of false concepts or misconceptions about natural hazards. – Explicit use of scientific concepts. – Convergence with other media and social networks*: links to social media platforms.* – Explicit use of information sources: *citing sources and origin of data.* – Message framework: *topics, causes/consequences, and tone of the message.* – Images.

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Gameplay	– Number of players and usage (individual or multi-player) – Player type: *profile tailored to their interests.* – Level of interactivity: *degree of user intervention, modification, and choice over the content.* – Duration of game – Game mission: *essential actions to win the game.* – Feedback system: *comments through text, audio, or audiovisual means received by the player for certain actions.* – Reward system: *actions that incentivize and the rewards themselves.* – Availability of instructions / possibility of saving game (yes, no)
Didactics	– Competencies: *Knowledge and attitudes attained by the student.* – Skills: *Mental operations achieved by the student.* – Conditions for problem-solving: *Type of reasoning employed to solve problems.* – Need for prior knowledge – Level of difficulty – Possibility of group work: *Refers to the ability to form a group of students around the computers.* – Accessibility: *Availability of the game for students with functional diversity.* – Interdisciplinarity: *Combination of two or more academic disciplines.* – Possibility of teacher evaluation: *The teacher can access the history of actions, intervention records, etc.*

3.2 Focus group with experts

In order to answer the second research sub-question, ("What are the educational and communicative elements or characteristics that serious games should have to improve DRM?) an expert focus group was created. An ideal focus group is composed of 6-10 participants and guided by a researcher who promotes participation. Focus groups are useful for supplying information on participants' opinions and feelings about an issue and assessing the reason for their point of view (Twining et al., 2017). Three characteristics permit this to be achieved: the open-ended question format, the closed environment of exchange and discussion, and enabling participants to share their opinions with others with the same interests and concerns (Jayanthi and Nelson, 2001). Firstly, a literature review allows the constructs of investigation to be determined. A combination of academic databases, including Web of Science, Scopus and Google Scholar was used for this purpose. The web search focused on identifying available research regarding the role of serious games in raising awareness of natural hazards and improving DRM.

The expert panel was very carefully chosen on the basis of knowledge or skill in the areas of either natural hazards and education or videogames. We employed a snowball sampling, asking the selected experts to recommend others who also matched our criteria. This study involved individuals with at least 5 years of professional or experiential knowledge of the research topic, constituting an informed panel and thereby justifying the use of the title "experts" (Mullen, 2003). Twenty-one international experts (from Spain, Italy, Brazil and USA) took part in the study, with the main areas of expertise of the participants structured into videogames (8 participants) and natural hazards and earth science education (13 participants) and the communication process was conducted online. The 62.5% of the videogame respondents were experts in video game design and the rest belonged to the areas of video game programming, development and production. As regards the surveys of experts in natural hazards, they present different natural hazards backgrounds (climate change, floods, earthquakes, volcanoes and mass movement) and professions (researchers, emergencies experts, a political and the partner of a consulting company in

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urban and territorial planning). To begin with, participants were informed through email about the focus and the approach of this study including the subject, goal, focus group description, planning and ethical issues, confidentiality and anonymity. The semi-structured discussions were conducted online thought open-ended questions and in a consensual way. The aim of this consensus was for the questions to allow the identification of indicators and criteria for the design of serious games on natural hazards in order to improve DRM. For this reason, we endeavoured to include specific questions, eliminating those that were similar, avoiding questions that were too open-ended and focusing on those that allowed for a relevant response to the topic of study. Two online semi-structured interviews (Tables S2 and S3) were created using Google forms, one addressed to natural hazards experts and earth science educators, and one addressed to video games experts. The survey was carried out from March 10 to May 20, 2022.

After sharing the interviews online, the experts in natural hazards and educators in earth science (13) responded during the first week. However, it was necessary to insist with 42 videogames experts to collect just 8 responds. Once all the responses had been collected, codes were formulated based on their analysis using the program MAXQDA (2020), because this software allowed the authors to analyse the qualitative data collaboratively, create a common language in our codebook and reach consensus while benefiting from the unique perspectives of each team member.

4 Results

4.1 Qualitative content analysis of serious games

Using the dimensions indicated in Table 1, the results of the analysis of each indicator are shown in Figure 1 and supplementary materials (Tables S4 to S8).

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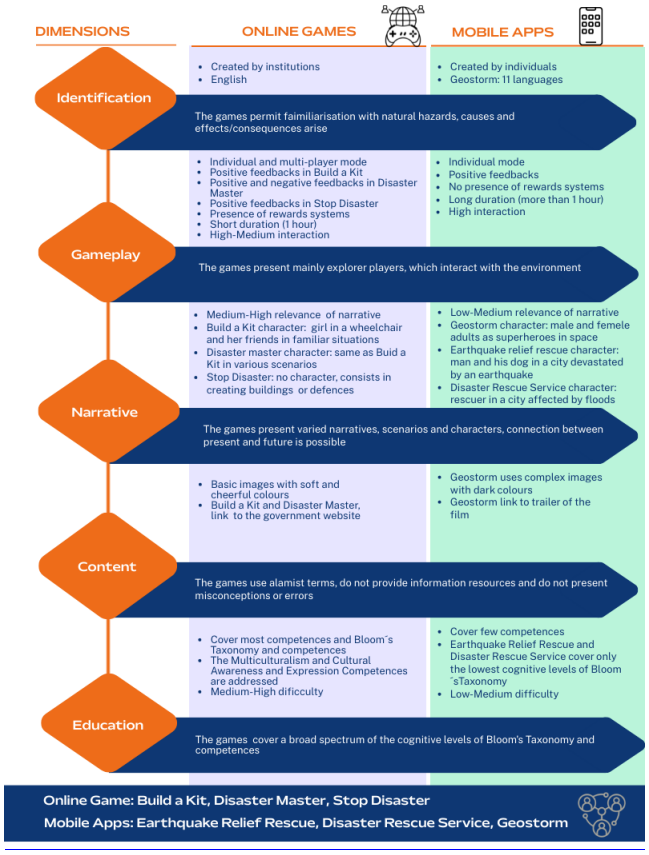

Figure 1. Results of the qualitative content analysis of serious games.

4.1.1 Identification

The results of the identification dimension can be found in Figure 1 and Table S4. We detected some differences between online games in regard to mobile apps. The selected game apps for phones and tablets are created by individuals; in contrast, in the case of the online games, they are created by institutions such as the US Government and the United Nations for Disaster and Risk Reduction. The language available in the games is English except in the case of Geostorm, which has a storyline based on a popular movie, and gives the option of 11 languages (Table S4). The communicative objective of the games

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analysed is to become familiar with natural hazards in general, to raise awareness of causes and consequences, to promote changes in attitude and develop ideas for action and prevention.

4.1.2 Game play

The results of the game play dimension are shown in Figure 1 and Table S5. The online games could be used both individual and multi-player mode, while in the case of the mobile apps only individual play is possible. The objective of Build a Kit is to select utensils from different scenarios, therefore decisions can be made through teamwork. Disaster Master consists of reading a story in the format of a comic book and answering questions in order to check knowledge acquired individually or as a team. Finally, in Stop Disasters, based on which buildings to build or improve, where to build hospitals, or which barriers to build against the natural hazards, can also involve teamwork.

