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Learning about post-disaster phases via ludic activities: A case study of Santiago, Chile

Diana Contreras [a,b,c,1,*]

[a] School of Earth and Environmental Sciences, Cardiff University, Main Building, Park Place, CF10 3AT, Cardiff, United Kingdom
[b] School of Engineering, Newcastle University, 2nd Floor Drummond Building, NE1 7RU, Newcastle Upon Tyne, United Kingdom
[c] Research Centre for Integrated Disaster Risk Management (CIGIDEN), ANID/FONDAP/15110017, Av. Vicuña Mackenna 4860, Macul, Edificio Hernán Briones, 3er Piso Campus San Joaquín, UC, 7820436, Santiago, Chile

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ABSTRACT

On February 27, 2010, a magnitude 8.8 Mw earthquake struck Chile and provoked a tsunami that wreaked havoc on the Chilean coast. A total of 830 failures in the transportation system were registered on roads, with 91 concession bridges and 221 public bridges suffered damage or collapsed. This study aims to test a methodology for teaching people about the characteristics of each post-disaster phase concerning road infrastructure and business continuity. The methodology is based on ludic activities designed as a non-structural mitigation action to reduce cascading risk and enhance business continuity. Activities include answering questions related to experiences with earthquakes, completing puzzles as a metaphor of a city during the reconstruction process and associating scale models of vehicles and machinery with a specific post-disaster phase. The methodology was tested with Chilean high school students aged 11 to 15. Answers from the participants indicate that girls were more aware of protection techniques during earthquakes than boys. In contrast, boys were more mindful of terminology and engaged in decision-making activities. The similarity between completing a puzzle and a city in reconstruction after an earthquake was easy for participants to understand. Initially, participants only identified relief as a post-disaster phase but did not recognise the other post-disaster phases of early recovery, recovery and development. After the workshop, they managed to identify vehicles related to the relief phase, some vehicles and machinery related to the early recovery and recovery phases, and others that can be used in more than one or two post-disaster phases.

1. Introduction

In the late 2000s, empirical data demonstrated that the cascading risk resulting from potential disruptions in interdependent systems after natural phenomena is not as exceptional as previously believed. Research studies have provided new evidence of the disruption to social, economic and cultural dimensions, with cross-scale implications for humanitarian relief and global supply changes [1]. Chile is located in the extreme south of South America and lies in the Pacific Ring of Fire, which poses a high seismic hazard. At 03:34 on February 27, 2010, a magnitude 8.8 Mw earthquake struck the country. The earthquake's epicentre was located 325 km southwest of Santiago (35 km depth), and Concepcion, the second-largest city in Chile, was the most affected area [2]. This earthquake

* School of Earth and Environmental Sciences, Cardiff University, Main Building, Park Place, CF10 3AT, Cardiff, United Kingdom.
E-mail addresses: contrerasmojicad@cardiff.ac.uk, contrerasmojicad@cardiff.ac.uk.
[1] Permanent address: Cardiff University, Research office 1.18, Main Building, Park Place, CF10 3 AT, Cardiff, United Kingdom (UK).

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also triggered a tsunami in which waves hit the Chilean coast before travelling to Peru and westward past Hawaii to Japan and New Zealand [3]. The impact of the earthquake and tsunami produced 547 casualties, 46 missing people and 160,000 destroyed houses as well as damage to 1.5 million houses [4], 4,013 schools, and 79 hospitals [5].

Approximately 300 of the 12,000 highway bridges in Chile were damaged, including 20 with collapsed spans [6]. Three bridges along the Panamericana Chilean Highway (Autopista nr. 5) and roads in the country's interior were affected [2]. The Puente Viejo Bridge that crosses the Bio-Bio River in Concepcion also collapsed. In Santiago, the Paso Miraflores Bridge was affected at several points along the Vespucio Norte Highway, and a section of the same highway was displaced. The Chilean section of the Panamericana Highway bridge over the Claro River was also affected. A total of 830 failures in the transportation system were registered on roads in public and private transportation networks [7], while 91 concession bridges and 221 public bridges suffered damage or collapse. Economic losses were estimated at US$30 billion [8], equivalent to approximately 17% of the Chile's gross domestic product (GDP). The cost of repairing the damage to the road infrastructure was estimated at US$850 million. The emergency and reconstruction programme of the Ministry of Public Works (MOP) estimated that approximately US$500 million was needed to repair the public road infrastructure [7]. On March 10, 2010, the MOP announced that the rehabilitation of damaged roads, airports, dams, canals, bridges and water towers would cost US$1.2 billion. However, to my best knowledge, there has not yet been an assessment of the losses caused by the business interruptions that resulted from these failures in the road network. After the earthquake, the Chilean government declared six regions as zones of catastrophe: Valparaiso, Metropolitana, Libertador, O'Higgins, Araucania, Maule and Bio-Bio [2,9]. These regions are presented in Fig. 1.

This study tests a methodology for teaching young people the characteristics of each post-disaster phase concerning road infrastructure and business continuity via ludic activities using puzzles and scale models of vehicles and machinery. Using puzzles derives from urban planning workshops oriented towards learning about land use via game pieces. The puzzles test interaction among participants and the capacity to plan and organise the pieces. Participants can then appreciate the difficulties in forming agreements and attaining specific goals during post-disaster recovery efforts to reconstruct a city. The idea of using emergency cars, construction machines, different forms of transport, and recreational vehicles came from my experience of monitoring recovery processes after earthquakes over time in the urban environment [10–14]. Changes in the urban environment can be identified by fieldwork or satellite images [11], and I discovered that road traffic and vehicle circulation are spatial indicators of post-disaster recovery progress [13].