The player trait most represented in the games analysed is explorer, with the creative trait also being found in Stop Disasters, where there is a high level of interactivity over the course of the game, giving players power to intervene in the content. In terms of game duration, there is a high degree of variability. The only example that could probably be completed in one hour is Build a Kit, while Disaster Master could also be completed in one hour, depending on student age and level of comprehension. The others games present levels that might also be played in one hour.

Positive feedback through messages that the player receives in light of certain actions, are abundant in the games, and we only found a reward system in the online examples. None of the games offer the possibility of saving progress in the middle of a level, but if you complete a mission or level, you can then continue in the next level at a later time, with the exception of Build a Kit.

4.1.3 Narrative

From the data examined, we observed different storylines, very different scenarios and a diversity of characters (Figure 1 and Table S6). We found characters shared between two of the games, as in the case of Build a Kit and Disaster Master, meaning that students could therefore see it as a continuation of the story, already know the characters. The scenarios used are diverse, with some as familiar to students as a teenage girl's bedroom or the living room and bathroom of a family home (Build a Kit), and others as removed as an international space station (Geostorm).

The game development locations cover different points of the planet. In the case of Disaster Master, a game created by the US government, the action takes place in different scenarios, all in US territory. Geostorm situates the player in different parts of the world such as Afghanistan, Dubai (United Arab Emirates) and Florida (US), according to the film on which it is based. Stop Disasters occurs in different parts of the world, depending on the natural catastrophe chosen, coinciding with the areas with the highest incidence of this natural hazard.

Present-future connection is addressed in most of the games. Only Earthquake Relief Rescue and Disaster Rescue Service focus their gameplay on a natural catastrophe that has already occurred and therefore the mission is limited to finding the injured, so players know the consequences. The situation of Geostorm is similar, with the natural catastrophe being in process

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and the consequences already experienced in the game, but action can still be taken to stop the catastrophe and restore normality. As can be seen, being based on a fictional film, Geostorm the game represents that fantasy and is less realistic than other games such as Disaster Master.

Finally, considering the types of players, we can highlight the great diversity present in the games analysed. The main character of Build a Kit is a girl in a wheelchair who faces the task of appropriate selection of utensils in an emergency situation, and Disaster Master presents the same character in a summer camp surrounded by her friends, each of a different origin. In the case of Geostorm, it also features both female and adult male characters in the role of superheroes.

4.1.4 Content

The results of the content dimension analysis are presented in Figure 1 and Table S7. As for the terms used in the games evaluated, we found rather alarmist examples such as "emergency", "catastrophe" and "disaster". The link to social networks in some of them is merely informative, as in the case of Geostorm, which directs to the trailer of the film on which it is based. In the case of Build a Kit and Disaster Master, we find that the link provided to the government website leads to a space where we can find more information on natural hazards, as an extension of the knowledge provided by the game.

In general, the majority of the games (Build a Kit, Disaster Master and Stop Disaster) are presented in basic images with soft and cheerful colours. The game with the best image quality and effects is Geostorm, which, simulating the special effects of the film, contains more complex images, although their colours are darker than in the rest of the games.

4.1.5 Learning implications

The results of the analysis of the educational dimension (Figure 1 and Table S8) show the great potential of the games, which cover a broad spectrum of the cognitive levels of Bloom's Taxonomy (reviewed by Anderson et al., 2001). Bloom's Taxonomy consists of a hierarchical structure of objectives or levels that allow educators to evaluate the learning process of students; it is also a useful starting point for designing activities to achieve meaningful and lifelong learning. Accordingly, the evaluation criteria related to "Remember" and "Understand" are classified as "Basic"; the criteria related to "Apply" and "Analyse" are catalogued as "Optimal"; and the criteria related to "Evaluate" and "Create" are classified as "Desirable". Taking into account these levels, the most complete are Stop Disasters, Disaster Master and Geostorm which cover all of them, however, Earthquake Relief Rescue and Disaster Rescue Service are the two games that cover only the Basic and Optimal learning levels.

Likewise, Disaster Master and Stop Disasters permit working with the key competences for lifelong learning according to the European education curriculum (European Commission, 2019). All the games analysed enable the obtaining of Citizenship Competence and Digital Competence. Build a Kit and Disaster Master enable the achievement of the Personal, Social and Learning to Learn Competence. In contrast, it is only possible to relate the Literacy competence to Disaster Master. Earthquake Relief Rescue and Disaster Rescue are the only games that do not work on the Mathematical, Science, Technology and

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The results of the game play dimension are shown in Table B5. The online games could be used both individual and collective way, while in the case of the mobile apps only individual play is possible. The objective of Build a Kit is to select utensils from different scenarios, therefore decisions can be made through teamwork. Disaster Master consists of reading a story in the format of a comic book and answering questions in order to check knowledge acquired individually or as a team. Finally, in Stop Disasters, based on which buildings to build or improve, where to build hospitals, or which barriers to build against the natural hazards, can also involve teamwork, thus making the game even more enjoyable. Therefore, these three online games offer further educational advantages over the mobile app examples.The player trait most represented in the games evaluated is explorer, with the creative trait also being found in Stop Disasters, where there is a high level of interactivity over the course of the game. These two characteristics are related, as it is necessary for players to interact with the environment to explore what is happening around them.In terms of game duration, there is a high degree of variability. The only example that could probably be completed in one hour is Build a Kit. Regarding the presence of levels rather than the whole game, the other games might also be played in one hour. Disaster Master could also be completed in one hour, depending on student age and level of comprehension.¶
Positive feedback abounds in the games and we only found a reward system in the online examples. None of the games offer the possibility of saving progress in the middle of a level, but if you complete a mission or level you can then continue in the next level at a later time, with the exception of Build a Kit.¶

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Engineering (STEM) competence. The Multiculturalism and Cultural Awareness and Expression Competences are addressed only by the online games (Build a kit, Disaster Master and Stop Disasters).

4.2 Expert focus group

Examples of videogames experts´ responses to the semi-structured interviews are shown in Table S9 and the analysed categories are shown in Table 2. Most of the videogame experts (63%) agree that the catastrophic/dramatic and adventure theme, teaching protocols for action and a possible escape dynamic are key elements in the design of a video game to raise awareness of natural hazards. In line with this catastrophic theme, some experts (33%) believe that the inclusion of the danger to human life element could enhance empathy on the part of players. Some experts (38%) add that it is also necessary for the game to be generally fun for children to want to play.

Table 2. Results of responses from video game experts.

	no. of votes	Importance
Elements		
Catastrophe	5	63
Adventure	5	63
Protocols	5	63
Escape	5	63
People/lives	3	38
Fun	3	38
Narrative/message	4	50
Cooperative	8	100
Character		
Socialiser	5	63
Explorers	3	38
Reward systems		
Recommended/satisfactory	2	29
Secondary	3	38
Feedback systems		
Positive feedback	2	25
Negative feedback	2	25
Positive and negative feedback	4	50
Duration		
Short	1	13
Variable	2	29
Level of interaction		

Deleted: 4.2.1 Videogames experts answers¶

Deleted: , and that it is always the message of the game that is fundamental to the educational intention (Table 1)

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Depend on narrative	4	43

The majority of the videogame experts (63%) agree that the most interesting type of character would be the socialiser in a cooperative game dynamic. They remark that for raising awareness of natural hazards, interacting and collaborating with other players who have been affected by the disasters could help to generate empathy. Similarly, some of them (33%) state that the profile of explorers is very interesting for this topic, since, being a natural phenomenon; it is also convenient for interaction with the environment.