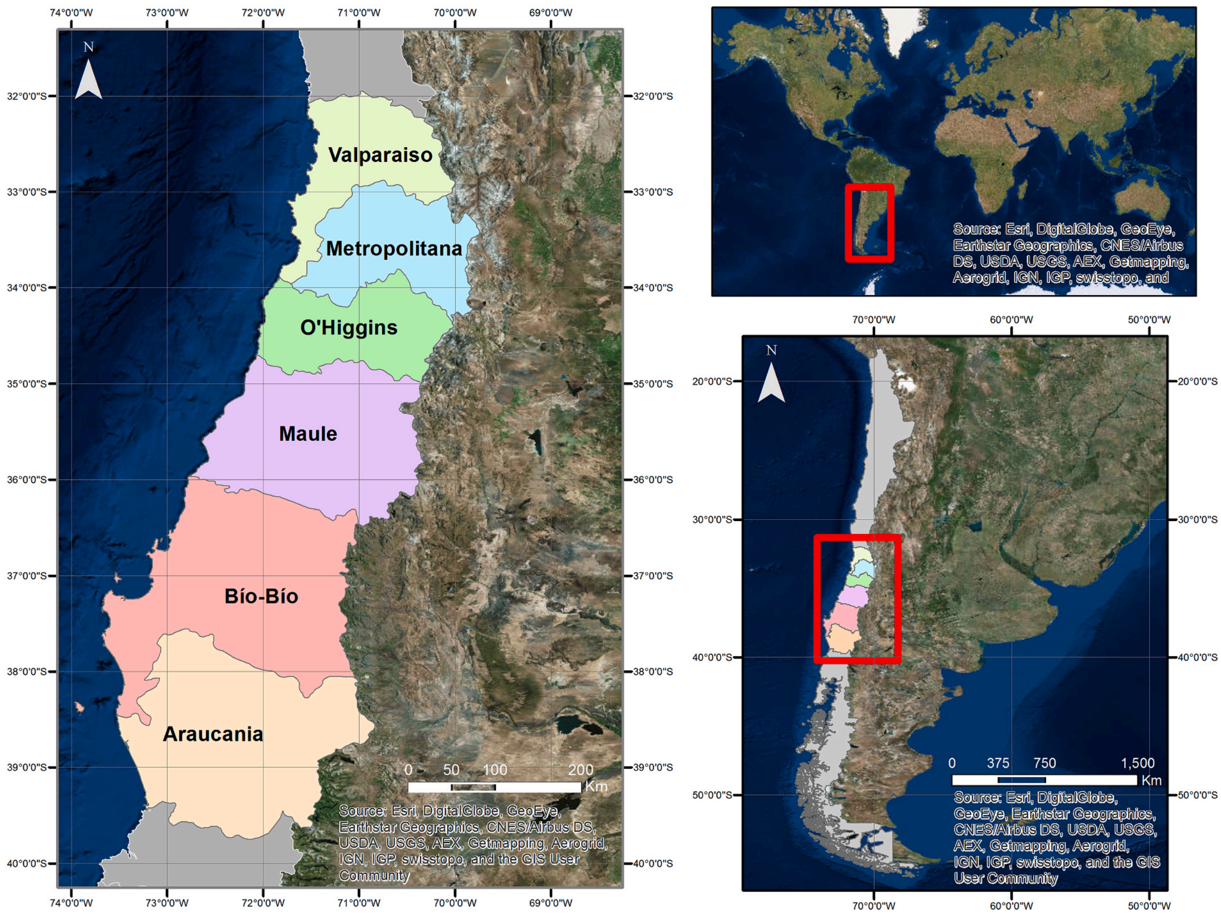

Fig. 1. Catastrophe zone after the earthquake on February 27, 2010 [9].

These ludic activities tested in this study are designed as a non-structural mitigation action to empower citizens to contribute to business continuity and recovery after an earthquake by coming to understand the dynamics of each post-disaster phase. The teaching methodology focuses on the importance of road infrastructure as the backbone of a city's connectivity and the path for returning to normality after an earthquake.

This teaching methodology has been tested previously. It was first applied in 2012 in Colombia with officials from the Colombian Geological Service (SGC by its acronym in Spanish) in the course 'Geographic information science (GIS) and Risk Analysis of Disasters' offered by UNIGIS Latin America (the University of Salzburg and University San Francisco de Quito). This methodology's second and third application took place in master's classes in 2014 and 2016 with GIS master's students in the Interfaculty Department of Geo-informatics Z_GIS at the University of Salzburg in Austria. The fourth application was with scientists from Central America (Costa Rica, El Salvador, and Honduras) in a training programme on risk assessments in the Assessing and Mitigating Earthquake Risk in the Caribbean and Central America (CCARA) Project, which was sponsored by the United States Agency for International Development (USAID) [15].

This paper is divided into seven sections. The introduction section has elaborated on the cascading risk in interdependent systems given the potential disruption and cross-scale implications. This section also describes Chile's seismic conditions and the effects of the largest earthquake and tsunami that affected this country in 2010, particularly in relation to transport infrastructure. The second section provides a literature review. This section addresses critical infrastructure (CI) focused on transport; cascading risks; post-disaster phases; system vulnerabilities; the interaction between infrastructure and other systems; the concepts of mitigation, adaptation, and coping actions; bussiness continuity and serious games in the context of disaster management. Participants, materials, and methods are discussed in the third section, which is subdivided into four subsections: participants, preliminary questions, learning with puzzles, post-disaster recovery and learning with vehicles and machinery. The fourth section presents the results of the teaching methodology and utilises the same four sections of the third section. Section five discusses the results of applying this methodology. Finally, the sixth section offers a conclusion based on the results, and the seventh section includes recommendations for future research.

2. Literature review

The level of a disaster's impact on infrastructure depends on the disaster type frequency [16] and the socio-economic conditions of the society affected [16–18]. Interacting risks have been tackled mainly in the context of earth sciences. Critical infrastructure is vital to the societal functioning [1], and transportation networks play an essential role in maintaining a community's economic and social well-being [19]. The conditions of these networks following a disaster significantly influence the community's recovery [24], avoiding the generation of cascading risks that could disrupt supply chains and the distribution of humanitarian relief [1,20]. Bridges, roads, streets and tunnels play a vital role during the emergency phase, early recovery, recovery, and development phases, the post-disaster phases established by the United Nations Development Programme (UNDP) [13], in terms of evacuation, search-and-rescue (SAR), building reconstruction, reactivation of the economy and reconstruction of the urban fabric [13,16]. The names allocated by different authors to post-disaster recovery phases are presented in Fig. 2.