The videogame experts recommend including reward systems because they increase engagement and fun. However, some (38%) remark that the reward system could be considered as a secondary element, claiming that by including it players may focus on the rewards and disconnect from the main objective, which is to raise awareness and increase knowledge about natural hazards. In the same way, according to some experts (13%), the abuse of the employment of levels and progression bars could distract from the main objective.

Some videogames experts (25%) agree that positive feedback is the most effective for motivation, but it would be interesting to include both positive and negative feedback so that players can see their actions have both good and bad repercussions. In this regard, these experts point out that the age of the students must be taken into account; if they are too young, it is more convenient to include positive feedback. However, as they advance in development and enter adulthood, it is advisable to include both. They also emphasise that in order to promote the acquisition of knowledge, feedback should always be constructive.

Regarding the duration of play, it should be a relatively short game, between 15 minutes up to several hours. This duration is recommended for both the full game and for the individual levels. The game can be longer, as long as it has concrete levels or scenarios that can be completed in a short period of time. Some experts (38%) emphasise that the most important element is the narrative of the game, which must engage players and that, where this is achieved, the length of the game can even be variable (Table 2).

Finally, the experts recommend there should be interaction in the game, as it generally engages players and makes it more fun. However, the code most represented in this question is narrative, given that in a serious game with a strong narrative the interaction can be lower and they can have a strong impact.

Examples of natural hazards experts´responses to the semi-structured interviews are summarized in Table S10 and the analysed categories are shown in Table 3. The natural hazards experts criticise the media for being too alarmist (46%), leading to uncertainty and focusing only on high-impact disasters once they have happened, which fails to enhance collective and individual prevention. In addition to this, they rarely contact university or technical experts, so they resort to misleading clichés. Therefore, the information they transmit is deficient (62%) and does not contribute to raising public awareness or to the acquisition of fundamental knowledge about natural hazards.

Table 3. Results of responses from natural hazards experts.

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Deleted: **Figure 1.** Responses from video game experts on the game feedback system. Each sector represents the relevance rating.¶ All of the experts agree that the game should have aspects based on curiosity, since curiosity leads to research, and research provides knowledge that allows us to provide solutions (Fig. 2). However, these aspects should be optional or very well integrated so that they are not forced or heavy. There are various responses to the question of randomness, with the experts commenting that chance aspects should not be included, as this diverts attention from what is important and leads players to experience the wrong stimuli. However, an abuse of chance can be frustrating for players, who feel they have no control over the game and may cause them to drop out, so this element should be balanced and not excessive.¶ ... [1]

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Deleted: **Figure 3.** Responses from videogame experts on the level of interaction. Each bar represents the relevance rating.¶ **4.2.2 Natural risk expert answers**¶

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	no. of votes	Importance (%)
Comunication		
Alarmist	6	46
Deficient	8	62
Inequalities		
Inequalities determinant	13	100
No dependent on vulnerability	2	15
Multiculturalism/gender		
Multiculturalis and gender important	10	77
Not important	3	23
Character		
Normal person	6	46
Eligible avatar	1	8
Not important	1	8
Sources of information		
Academic	11	85
Official institutions	2	15
Historical	1	8
Scientific communicators and journalists	2	15
Narrative and context		
Simple and non-technical	4	33
Saviour character	3	22
Past episodies	3	22

The natural hazards experts also agree that social and structural inequalities significantly condition the vulnerability of a territory or a society, since livelihoods, housing, etc. are often more vulnerable to natural hazards as well as access to training and information also being unequal. Therefore, a balanced society will be much more resilient as a whole than an unequal society. The experts suggest that video games could help to better understand natural hazards and raise awareness among players, i.e. they could be good training in prevention and vulnerabilities to natural hazards, providing information on self-protection, planning and emergency management in a playful and enjoyable way. Aspects of multiculturalism and gender should be included in the game, which must consider interracial, intercultural, disability and gender factors, as these are fundamental for any society. All cultures and genders should be included in video games given that the whole of society, without exception, can be affected. For this reason, the main character of the game on natural hazards should be an ordinary,

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responsible, coherent and supportive person, who has fears and faces them by learning, and who can also fail. In other words, a character with whom players can see themselves represented.

The natural hazards experts propose different sources of information to be used in natural hazard games such as historical sources and those from official institutions. However, the most important example is the academic source, in order not to introduce erroneous data or information.

In regard to the game narrative and context answers, most of the natural hazard experts opt for simple, non-technical narratives in order for players to become familiar with the language and feel that it is a real situation. They mention the figure of a saviour character in the face of natural hazards, making them aware of the resulting environmental and social problems. The last code present among the expert responses is the representation of past episodes related to natural hazards-related disasters that have occurred through time. In this way, they convey that natural hazards are things that have always existed and will continue to exist, reinforcing the idea they are real and have happened at different times in human history.

The tone of the message that should be used in video games about natural hazards presents some controversy (Fig. 2). The experts opine that an informative tone is important for transferring the information combined with an emotional tone to have a greater impact on the user, helping to raise awareness. All of the natural hazards experts reject the alarmist tone with the exception of two, who propose mixing the informative tone with the alarmist tone to prevent the former from being boring and causing indifference. Experts who suggest a purely informative tone also propose a clear and concise message based on science, so that players know what can really happen and how to act in an objective manner.

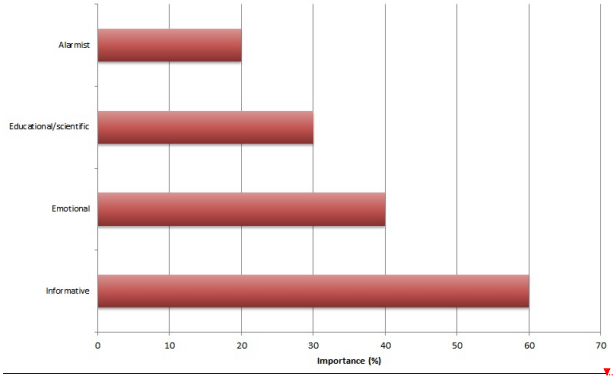

Figure 2. Responses from natural hazards experts on message tone. Each bar represents the relevance rating.

4.3 Integration finding

In this section, the findings of the methodological triangulation were compared – literature review, qualitative content analysis and expert focus group – and further summarised:

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Deleted: **Figure 4.** Responses from natural risk experts on narrative and context. Each bar represents the relevance rating.¶

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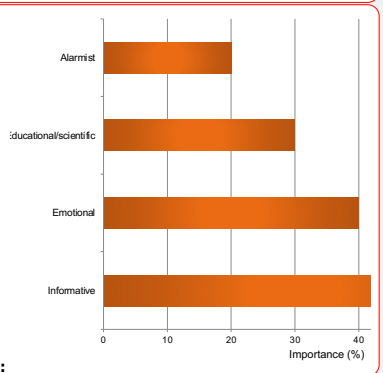

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4.3.1 Characters

The main characters of the game should be socialisers or explorers with characteristics of an ordinary person who reflects their fears and may fail, who also presents a saviour attitude. Multicultural and gender aspects should be included in the characters, along with the consideration of interracial and disability aspects. Games on natural hazards should take into account gender and cultural differences in order to reflect today's society.

The only game with a socialising character in a cooperative dynamic is Disaster Master. The three mobile apps, Geostorm, Disaster Rescue Service and Earthquake Relief Rescue all feature more exploratory characters. In this sense, Disaster Rescue Service and Earthquake Relief Rescue do present a cooperative dynamic, but there is no opportunity for interaction between players.

4.3.2 Information and message tone

Information should be presented in a non-alarmist and non-catastrophist way. The sources of information used for the development of the games should be mainly academic. The tone of the game message should be clearly informative, clear and concise. It should also have an emotional tone to connect with players.

The mobile apps present a more catastrophist and alarmist tone, with people's lives endangered and the adventure factor increased but without working on the narrative. However, Disaster Master also plays with this point of catastrophism and fun, and at the same time has a narrative that aims to transmit knowledge and teach protocols for action. Stop Disaster has message texts explaining in a very clear, concise and simple way the usefulness of each material to prevent the impact of natural hazards and how they should be used. Build a Kit bases its game on teaching protocols of action against a natural hazards-related disaster.

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4.3.3 Narrative, dynamics, reward systems and feedback

The narrative of the game should be simple and non-technical, and could represent past episodes. The videogame experts recommend a narrative based on a catastrophic/dramatic and adventure theme. The dynamics of the game should be cooperative. Reward systems and levels or game progression bars should be included secondarily. Feedback should be included taking into account user age, and positive feedback is especially important. The duration of the games should be between 15 minutes and several hours. The game always should be fun.

Build a Kit, Geostorm, Disaster Rescue Service and Earthquake Relief Rescue present only one reward system, which consists in completing the level or scenario where you are, choosing the right tools to make an emergency backpack, opening the office door to escape, or arriving in time to rescue an injured person. The other two games have game progression indicators and award points to the player when they choose the correct answer or construct a building in a suitable location, but always secondarily. All of the games have feedback systems for the players, and their lengths are within the recommendation of experts.

5 Discussion

5.1 Communication and education on natural hazards through serious games

Serious games analysed present highly varied narratives. In most of these games a connection is made between the present and the future, allowing players to be aware of the impact of their decisions and to experience them directly through the game. The central character is usually an explorer associated with a high level of interactivity over the course of the games. These two characteristics are related, as it is necessary for players to interact with the environment to explore what is happening around them.

Examples of positive feedbacks are common in the games and only online games present rewards systems, which incentivize users to obtain rewards through specific actions. The scenarios used are diverse, with some as familiar as our home (Build a Kit), and others as unfamiliar an international space station (Geostorm). Both cases could contribute to student motivation. Recognition of the familiar setting can increase empathy with and thus awareness of the situation. However, the surprise of the space station as a more spectacular setting can lead to greater motivation. The game development locations have great educational value, as each game situates players in a real area of the planet so they can relate to the natural hazards faced, which can be fixed from the beginning of the game (Stop Disaster). As all these places are real, the sensation of the true effects and consequences is easier to assimilate, therefore also facilitating awareness and promoting the acquisition of knowledge.

Few games consider the multicultural and inclusivity aspects, with only Build a Kit and Disaster Master presenting characters with different backgrounds and individuals with functional diversities, which can be connected to the previous findings of Solinska-Nowak et al. (2018). The inclusion of people with functional diversities, and even more so of young adolescents as the target group of the game, is important, as is that of young people from different backgrounds and cultures, no longer only as characters in the game, but as a group of friends who together provide a solution to a situation of risk. Geostorm present the possibility of playing in different languages, thus increasing the inclusivity; in addition, the characters, adult women as well as men, in the role of superhero, breaks the gender gap that we can easily find in many games where the hero figure is attributed to the male gender. In these cases, awareness-raising is much richer, as it encompasses aspects of knowledge of natural hazards, and also of tolerance, inclusion and social empathy.

Taking into account the learning performance, the results of the educational dimension show the great potential of games, which cover a broad spectrum of the cognitive levels of Bloom's Taxonomy (reviewed by Anderson et al., 2001). However, most of these games do not focus on explaining any scientific concepts about natural hazards, such as earthquake epicenter and floodplain, among others.

5.2. Educational and communicative elements recommended for improving DRM in serious games

The expert opinions are in line with the results of other studies on how to promote social resilience (Tanwattana and Toyoda, 2018; Kwok et al., 2016). In this sense, resilience could be encouraged with a cooperative dynamic, where democratic and collaborative decision-making and problem solving occur and community beliefs and values are shared, thus promoting

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collective efficacy. The use of simple and non-technical narratives based on academic information could promote natural risk knowledge and hazard consequence and therefore community preparedness for natural hazards. The multiculturalism, diversity and gender awareness that should be considered in the games could favour community inclusiveness in DMR and encourage a sense of community and attachment.

Regarding the socialiser or explorer characters desirable in DRM games, Safran et al. (2024) reveal that the players performance is related to the video game narrative and highlights the importance of character characteristics, so, high-powered avatars lead to a greater increase in attempts to adopt health-promoting behaviour. Klimmt et al. (2009) assert that players undergo significant changes in self-perceptions to align themselves with certain characteristics of such characters. Therefore, the identification with the character that players undergo can increase perceived self-efficacy concerning the acquisition of health-promoting behaviour (Peng, 2008).

The feedback in DRM games could be more efficient when based on a direct and specific information that achieves objectives and is presented close to that of the item being evaluated, and this feedback should be both positive and empowering (Prensky, 2001). Rewards systems are recommended because they enhance motivation and entertainment; however, too many of these could distract from the main objective of the game (Chou, 2015). In addition, an engaging game should be entertaining, in this way, players are more likely to play the game multiple times, thus keeping the issue active in their minds (Ouariachi et al., 2019).

Controversy of criteria between experts in relation to the tone of the message has been found. The natural hazards experts recommend a non-alarmist and non-catastrophist tone, while the video game experts agree on a catastrophic/dramatic tone. In this regard, self-efficacy may be diminished by the panic and stress provoked by perception of both the gravity of a hazard and one's own susceptibility to it, which is important for motivating risk-mitigating action (O´Neill, 2004). The natural hazards frequently provoke negative emotions, including denial and fatalism, which are counter to the problem orientation necessary in triggering risk-mitigating actions (Safran et al., 2024). However, Zhao et al. (2023) show that these negative emotions are necessary because they have a greater impact on decision-making than the positive emotional state. Therefore, well-designed video games could balance threats by offering ways to overcome them, incorporating mediated disaster-related problem-solving experiences (Safran et al., 2024).

6 Conclusion

In response to the need for engaging and motivational approaches to education and communication, videogames have been recognised as one of most useful strategies in teaching DRR (e.g. Hawthorn, 2021). However, the impacts of video games on players in order to improve DRM in citizens remain relatively unstudied (e.g. Safran et al., 2024). This study therefore presents new insights revealing how serious games could communicate and educate DRM more effectively.

In order to know how to communicate and educate more effectively in regard to natural hazards through serious games, this work determines the desirable characteristics that games should have through expert interviews. These desirable characteristics

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are: exploratory characters in a cooperative dynamic, with simple and non-technical narratives, based on academic sources, multiculturalism, consideration of diversity and gender, fun, short games and a constructive feedback system, with rewards in contrast having a secondary presence. These findings can be considered by videogames designers in order to create new natural hazards games that improve DRM.