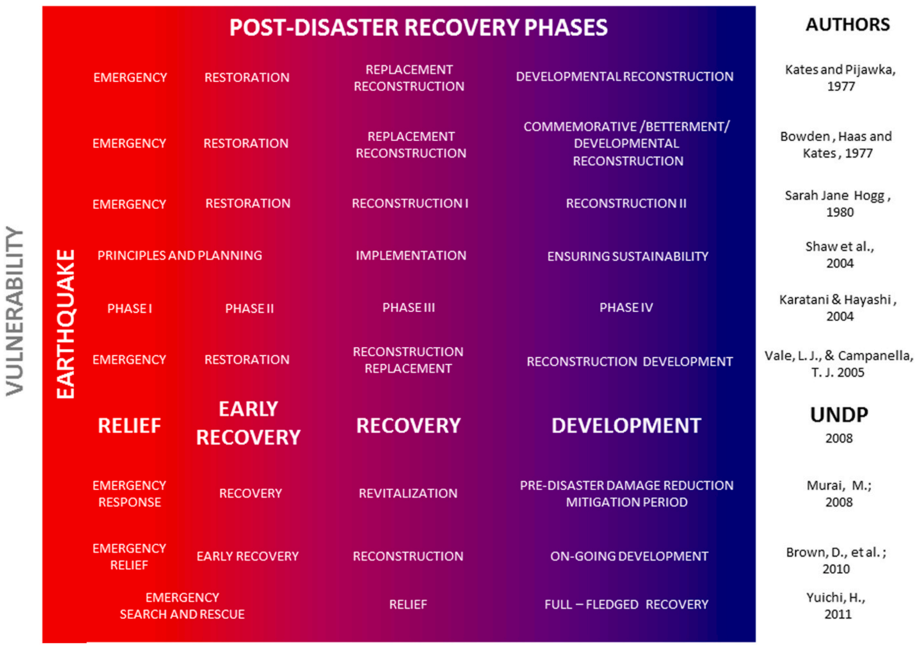

Fig. 2. Names assigned to post-disaster recovery phases by different authors. Source: Adapted from UNDP (2008) [13].

Post-disaster recovery is defined as a complex, multidimensional, long-term process involving planning, financing, decision-making and reconstruction. The recovery process aims to restore sustainable living conditions to a community or area affected by a natural phenomenon [10]. During the relief or emergency response phase, the priority is to save lives by deploying SAR task forces [21,22] and surveying buildings to determine their degree of damages [23]. The early recovery phase aims to start the return of the community to everyday life by removing debris, rehabilitating roads, demolishing damaged buildings [21,24], and start closing temporary shelters. The main objective during the recovery phase is for the disaster area to return to normality [21] through the continuous implementation of the recovery plan and to close all temporary shelters. The development phase focuses on improving upon the state that existed before the event, or the state that would have existed had the event not occurred [25], implementing the lessons learnt from the event.

Road infrastructure failure implies emergency clean-up, restoration and repair of the damaged infrastructure [16]. Earthquakes such as the 1989 Loma Prieta earthquake (USA), 1994 Northridge earthquake (USA), and 2010 Chile earthquake [2,26–30] reveal the vulnerability of highway bridges to seismic hazards [19]. Vulnerability is defined as those conditions determined by physical, social, economic, institutional, cultural and environmental factors that increase the fragility and susceptibility of an individual, community, assets or system to the materialisation of a hazard [1,31,32]. Compound, interacting, interconnected and cascading risks are likely different components of hazards and vulnerabilities [1]. After earthquakes, roads are blocked, and bridges are destroyed or flooded in the case of additional meteorological events. Regional road networks have few and long-spanning link densities. Therefore, they are highly exposed to natural phenomena and susceptible to potential closures after a disaster [33]. When monitoring recovery using satellite images, vehicles on roads are interpreted as a sign of recovery, signalling that road conditions are suitable and that urban facilities are open [11,14,34].

Empirical evidence has demonstrated that the dynamic interaction between physical infrastructures and social and natural systems which are systems of systems [35] is stronger when a disaster happens, [36]. Past research has indicated that focusing on the physical vulnerability of infrastructures is not the right approach to addressing the complexities of socio-technical interactions [37,38]. The vulnerability of a system upsurges its sensitivity to the risk of being impacted by natural phenomena. This fact reflects the complexity of social and economic factors that interact with the physical aspects of hazards [1]. In recent years, there has been a steady increase in the research literature that address the challenges of interconnected, compound, interacting and cascading risk, aggregating elements of CI protection considering the social consequences from its failure. Cascading events result from the vulnerability accumulated at different scales involving socio-technical drivers [1]. The concept of mitigation within this context involves all the activities necessary to reduce the impact of natural phenomena such as earthquakes and tsunamis [39]. These actions are prescriptive or corrective interventions that reduce damage and losses due to natural phenomena [40].

The network performance metrics in post-disaster recovery include rapidity (recovery time), monetary loss (user cost), service performance (travel time and travel distance) and area under the recovery curve [41]. Figures in these metrics can be improved through adaptation strategies implemented by users. Promoting strategies to increase systems' autonomy (including people) and adaptive capacity could be the answer to achieving improvement in network performance metrics [1]. Community adaptation is defined as the actions taken by a community after a disaster to reduce impact and accelerate the recovery process based on the innovative use of community resources [16]. Activities in the physical dimension such as clean-up, restoration and repair of damaged infrastructure are usually assumed by a governmental institution. Nevertheless, there are cases in which the community undertakes the restoration of roads because governmental resources are allocated to more pressing activities [16,42]. In February 2010, following the 2009 earthquake in L'Aquila, Italy, hundreds of volunteers worked each Sunday to remove debris from the streets of the city centre [43]. The situational reports issued by the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) during the relief phase after the 2010 earthquake in Chile confirmed the importance of the road network [2,26–29] for transporting SAR teams [41], distributing humanitarian aid and repairing lifeline services and CI. During the early recovery and recovery phases, the rehabilitation of roads and transportation systems is essential to reconstructing the urban fabric damaged by blocked roads and encouraging economic recovery. Failures in the recovery strategy of road and transportation systems isolate a geographic zone and cause a contraction of its economy, which happened in L'Aquila after the 2009 earthquake [14]. Lack of awareness of CI dependency and urban facilities among responders and planners results in the extended impact of disasters [1,44]. There is significant evidence of the relationship between CI resilience, environmental hazards and cascading events [45].

Commuters, or people who travel some distance to work regularly, adapt to disruptions in transport infrastructure. These adaptation strategies include changing routes (e.g., using more accessible public roads or travelling through private or temporary roads), changing schedules (departing earlier or later), changing mode of transport, selecting alternative destinations, car-sharing, or working from home [16,46–49]. Several research studies have indicated that commuter behaviour changes due to infrastructure disruptions have a lasting impact on people's travel [16,50]. In contrast, others have argued that changes in commuter behaviour do not have long-term effects, and behaviours revert to pre-disaster patterns once the infrastructure is rebuilt [16,51]. Employees' inability to commute to work can delay business operations, forcing employers to develop business continuity strategies. These strategies comprise renting vanpools, subsidising hotel expenses for employees to stay close to the workplace [16,50] or providing a shopping bus service operated by a local supermarket [16,42]. Farmers around the Lockyer Valley (South East Queensland, Australia) implemented another strategy for making roads accessible by using their heavy farm machinery to clear roads and rivers of debris after repeated flooding events [16]. In addition, other communities affected by floods in Northern Queensland, Australia, reduced the community's reliance on road networks by gathering provisions, securing backup power, collecting medical supplies and opening a daycare in their location [16,52].