The recommended features set out in this work were tested in the selected online games and mobile apps in order to discover the serious games that educate and communicate more effectively in DRM. In this sense, only the online games comply with the fundamental narrative highlighted by the experts in order to fulfil the educational function of the game. The apps focus their game dynamics more on interaction, both of the player with the game controls and of the character with the environment. This interaction could enhance the fun aspect of the game and therefore increase desire to play. Regardless, the educational aspects of online games is much greater, both in the explicit knowledge of the messages of the game, as well as in its dynamics and progress. In addition, only three online examples (Build a Kit, Disaster Master and Stop Disasters) work on issues of multiculturalism, diversity and gender, offering learning of value that is of great social importance, as well as geographically locating the areas where natural hazards are most likely to occur, thereby facilitating awareness. The results obtained in this work are intended to provide valuable guidance to teachers in selecting games for implementation in the classroom.

The limitations of this study are related to the subjective nature of qualitative analyses, due to their focus on interpreting meaning and the meaning-making process. Consequently, a methodical approach of triangulation (content analysis of selected serious games, a focus group with experts and literature review) was used to minimize this limitation (Ouariachi et al., 2017b).

This study is exploratory in nature, thus we encourage researchers to delve deeper into how videogames can enhance DRM. Further research could improve our understanding of how specific narrative and gameplay elements (e.g. collaborative or competitive, duration of game and feedback and rewards systems), mechanics (e.g., mission achievement, creating new resources, discovering clues), and characters (e.g. different player roles, character characteristics, selectable avatars) in disaster-related video games improve DRM education. In this sense, subsequent studies could concentrate on validating the effectiveness of the proposed features in enhancing behaviour change of citizens for improving adaptation and resilience to natural hazards.

Competing interests

The contact author has declared that none of the authors has any competing interests.

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Moved up [2]: The expert opinions are in line with the results of other studies on how to promote social resilience (Tanwattana and Toyoda, 2018; Kwok et al., 2016). In this sense, resilience could be encouraged with a cooperative dynamic, where democratic and collaborative decision-making and problem solving occur and community beliefs and values are shared, thus promoting collective efficacy. The use of simple and non-technical narratives based on academic information could promote natural risk knowledge and hazard consequence and therefore community preparedness for natural risk. The multiculturalism, diversity and gender awareness that should be considered in the games could favour community inclusiveness in DMR and encourage a sense of community and attachmentRegarding the game characters desirable in DRR games, Safran et al. (2024) reveal that the performance of players is related with the video game narrative and highlight the importance of character characteristics, so, high-powered avatars lead to a greater increase in attempts to adopt health-promoting behaviour. Klimmt et al. (2009) assert that players undergo significant changes in self-perceptions to align themselves with certain characteristics of such characters. Therefore, the identification with the character that players undergo can increase perceived self-efficacy concerning the acquisition of health-promoting behaviour (Peng, 2008).¶

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Controversy of criteria between experts in relation to the tone of the message has been found. The natural risk experts recommend a non-alarmist and non-catastrophist tone, while the video game experts agree on a catastrophic/dramatic tone. In this regard, self-effic ... [4]

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Deleted: **Appendix A. Games on natural hazards.** ¶
Table A1. Games on natural hazards found in the literature review. ¶
Game ... [5]

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Supplementary material S1: Games on natural hazards.

Table S1. Games on natural hazards found in the literature review.

Game	**Supplier / website**
Phone and table apps	
Sai Fah - The Flood Fighter	Opendream Co., Ltd.
Earthquake Safety Tips - How To Protect Yourself	BABYBUS CO., LIMITED
Seismic Safety - earthquake protection (available only in Chinese)	Zhi Yong Information
Earthquake Relief & Rescue Simulator	Atif Mumtaz
The Earth by Tinybop (payment required for download)	Tinybop Inc.
How It Works? (payment required for download)	Learny Land S.L.
Pompeii Run Volcano Escape	Big Goose Egg, LLC
Volcano Defense	Adknown Inc.
Geostorm	Talespin, LLC
Emergency hero flood rescue	Adeel Ahmad
Lifeboat Rescue - Save Life	Atif Mumtaz
Disaster Rescue Service	Syd Umer Aftab
Online games	
Build a kit	https://www.ready.gov/kids/games/data/bak-english/index.html
Disaster Master	https://www.ready.gov/kids/games/data/dm-english/
Earth Girl. The Natural Disaster Master (difficulty downloading game	https://earthgirl2.com/level-and-character-art/

content required to play the game on the PC)	
Earthquake Response (difficulty downloading game content required to play the game on the PC)	http://www.enabledgames.com.au/stc/
Extreme Event Game (min. 6 players)	https://learn.labx.org/ee-download
Stop Disasters	https://www.stopdisastersgame.org/
Act to adapt	https://www.climatecentre.org/games/2541/act-to-adapt/
Before the storm	http://petlab.parsons.edu/redCrossSite/rulesBTS.html#downloadsBTS
Buzz about Dengue	https://www.climatecentre.org/games/2530/buzz-about-dengue/
Cultural Memory Game: Earthquake and Flood version	https://culturalmemory.socialsimulations.org/
Board games with downloadable materials available	
Act to adapt	https://www.climatecentre.org/games/2541/act-to-adapt/
Before the storm	http://petlab.parsons.edu/redCrossSite/rulesBTS.html#downloadsBTS
Buzz about Dengue	https://www.climatecentre.org/games/2530/buzz-about-dengue/
Cultural Memory Game: Earthquake and Flood version	https://culturalmemory.socialsimulations.org/
Decisions for the decade	https://www.climatecentre.org/games/2520/decisions-for-the-decade/
Dissolving Disasters (especially because it involves communication and how to handle the moment)	https://www.climatecentre.org/games/2516/dissolving-disasters/
Evacuation Board Game	http://www.floodsite.net/juniorfloodsite/html/en/student/thingstodo/games/boardgame.html
Evacuation Challenge Game	https://evacuationchallenge.socialsimulations.org/

Evacuation Role Play Game	http://www.floodsite.net/juniorfloodsite/html/en/student/thingstodo/games/roleplayinggame.html
Flood Resilience Games	https://floodresilience.socialsimulations.org/
Game of Floods	https://www.marincounty.org/depts/cd/divisions/planning/csmart-sea-level-rise/game-of-floods
Gender and Climate Game	https://www.climatecentre.org/games/2510/gender-and-climate-game/
Gifts of Culture: Diversity in the context of flood resilience	https://giftsofculture.socialsimulations.org/en/
Lords of the Valley: Experience and explore sustainable practices in complex environments	https://lordsofthevalley.socialsimulations.org/
Paying for Predictions	https://www.climatecentre.org/games/2501/paying-for-predictions/
Ready!	https://www.climatecentre.org/games/2497/ready/
Riskland	https://www.unisdr.org/2004/campaign/pa-camp04-riskland-eng.htm
Save Natalie! The preparedness game	http://helid.digicollection.org/en/d/Jdnd24/5.html
Upstream Downstream	https://preparecenter.org/resource/the-upstream-downstream-game-2/
Weather or Not	https://petlab.parsons.edu/redCrossSite/rulesWON.html

Supplementary material S2: Questions in semi-structured interviews

Table S2. Questions for experts in video games in semi-structured interview.

Q1. What characteristics/elements should a video game about natural hazards have to raise awareness among users?
Q2. Which do you think is more efficient for raising awareness among users, a cooperative or competitive video game? Why?
Q3. Which type of player would create more empathy among users? * Bartle's taxonomy presents 4 types of players: Killers (action with other players), Socializers (interaction with other players), Achievers (action with the world), and Explorers (interaction with the world) (Bartle, 1996).
Q4. Would including a reward system in a video game about natural hazards help engage users? Why?
Q5. Do you believe that including levels, progress bars, etc., to track the progression and development of a video game about natural hazards would motivate users? Why?
Q6. Does a system of positive feedback make a video game more appealing? Or would a system that combines positive and negative feedback be more suitable for raising awareness among users? Why? *Positive feedback is understood as the positive stimulus that the game displays to the player when they perform well, such as messages on the screen congratulating them. *Negative feedback is understood, predictably, as the opposite of positive feedback.
Q7. What would be the ideal duration of a video game to engage users?
Q8. Is the level of interactivity of a video game about natural hazards crucial to achieving its objective? In what sense?

Table S3. Questions for experts on natural hazards in semi-structured interview.

Q.1. How would you describe the current communication occurring in the media about natural hazards? Do you believe this communication effectively raises awareness among citizens about natural disasters? Why or why not?
Q.2. Do you believe that structural inequalities determine the level of vulnerability to natural hazards? If so, how? What role could video games play in addressing society's vulnerability to natural hazards? (*Structural inequality is understood as a system of privileges created by institutions within an economy (Amadeo, 2020).
Q.3. Should aspects of multiculturalism and gender be included in video games about natural hazards? If so, which ones and why?
Q.4. How should the main character of a video game about natural hazards be represented? What characteristics should they possess?
Q.5. What type of informational sources should a video game about natural hazards be based on? For example: academic sources, journalistic sources, etc.
Q.6. What type of narrative, what storyline that contextualizes the game, would be most effective in raising awareness about natural hazards?
Q.7. What tone of message would be most effective to use in a video game to improve disaster risk management? For example: alarmist, informative, emotional, etc.

Supplementary material S3: Results of the qualitative content analysis of serious games.

Table S4. Results of identification dimension.

Name of game	URL/App	Type of creator	Language	Communicative objective	Brief description
Build a Kit	<https://www.ready.gov/kids/games/data/bak-english/index.html>	Official Website of the United States Government	English	Developing familiarity with subject matter and acquiring knowledge about how to react to disasters.	Various questions to answer that promote reflection on how to act in those circumstances.
Disaster Master	<https://www.ready.gov/kids/games/data/dm-english/>	Official Website of the United States Government	English	Developing familiarity with subject matter and acquiring knowledge about how to react to disasters.	Various questions included in a narrative to answer in order to verify comprehension of story and promote reflection on how to act in face of natural hazards.
Stop Disasters	<https://www.stopdisastersgame.org/stop_disasters/>	Website of the United Nations Office for Disaster Risk Reduction (UNDRR)	English	Developing knowledge of prevention to decrease probability of disaster.	Simulation in which player creates territory with lower probability of experiencing natural hazard, analysing buildings within it.
Earthquake Relief Rescue +	App	Atif Mumtaz	English	Developing knowledge related to topic.	Simulation in which victims of an earthquake are searched for and rescued in a city that has been devastated, with assistance of a dog.
Disaster Rescue Service	App	Syd Umer Aftab	English	Developing knowledge related to topic.	Simulation in which victims of a major flood are searched for

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					and rescued using a boat or a helicopter.
Geostorm	App	Talespin	English, French, German, Polish, Portuguese, Russian, Italian, Spanish, Turkish, Chinese, Hungarian	Familiarisation with mode of operation.	Player surpasses various levels to escape from a building destroyed by a natural hazard.

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Table S5. Results of gameplay dimension.

Name of game	Build a Kit	Disaster Master	Stop Disasters	Earthquake Relief Rescue +	Disaster Rescue Service	Geostorm
Number of players and usage (individual or multi-player).	1, for individual or multi-player use	1, for individual or multi-player use	1, for individual or multi-player use	1, for individual use	1, for individual use	1, for individual use
Type of player.	Explorer	Explorer	Explorer / creator	Explorer	Explorer	Explorer
Level of interactivity.	High	Medium	High	High	High	High
Game duration.	Depending on prior knowledge, from 15 minutes to 1 hour.	From 45 minutes to 1.5 hours or more.	One session, one hour; the entire game, days.	More than an hour. Days.	More than one hour. Days.	More than one hour. Days.
Game mission.	The aim of the game is to select the correct tools to survive a disaster; if you do not select them or choose the wrong ones, you will not progress to the next scenario.	The objective is to verify that the player understands how to react to disasters or prevent risks from the comic by asking questions about things that have been said in the story. If you answer too many questions incorrectly, you lose the level and have to start over. At the end of a level, you receive a password that allows you to play the next level.	The mission is to invest the starting money that the player has in improving the resilience of buildings, creating buildings to protect the entire population, or building defences. The game indicates the probability of the catastrophe occurring, which increases over time until it happens, and you check if you have saved lives with your modifications or not.	The aim of the game is to guide the rescue dog to the trapped person using the mobile phone/tablet controls.	The objective of the game is to use different vehicles to find people who need to be rescued.	The mission of the game is to guide the character through a scenario affected by a natural hazard finding the exit from different rooms and searching for the documentation necessary to restore Earth's protection.
Feedback system.	Positive	Positive and negative	Negative	Positive	Positive	Positive
Reward system.	Yes, next level.	Yes, next level and game points.	Yes, congratulations on saving lives and game points.	No	No	No
Availability of instructions / possibility of saving game (yes, no)	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No	Yes/Yes

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Table S6. Results of narrative dimension.

Name of game	Build a Kit	Disaster Master	Stop Disasters	Earthquake Relief Rescue +	Disaster Rescue Service	Geostorm
Relevance of narrative	Medium	High	Medium	Low	Low	Medium
Global History	The player joins Gayle and her friends in aiding them to gather supplies in preparation for an emergency. The player progresses through various levels in which they must select the appropriate tools for themselves and their family to survive a natural hazard.	The overarching framework is the narrative of a comic-style story in which you have to answer various questions about natural hazards to earn points. There are eight different levels, so if you score enough points to complete a level, at the end of it, you receive a password that allows you to move on to the next level. Each level deals with a different natural hazard.	At the beginning of the game, you must choose a natural hazard; tsunami, hurricane, fire, earthquake, or flood; and thereafter build upon an already established community to provide defense and enhance structures for the inevitable natural hazard that is to come.	A major earthquake has struck the city, roads and buildings are destroyed, and there are various injured individuals in need of rescue. With the assistance of a trained dog, the task is to locate these injured individuals.	The player acts as a rescue services specialist, saving lives and assisting individuals affected by floods in a large city by transporting them to a safe area.	Following the sabotage of a network of weather satellites that protect the Earth, a series of meteorological catastrophes are destroying several cities worldwide. The game involves gathering essential data to prevent a geostorm and escape from the affected areas.
Representation of character	Gayle, a girl in a wheelchair, and her friends are a group of teenagers from diverse ethnic backgrounds.	Once again, it is Gayle and her friends: Raina, Sonny, Misti, Ray; in various scenarios where they encounter numerous natural hazards.	There is no character	A man and his dog, without mentioning any names.	Various impersonal characters: helicopter or boat pilot, doctor, and rescuer.	A SataCorp office worker in Dubai, an astronaut stationed at the ISS IV, a communications officer in the special forces, and an atmospheric weather analyst.
Representation of environment	Different settings: Gayle's room, a family living room, a	Each level unfolds within a distinct environment, contingent upon the phenomenon.	Populations are depicted in the following locations according to the	A city devastated by an earthquake.	Simulation of Los Cantos City	SataCorp offices in Dubai, International Space Station IV, a remote village in

Eliminado: Supplementary material S34: Results of narrative dimension in the qualitative content analysis of serious games.¶

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Eliminado: The overarching framework is the narrative of a comic-style story in which you have to answer various questions about natural disasters to earn points.