Stakeholders do not always understand the factors that lead to disasters but still develop adaptation or coping strategies. Pescaroli developed an integrative research process to apply the theory of cascading disasters to response and preparedness strategies of stakeholders in London, England [45], proposing the implementation of focused training to improve business continuity strategies and enhance operational resilience to different triggers [45]. To teach the efficacy of business continuity strategies, it is necessary to adopt cross-disciplinary approaches. Game sciences is the new term that has replaced 'serious games', and it is part of 'education science'. This new term links game studies to the greater scientific capability of modelling and understanding groups and individuals' learning behaviour while gaming, learning design using the metaphor of game design, and elucidating how playwork and games help people learn [53].

Ludic activities through serious games have been developed to raise awareness and support learning [54] by using the potential of games to engage people and transfer knowledge [55]. The traditional cognitive learning approach, whereby people only think, analyse, comprehend and memorise, has been replaced by an unlimited and unrestricted approach that includes trying, touching and exploring [56]. This experiential approach is fundamental in the learning process [57]. Games have not been a well-understood aspect of learning. The lack of robust scientific and evidence-based research was one of the main stated inhibitors to uptake educational

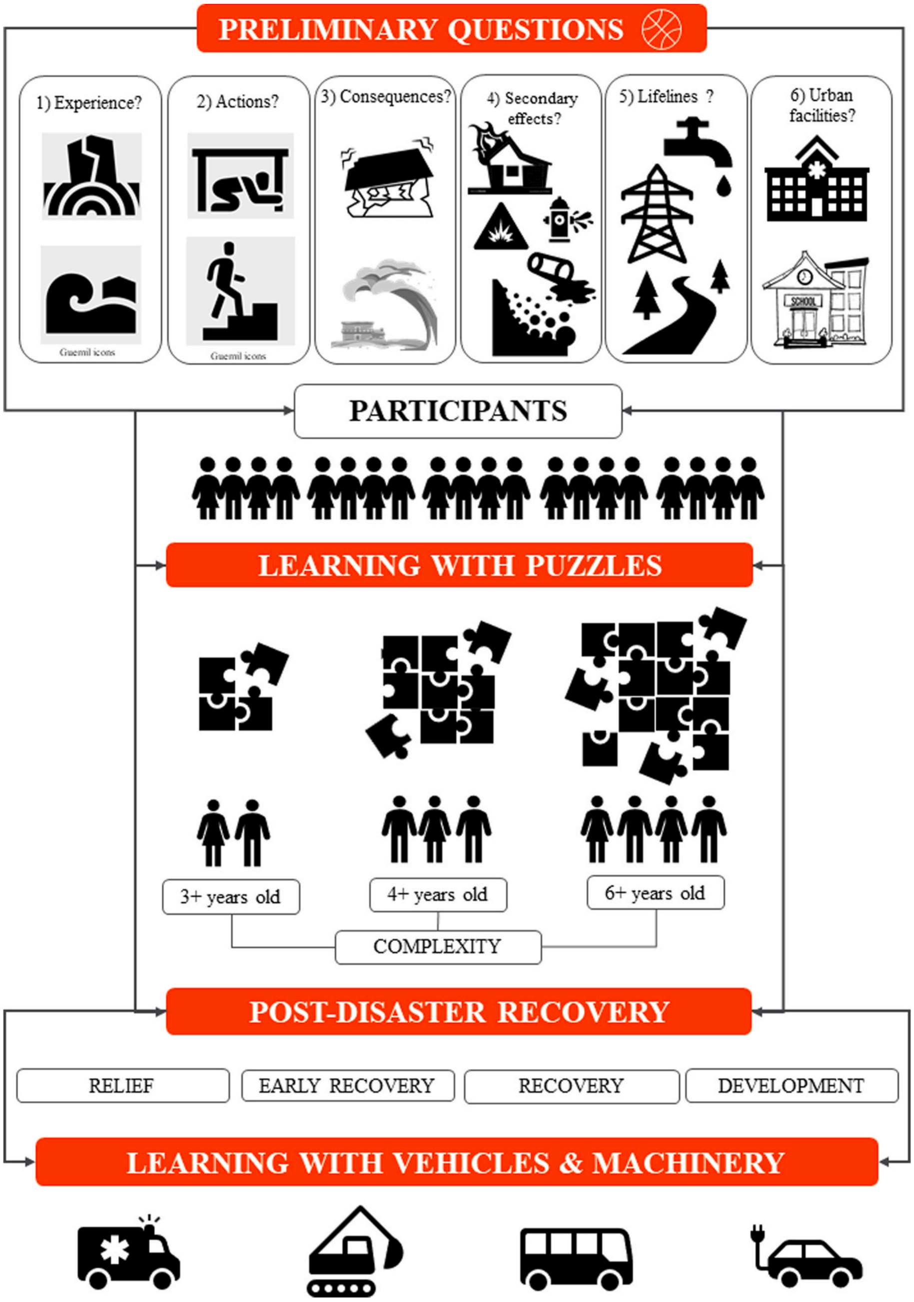

Fig. 3. Methodology.

games and approaches. Game-based approaches require cross-disciplinarity, longer time slots for classes, mixed groups, social learning, and team teaching models to take advantage of the game and gameplay as learning approaches. Non-entertainment games demonstrated their suitability for use in military training, health education, and therapy in the early 2000s [53].

People need to be engaged, motivated, surprised, and challenged to learn [54,58]. A fun environment facilitates discussion among participants, knowledge sharing, collective decision-making, exploration of new strategies, development of new social and personal skills, and new conceptual learning [55,56,59,60]. Hence, gaming is useful for understanding the complexities and challenges of coping with natural phenomena and boosting resilience [61]. The first randomised controlled trials (RCTs/PCTs) started in the late 2000s, and one of the first studies compared traditional and game-based approaches in emergency response training [53,62]. Wouter et al. found that trainees in serious games learnt more than those taught with traditional instruction methods, when the game included additional instruction methods when multiple sessions were added, and when trainees worked in groups [53,63]. An example of a serious game in the context of disaster is 'Hazagora: Will You Survive the Next Disaster?' In this game, participants learn the mechanisms of geohazards, their role in controlling their community's vulnerability profile and strategies to build a society resilient to the impacts of geological phenomena [61]. Other games have also been designed to raise awareness of one or several hazards, such as 'Stop Disasters!' (UN/ISDR, 2004), 'Riskland' (UN/ISDR, 2004), 'Disaster Hero' (FEMA), 'Save Natalie!' (International Decade for Natural Disaster Reduction), 'Volcano Disaster' and 'Volcano Video Productions'. Games and interactive simulations produce better cognitive outcomes, and this result is accentuated when students are empowered to control games and simulations versus when access is tutor-controlled [53,64]. The target audience of these games has mainly been young people as children are considered a vulnerable group in disaster situations [31,65].

3. Participants, materials and methods

This study represents the first time that this methodology based on ludic activities was tested with children and teenagers who had experience of earthquakes and/or tsunamis. The methodology comprised four activities: (1) preliminary questions about experience with earthquakes and knowledge of the urban environment; (2) learning with puzzles as a ludic activity without information on post-disaster recovery; (3) explanation of the concept of recovery and the activities in each post-disaster phase; and (4) learning with vehicles and construction machinery, a ludic activity, accompanied by brief theoretical information about post-disaster recovery. The methodology is depicted graphically in Fig. 3.

3.1. Participants

The activities were undertaken by high school students in the Youth Lab of Reflection and Citizen Participation. This lab was organised by the EXPLORA – National Commission of Scientific and Technological Research (CONICYT) RM Sur Oriente Project. In 2020, CONICYT changed its name to the 'National Research and Development Agency' (ANID). The workshop took place from 10 to 12 December 2018 at the National Museum Benjamín Vicuña Mackenna in Santiago, Chile. A total of 84 students in three groups (one group per day) from the 'Almendral School' attended the workshop; the students were distributed across four age groups, as shown in Table 1. The gender and age distribution of the participants is illustrated in Fig. 4.

3.2. Preliminary questions

The last strong (8.8 Mw) earthquake in Chile before the workshops was on February 27, 2010 [66]; therefore, given the age range of the participants (11–15 years), I started the workshop by asking who had experienced an earthquake and/or a tsunami. The second question was more oriented towards knowing what to do during an earthquake, and the third question concerned the consequences of earthquakes. The fourth question was related to the concept of secondary effects, while the fifth question dealt with the concept of lifelines, and the sixth question related to urban facilities. Answers to these questions indicated whether participants knew about the impacts of earthquakes and tsunamis in the urban environment. Answering each question was voluntary. The moderator threw the participant who answered the first question a tennis ball. If there were no volunteers, the moderator tossed the ball to a random participant to start the activity. The tennis ball was then passed to another participant who should answer the following question, and the ball continued to be passed until the preliminary questions were finished. The purpose of the tennis ball is to involve all the participants in the activity and avoid having only some participants answer.

3.3. Learning with puzzles

This ludic activity was undertaken without providing information about recovery. The activity employs three kinds of puzzles that differ in size and complexity (3+, 4+ and 6+ years old), as shown in Fig. 5. Two puzzles were already partially complete by the time of

Table 1
Characteristics of the sample population.

DATE	GROUP	SCHOOL YEAR	AGE	GENDER		TOTAL (Number)
			Years	Girls	Boys	
December 10, 2018	1	Second middle	15	18	12	30
December 11, 2018	2	Sixth basic	11	7	5	12
		Seventh basic	14	9	16	25
December 12, 2018	3	Eighth basic	15	4	12	16

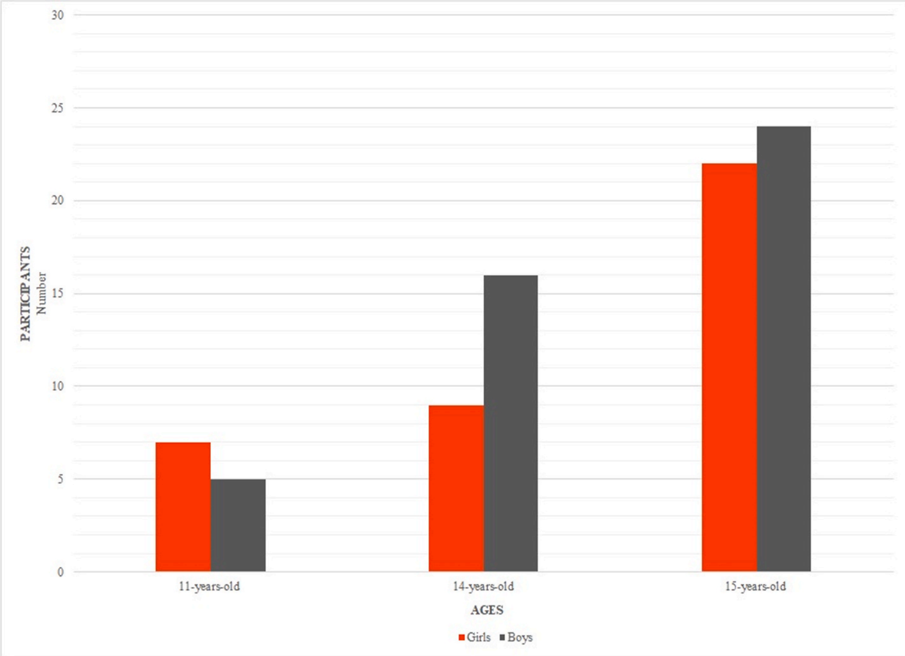

Fig. 4. Age and gender distribution of the participants in Santiago, Chile.

the workshop, ranging from almost completed in the case of the 3+ puzzle, half-completed for the 4+ puzzle and not started in the 6+ puzzle. Participants were divided into three teams; the number of team members was determined by the size and complexity of the puzzle. Fewer participants were assigned to the puzzle with a lower degree of complexity, and more participants were assigned to the more complex one. However, this distribution of participants can change for small groups. The same number of participants can be assigned to each puzzle, regardless of complexity and completeness, thereby increasing the difficulty of the ludic activity. In this study, the exercise was arranged as a competition in which teams sought to finish first.