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	family bathroom, and a convenience store.	The wildfire occurs at a summer camp in Colorado; the tornado strikes at a high school in Iowa; the hurricane ravages Louisiana; the house fire erupts in Connecticut; the winter storm/freezing occurs in Iowa; the tsunami hits Hawaii; the earthquake shakes California; the lightning storm occurs in a park in Iowa; and the heatwave does not specify a location.	natural hazard; for the tsunami, one in Southeast Asia; for the earthquake, one in the eastern Mediterranean; for the flood, one in Central-Eastern Europe; for the wildfire, one in central Australia; and for the hurricane, one in the Caribbean. The populations are represented in a somewhat unrealistic manner.			Afghanistan, and a warehouse complex in Orlando, Florida.
Dimension/ Space/ Scale	Fictitious / local	Real/local.	Real sites, fictional/local	Fictitious / local	Fictitious / local	Fictitious / local
Dimension/ Time	Present	Present	Present	Present	Present	Present

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Table S7. Results of contents dimension.

Name of game	Build a Kit	Disaster Master	Stop Disasters	Earthquake Relief Rescue +	Disaster Rescue Service	Geostorm
Terminology employed to describe natural hazards.	Emergency, disaster	Disaster, wildfire, tornado, hurricane/blackout, home fire, Winter storm/extreme cold, tsunami/earthquake, thunderstorm/lightning	Disaster, tsunami, hurricane, wildfire, earthquake, flood	Earthquake	Disaster, flood	Thunderstorm, alert, emergency
Presence of misconceptions or errors regarding natural hazards.	No	No	No	No	No	No
Explicit use of scientific concepts.	No	Wildfire, tornado, hurricane/blackout, winter storm/extreme cold, tsunami/earthquake, thunderstorm/lightning	Tsunami, hurricane, wildfire, earthquake, flood	Earthquake	Flood	Thunderstorm
Convergence with other media and social networks.	Government website: https://www.ready.gov/kids	Government website: https://www.ready.gov/kids/disaster-facts	No	No	Facebook, Youtube	Youtube
Explicit utilization of information sources.	No	No	No	No	No	The film "Geostorm"
Message framework	*Themes:* Preparedness for emergency or natural hazard. *Consequences:* Not knowing how to react can lead to	*Themes:* Natural hazards can occur in any environment and situation. *Consequences:* Knowing certain actions such as prevention or reaction to natural hazards is necessary to avoid a catastrophe.	*Themes*: Defences and improvement of buildings to prepare for the inevitable disaster. *Consequences:* These actions can save lives.	*Themes:* An earthquake has shaken the city, leaving roads and buildings in ruins. *Consequences:* There are people trapped who will die if they are not rescued.	*Themes:* Excessive rainfall has flooded an entire city. *Consequences:* There are many people who need to be rescued at various points in	*Themes*: A network of weather satellites protecting the Earth has been sabotaged. *Consequences:* Cities worldwide are being destroyed by meteorological

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	disastrous consequences.				the city via helicopter or boat.	catastrophes. Essential data must be collected to prevent a geostorm.
Images	Static drawings of a teenage girl's bedroom, a family living room, a family bathroom, and a variety store.	Drawings of various scenarios in a comic style.	Basic pixelated drawings of villages.	Scenario of a destroyed city.	Scenario of a flooded city.	Different scenarios previously specified in other sections with high-quality graphics.

Table S8. Results of educational dimension.

Name of game	Build a Kit	Disaster Master	Stop Disasters	Earthquake Relief Rescue +	Disaster Rescue Service	Geostorm
Competencies	CC, DC, PSL, CAE	MC, CC, DC, PSL, CAE, STEM.	STEM, CC, DC, CAE.	DC, CC.	DC, CC.	DC, STEM, CC.
Skills	Remember, understand, apply, analyse.	Remember, understand, apply, analyse, evaluate.	Remember, understand, apply, analyse, evaluate, create.	Remember, understand, apply.	Remember, understand, apply.	Remember, understand, apply, analyse, evaluate.
Problem-solving conditions	Productive reasoning, memory.	Productive reasoning, memory.	Productive reasoning, creativity.	Productive reasoning.	Productive reasoning.	Productive reasoning, creativity.
Need for prior knowledge	No	No	No	No	No	No
Level of difficulty	Medium difficulty	Medium difficulty	High difficulty	Low difficulty	Low difficulty	Medium-low difficulty
Possibility of working in groups	Yes	Yes	Yes	No	No	No
Accessibility (possibilities for people with functional diversity)	No	No	No	No	Yes	No
Interdisciplinarity: *combination of two or more academic disciplines*	No	Yes	Yes	No	No	Yes
Possibility of teacher evaluation	Yes, through correct answers.	Yes, through accumulated points.	Yes, through a life-saving score.	No	No	No

Note: Digital competence (DC); Citizenship competence (CC); Mathematical, Science, Technology and Engineering competence (STEM); Personal, social and learning to learn competence (PSL); Multilingualism competence (MC); Cultural awareness and expression competence (CAE)

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Supplementary materials S4. Response of the experts

Table S9. Response of the videogames experts

Q1. What characteristics/elements should a video game about natural hazards have to raise awareness among users?
I think the most important thing is for a video game to be fun given that if this aspect isn't satisfactory no one is going to finish it. I think it would be important for the game to be fun and have an accompanying narrative in order to be able to introduce the topic through it.
Replicate its disaster film equivalent, with escape dynamics, where devastation is represented, in material and human life terms, and the dramatic consequences of both. Maybe show the player the protocols that exist for each natural hazard, but in a very subtle way integrated into the narrative. People need to empathise, in order to understand and become aware.
It's important to include it mainly when designing levels in adventure games.
Q2. Which do you think is more efficient for raising awareness among users, a cooperative or competitive video game? Why?
Cooperation involves collaboration for a greater purpose. It has components much more connected to socialisation and empathy.
In this case cooperative, because pressure should come not from what other players are doing, but from the possible catastrophe.
Q3. Which type of player would create more empathy among users? * Bartle's taxonomy presents 4 types of players: Killers (action with other players), Socializers (interaction with other players), Achievers (action with the world), and Explorers (interaction with the world) (Bartle, 1996).
Explorers, they could have a first person experience without searching for a specific objective.
I suppose if the aim is to raise awareness about climate hazards, interact with other users, requiring collaboration in order to help each other or others affected by these natural hazards it would help to generate more empathy (socializers).
Q4. Would including a reward system in a video game about natural hazards help engage users? Why?
In a video game there are always rewards, be they visual, auditive, prize related, etc. In this case I think that it would be enough for the game to be fun and for you to see a positive visual change that players find satisfying. Seeing that your actions create a positive change in an environment is a reward in itself, it wouldn't be necessary to add external prizes.
Yes. The reward system is one of the most effective methods for keeping users in a video game. It is important for the player to get to the end in order to transmit the complete message. Although this can be achieved with a good narrative, it is always recommendable to add a further element that can keep them engaged, such as a reward, either for using in the game itself (better weapons, special skills, collectables...) or outside of it, such as the well-known Trophy system, which allows players' friends to see what their colleagues have achieved.
I wouldn't include it, it would distort the message intended, making it somewhat secondary to the reward they want to obtain.
No. I would focus the game on a narrative experience without rewards or monetisation. Both would disconnect the player from what is truly important.
Q5. Do you believe that including levels, progress bars, etc., to track the progression and development of a video game about natural hazards would motivate users? Why?
Anything visual is better than text. It is essential to show player progress.
No. It is more or less the same for monetisation and progress. It can potentially distract the player from the intended message.
Q6. Does a system of positive feedback make a video game more appealing? Or would a system that combines positive and negative feedback be more suitable for raising awareness among users? Why? *Positive feedback is understood as the positive stimulus that the game displays to the player when they perform well, such as messages on the screen congratulating them. *Negative feedback is understood, predictably, as the opposite of positive feedback.
Preferably a system with positive feedback. In the majority of cases players need positive feedback on what they do.
Depending on the game concept. There are games that play with this moral duality, where acting in one way or another affects the story, playability and/or character skills.
Depends on the age of the target audience, from a certain age it is convenient for there to be both.