The size of the puzzle represented the size of the city. The number of pieces represented the number of buildings that make up the

Fig. 5. Puzzles for the exercise: complexity a) 3+ years old, b) 4 years old, c) 6+ years old.

city. Pieces already assembled in the puzzle signified buildings not affected by the earthquake, while the pieces to be assembled represented the number of damaged or collapsed buildings in need of repair and/or reconstruction. The number of pieces represented the number of damaged or collapsed buildings. The complexity (3+, 4+ and 6+) reflected three scenarios with different difficulty levels represented by a diverse number of fatalities, injuries and secondary effects (landslides, fires, explosions, leaks and spills) caused by the earthquake. The participants acted as stakeholders (affected community, emergency managers, government officials and policymakers). Team members had to plan, organise and complete the puzzle as soon as possible. This activity simbolised resembles the creation of reconstruction plans during the post-disaster phase, when stakeholders must agree on a recovery plan.

3.4. Post-disaster recovery

After finishing the puzzle activity, the similarity of this ludic activity to reconstruction planning was explained to the participants. Then, the concept of post-disaster recovery and the characteristics of each post-disaster phase were described in 17 slides based on examples from recovery processes undertaken in Mexico City (Mexico), Kobe (Japan), Armenia (Colombia), L'Aquila (Italy) and Christchurch (New Zealand) after earthquakes in 1985, 1995, 1999, 2009 and 2011, respectively. The description of each post-disaster phase includes the activities to undertake and the estimated time to needed accomplish the goals necessary to enter the next post-disaster phase, thus emphasising the role of infrastructure and urban facilities as destination points.

3.5. Learning with vehicles and construction machinery

The names of the post-disaster phases were plotted in a banner in polyvinyl chloride (PVC) fabric based on Fig. 2. The set of vehicles consisted of four groups: (1) emergency response vehicles, (2) vehicles and construction machines, (3) public transport and 4) public and private vehicles. These groups correspond to the relief, early recovery, recovery, and development phases. The set of emergency response cars is presented in Fig. 6. Vehicles and construction machines linked to early recovery and recovery are displayed in Figs. 7 and 8, respectively. This methodology encourages public transport during the early recovery and recovery phases to reduce congestion and facilitate the vehicle movement needed for reconstruction works. Public transport use is a best practice adopted by commuters during the post-disaster development phase as more environmentally friendly behaviour. Finally, the set of cars linked to the development phase is shown in Fig. 9. This set reflects progress and wellness in the community affected by the earthquake. Participants had to distribute the vehicles among each post-disaster phase printed on the PVC banner according to their judgment and the vehicle's potential role in each phase. Vehicles could be placed in two or more post-disaster phases. This activity allowed participants to evaluate the knowledge they have gained regarding the characteristics of each post-disaster phase, and it opened up discussion about participants' roles during each post-disaster phase.

4. Results

4.1. Preliminary questions

The answers to the first preliminary question regarding which participants had experienced an earthquake are detailed in Table 2

Fig. 6. Relief or emergency phase. Emergency response vehicles: a) ambulance (van), b) ambulance (car), c) fire truck (aerial ladder platform truck), d) fire engine (pumper), e) helicopter, f) police van, g) Photos: Diana Contreras.

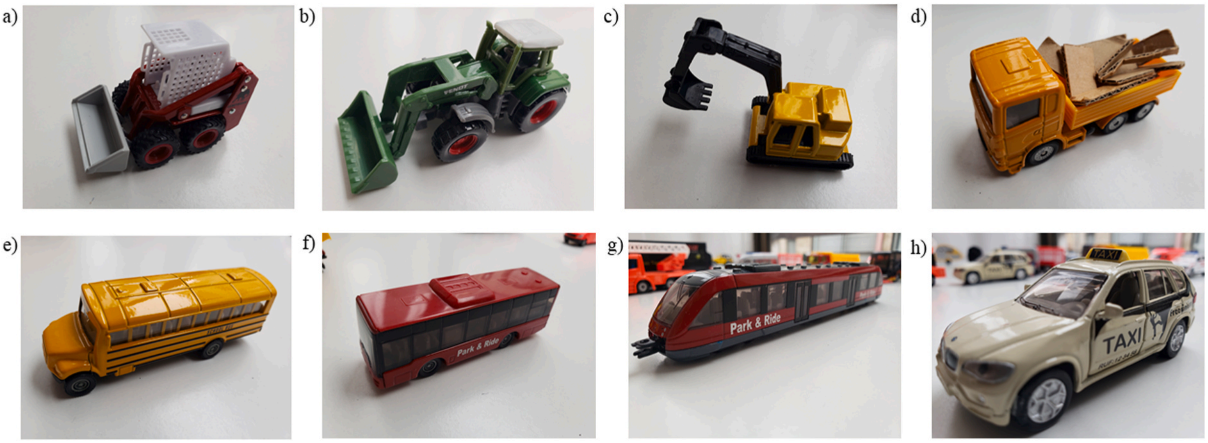

Fig. 7. Early recovery phase. Construction machines and vehicles: a) skid steer loader, b) wheel loader, c) backhoe, d) dump truck, e) school bus, f) public bus, g) tram, h) taxi. Photos: Diana Contreras.

Fig. 8. Recovery phase. Construction machines and vehicles: a) crane, b) cement mixer, c) dump truck, e) post truck, f) train, g) beverage truck. Photos: Diana Contreras.

and Fig. 10. Regarding the second question of what to do in an earthquake, the most frequent answer across the three workshops was to remain calm. Additionally, one 11-year-old girl also suggested ducking under a table. The students recognised damages in buildings but no injuries and fatalities as consequences of earthquakes. The concept of a secondary effect was unfamiliar to the students, but landslides, fires and tsunamis were identified as secondary effects. Only one 11-year-old boy mentioned a landslide as a secondary effect of an earthquake.

The concept of lifelines was unknown to the participants, except for one 11-year-old boy who identified roads as lifelines and even highlighted their importance for fire engine traffic after an earthquake. The concept of urban facilities was unknown to the participants. The use of the tennis ball to nominate participants to answer questions was considered fun and was well received.

4.2. *Learning with puzzles*

All of the student groups compared doing a puzzle with a city's reconstruction. Participants agreed that a low level of complexity and a higher degree of completeness was why the group working with the 3+ years puzzle finished first. However, in the second workshop, one 11-year-old boy decided to even start this puzzle from scratch without consulting the other team members, and they still managed to finish first, given the low complexity of the 3+ years puzzle.

In answer to how difficult it was to agree on how to set up the puzzle pieces, some participants considered it difficult while others did not. Those who considered it easy agreed to start from the borders, while those who considered it difficult began by putting

Fig. 9. Development phase. Vehicles: a) garbage and recycling truck, b) tourist bus, c) van, d) motorhome, e) car with boat f) sports car. Photos: Diana Contreras.

Table 2
The number of participants who had experienced an earthquake.

DATE	GROUP	SCHOOL YEAR	AGE (years)	TOTAL (number)	EARTHQUAKE EXPERIENCED	
					Number	%
December 10, 2018	1	Second middle	15	30	13	43
December 11, 2018	2	Sixth basic	11	12	21	57
		Seventh basic	14	25		
December 12, 2018	3	Eighth basic	15	16	16	100

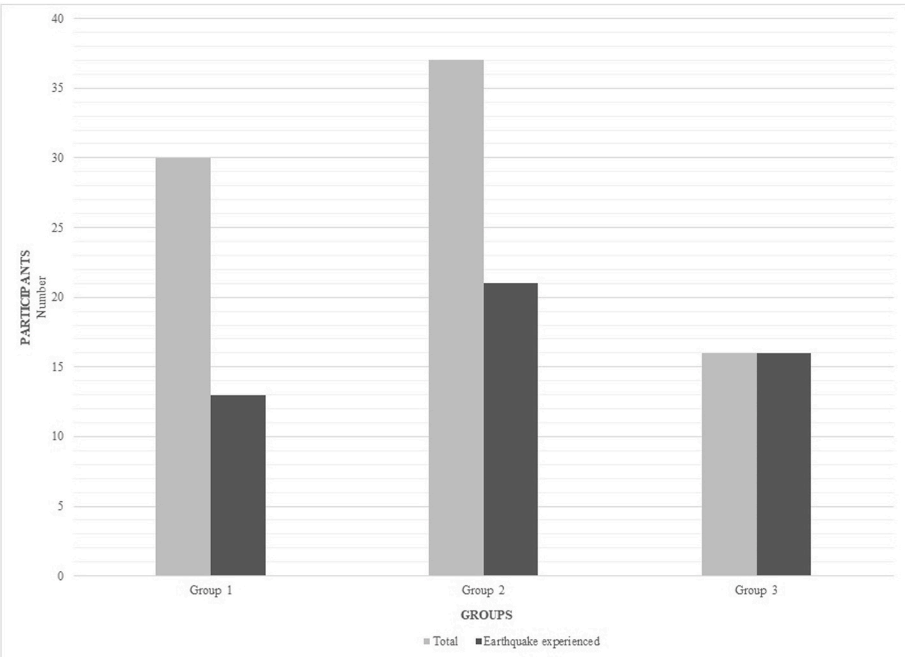

Fig. 10. The number of participants who had experienced an earthquake.

together similar colours. I asked participants about the role that they represented while doing the puzzle. Only one 11-year-old boy from the second group answered the question, imagining himself as a member of the National Office of Emergency from the Ministry of Interior and Public Security in Chile (ONEMI) or as a politician in charge of reconstruction. The engagement of the participants with the ludic activity can be observed in Fig. 11.

4.3. Recovery

Each of the three groups received the lecture well, but it generated more interest among children than teenagers. We therefore decided to change the arrangement of the chairs for the second group. Instead of rows, I asked them sit around the table where the puzzles and the vehicles and construction machinery were located it to engage them more. For the third group, which was the smallest group, we continue sit around the table. Each of the groups attending the lecture are portrayed in Fig. 12.

4.4. Learning with vehicles and construction machinery

The participants had a positive response to the exercise with the vehicles. Before the exercise, they did not identify the post-disaster phases; the only clear issue for them was that the priority during the relief or emergency phase was to save people's lives. After presenting the characteristics of each post-disaster phase, the students easily recognised and associated the emergency vehicles with the relief phase and some construction machines with the early recovery and relief phases. Other means of transport were allocated to the recovery and sometimes to the development phases. The participants correctly explained that debris could not be removed with heavy machinery during the relief phase due to the probability of survivors who could be injured. One 11-year-old boy from the second group mentioned the importance of building damage surveys, particularly checking gas installations to avoid fires. He was correct, but the moderator further added that the building damage survey is also useful in determining the safety conditions of buildings and deciding whether evacuation is necessary. The participants intelligently identified that some vehicles allocated to the development phase could likewise be used in the relief or emergency, early recovery, and development phases, such as the mobile station for press coverage (Fig. 6 g); the motorhome for shelter (Fig. 9 g); the car with the boat (Fig. 9 e), the tourist bus (Fig. 9 b) and the van (Fig. 9 c) for evacuation; and the garbage and recycling truck (Fig. 9 a) for cleaning debris. The result of this activity is illustrated in Fig. 13.

5. Discussion

This methodology was conceived as a mitigation strategy to reduce the probability of generating cascading risk caused by breakdowns in interdependent systems by enhancing business continuity, associated mainly with the anthropogenic domain and the vulnerability component of risk that focuses on managing social and infrastructure nodes. This methodology is a buffering strategy thought to increase the autonomy and adaptive capacity of the population in case of road failure [1] and to promote good practices in emergency planning [1,45,67] by ludic activities based on questions, metaphors [53] with puzzles and scale models of vehicles and construction machinery.

Group one was composed of 11-year-old children and included more girls, whereas groups two and three had greater proportion of

Fig. 11. Learning with puzzles: a) Group 1, b) Group 2, c) Group 3. Photos: Diana Contreras.

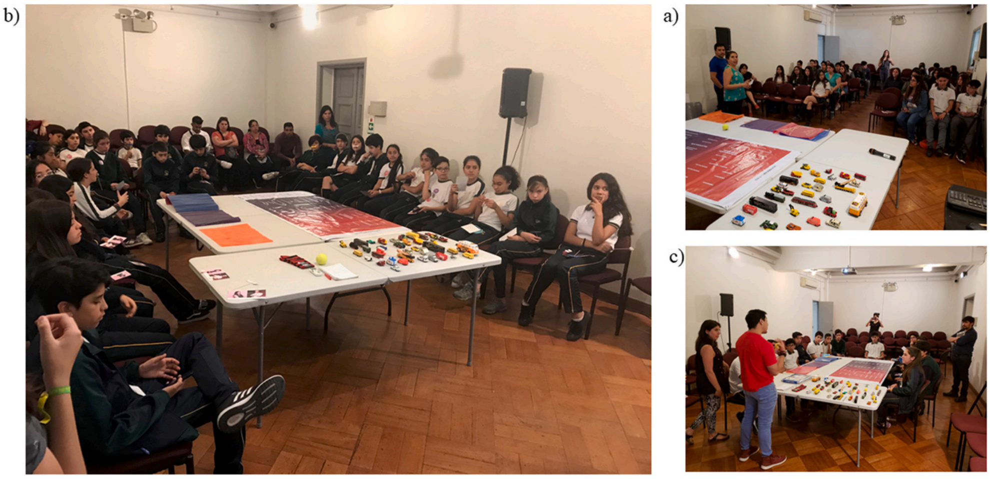

Fig. 12. Recovery lecture: a) Group 1, b) Group 2, c) Group 3. Photos: Diana Contreras.