The game should provide positive and negative feedback, otherwise it's just a little distraction that won't be remembered.
As long as comments are constructive it doesn't matter whether they're positive or negative.
Q7. What would be the ideal duration of a video game to engage users?
Relative. But it always needs to be taken into account that the first 15 mins of a game are where the player-game synergy is defined.
For a game of this type whose aim is to raise awareness I´d say that a short duration may be more effective, and focused on the subject you want to deal with (2-4 hours) rather than a long game.
There's no ideal duration, it depends on many things such as re-playability, whether or not it focuses on the narrative, the desired topics... For a game of this type whose aim is to raise awareness I´d say that a short duration may be more effective, and focused on the subject you want to deal with (2-4 hours) rather than a long game.
It would be better to have a game for casual players that engages them to play for short periods over a number of days.
Q8. Is the level of interactivity of a video game about natural hazards crucial to achieving its objective? In what sense?
It depends, there are games with a considerable narrative component that don't need much interaction, they're more like visual novels, and the story itself can have a great impact.
Games where the narrative is secondary, interactivity is the most essential aspect. Generally all games with quick sessions. The story is almost non-existent and develops more outside the game via the online community than during the game itself.
Yes, as long as the video game is focused on showing these natural hazards and seeing the consequences of our actions.
It's normally easier to make an interactive game fun and motivating than a non-interactive one.

Table S10. Response of the natural hazard experts.

Q1.How would you describe the current communication occurring in the media about natural hazards? Do you believe this communication effectively raises awareness among citizens about natural disasters? Why or why not?
No, Because it´s too alarmist and focus and focuses on catastrophes when they happen, insted of enhancing collective and individual prevention.
1) I don't think the media do enough research and only transmit alarm and uncertainty. 2) No. 3) the fear and alarm generated by the media in general (there are outlets that do do this through specialist researchers) don't help to raise awareness in the population as regards seismic phenomena, they only create anxiety. If they were transmitting information on what to do in the event of an earthquake and what institutions are doing, it would be a different matter.
Highly lacking. Although many journalists take the time to contact academic or technical experts in the subject, there are many others who give a voice to politicians or members of the general public who lack knowledge, and who resort to erroneous topics such as the need to drag rivers, remove vegetation from their banks, etc...
Q2.Do you believe that structural inequalities determine the level of vulnerability to natural hazards? If so, how? What role could video games play in addressing society's vulnerability to natural hazards? (*Structural inequality is understood as a system of privileges created by institutions within an economy (Amadeo, 2020).
Inequalities in society create different degrees of vulnerability because the means of life, housing, etc. of the most disadvantaged such as access to training and information is also unequal. Video games are an "attractive" format that can help to promote means of self-protection and knowledge of hazards.
I think inequality is directly related to vulnerability and it shouldn't be this way. The greater the vulnerability the greater the hazard. We can only reduce the vulnerability hazard, because the earthquake can't be removed from the equation. Video games could be good training in prevention, as they could provide information on self-protection, emergency planning and management.
Yes, obviously structural as well as social inequalities have a significant bearing on the vulnerability of a territory or society. An equal society will be much more resilient as a whole than an unequal society.
Inequalities do determine the level of vulnerability. · Video games can help to provide better knowledge of natural hazards and raise awareness.
Physical vulnerability can increase in the face of inequalities, but there are structural vulnerabilities that will affect everyone equally, telecommunications, lack of electricity, destruction of productive fabric, etc.
Q3. Should aspects of multiculturalism and gender be included in video games about natural hazards? If so, which ones and why?
Of course, different languages, including interracial, multicultural and gender related aspects. Without forgetting the inclusion of people with different disabilities.
Yes, all cultures and genders must be included in video games given that the whole of society, without exception, may be affected.
The level of exposure to hazards depends on awareness and investment. In terms of awareness, it depends on the age range that consumes video games.
Q4.How should the main character of a video game about natural hazards be represented? What characteristics should they possess?
A normal person.
A normal, responsible, coherent and supportive person.
They should be represented as an average person, with fears, who confronts them while learning at the same time. If they fail, they learn, that is they can fail and stop being afraid of failure. Nowadays it seems that failure is frowned upon in society and our lives must be shown as perfect and idyllic, creating personal frustration.
I don't think the best option would be for this character to be customisable, that is, that you could choose anything from gender to bodily characteristics so that both children and young people (although it is evident that any person can participate) were able to choose the one they identified with.
They could be a man and a women who weren't excessively brave, fearful but calm and respectful towards the given recommendations. Look for characters the population can relate to and respect

for the recommendations given. Look for characters the population can relate to.
I don't think this is a determining factor.
Q5.What type of informational sources should a video game about natural hazards be based on? For example: academic sources, journalistic sources, etc.
Undoubtedly academic.
To create the video game I would use academic sources, science communicators and maybe science journalists so that between all of them a message is created based on scientific facts but in a language that reaches the target audience.
Academic and official institutions responsible for civil protection.
Historical and academic.
Q6.What type of narrative, what storyline that contextualizes the game, would be most effective in raising awareness about natural hazards?
It should be a simple, non-technical narrative, to make the message clear and concise for the population.
I suppose the player should be placed in a role of saviour from natural disasters, putting them in the face of environmental and social problems that arise.
Maybe speak about previous episodes, analyse them (what's happening, what needs to be done) and create an episode for carrying out that which has been learnt and making them see that natural disasters occurred in the past and could happen again.
Q7.What tone of message would be most effective to use in a video game to improve disaster risk management? For example: alarmist, informative, emotional, etc.
I imagine that the most effective message is the informative type, based on knowledge. In reality ecosystems undergo important fluctuations in their working, and only when humans (as ignorant or selfish creatures) interact with this territory inadequately, these fluctuations turn into natural disasters. In other words, if we understand the function of ecosystems and adapt to them (instead of wanting ecosystems to adapt to us) natural hazards cease to exist.
Alarmist and emotional tones should be avoided. As I said before, the message must be clear, concise and based on science. Society should know what could happen and how to act objectively depending on the circumstances. An alarmist message will only create panic and rejection.
Neither totally alarmist, which leads to rejection, nor informative, which produces indifference.
Informative and emotional, with messages based on science that have and impact and drive people to increase their impact and awareness.