Fig. 13. Recovery lecture: a) Group 1, b) Group 2, c) Group 3. Photos: Diana Contreras and Cristina Vizconti.

boys. The children and especially the girls, 11-year-old range tended to participate with enthusiasm in the preliminary questions exercise, especially girls. Regarding the question of experience with an earthquake, not as many participants declared having experienced an earthquake as anticipated. Nonetheless, given the participants' ages in groups one and three (between 15 and 16 years old), some attendees may have preferred not to answer. Teenagers often have an apathetic attitude toward questions formulated by adults. None of the participants mentioned evacuating the building as an emergency response during an earthquake. It can be assumed that participants did not consider horizontal or vertical evacuation because Santiago is not located on the coast and is not exposed to tsunami hazard. Participants' successful identification of damages in buildings due to an earthquake could be because some damages are still visible in the affected area 10 years after the 2010 earthquake, [66], such as the Puente Viejo Bridge [68]. Images of damages were also often shown in the media after the earthquake.

In contrast, injuries and fatalities are not visible, and the latest earthquakes in Chile have left almost no casualties (e.g., the 2019 Coquimbo earthquake, Mw 6.7, intensity VIII [68]; left only two casualties, and these were due to cardiac arrest rather than a building collapse [69]). It is rewarding that at least one 11-year-old boy could identify landslides and fires as a secondary effect of earthquakes and recognise the need to close gas installations. Although the participants were unfamiliar with the term 'lifelines,' they were able to associate the term with roads and understood their importance for fire engine traffic after an earthquake. This level of awareness among children could be due to the high seismic hazard of Chile. Lack of familiarity with the term 'urban facilities' could be due to participants' ages. Participant answers according to gender indicate that girls are more aware of protection techniques during earthquakes than boys; this fact could be explained by the traditional caring role of women in society. In contrast, boys had basic notions of secondary effects and the concept of landslides and took the initiative in the puzzle and the exercises with vehicles and construction machinery, where decision-making plays an important role.

Regardless of age or gender, participants from all three groups were excited about the puzzle exercise. At the end of the puzzle activity, participants who could not complete their puzzles were disappointed. It was thus necessary to explain that it was not possible to finish the third puzzle (6+ years) in the time allocated for the activity. The third puzzle represents a hypothetical case because cities are entirely destroyed only in exceptional cases such as Pompeii (Italy) or Armero (Colombia), both of which involved volcanic eruptions rather than earthquakes. The destruction of Hiroshima and Nagasaki was due to an intentional anthropogenic action in World War II instead of a natural phenomenon. An earthquake does not affect a whole city to the same degree due to the different levels of physical vulnerability of the various zones that comprise the city. Groups one and three were excited about this ludic activity to the point that they managed to complete the most complex puzzle during the recovery lecture. Other participants were involved in the exercise of learning with vehicles and construction machinery. The participants who completed the 3+ and 4+ puzzles highlighted that the border made it easy for them to complete the puzzle; this border was absent in the more complex 6+ puzzle, increasing difficulty. This border aspect is comparable to reconstructing cities with clear limits. The puzzle without a framework represents large cities with surrounding informal developments or conurbations. In this kind of settlement, there are no legal rights over the land, rendering occupants ineligible for government subsidies to repair or reconstruct their houses after an earthquake.

The first group, particularly the male participants had the most enthusiasm in the learning with vehicles and construction machinery exercise. During the relief phase, the mobile station for press media represents the population's need for information right after the earthquake. However, as one of the 11-year-old boys noted, the press is also necessary to report the progress of the post-disaster recovery, a valid statement that I assume is a lesson learnt from the workshop. Among the set of vehicles, those that indicate a return to normality are the public bus (Fig. 7f), the tram (Fig. 7g), the taxi (Fig. 7h), the post truck (Fig. 8e) and the train (Fig. 8f). The beverage truck (Fig. 8g) and tourist bus (Fig. 9b) represent business continuity. The garbage and recycling truck (Fig. 9 a), initially assigned to the development phase in the framework of this methodology, was placed by one 11-year-old girl in the early recovery phase. According to her, it is important to consider what could be reused from the debris, another meaningful statement that I interpret as a lesson learnt from the workshop. One 11-year-old boy posited that the motorhome (Fig. 9d) could be used during the relief or emergency phase as a shelter or for holidays during the development phase. The same boy suggested that the car with the boat could be used in an evacuation due to a flood in the relief phase or for holidays during the development phase. The same functions are possible for the tourist bus (Fig. 9b) or the van (Fig. 9C). Again, these are insightful claims that I consider additional lessons learnt from the workshop that cover seismic as well as other hazards like floods. The motorhome, the car with the boat, the tourist bus and the van are associated with recreational activities during the development phase.

This research contributes evidence to the use of ludic activities in disaster management training. I expect that this change in risk perception and increase in awareness among children and teenagers will reduce the impact of natural phenomena by preparing individuals to contribute to the emergency response as citizens, urban planners, emergency response practitioners, or policy officers in the future. Finding the balance between solid learning design, game playability and fun that aligns learning outcomes with assessments is the main challenge to achieving effective educational game design [53].

6. Conclusions

This methodology obliquely makes participants aware of the interdependencies of CI and the importance of preparedness versus response and recovery [70]. The ludic activities that integrates this methodology were I swell received and generated engagement among children and teenagers, with the exception of the preliminary questions that some teenagers did not answer. Participants did not consider the option of evacuating, which is a mistake given the risk of a tsunami on the coast of Chile. Furthermore, participants did not associate injuries and casualties with the damages earthquakes produces in buildings. The participants were able to identify landslides and fires as secondary effects of earthquakes but were unfamiliar with terms such as 'lifelines' and 'urban facilities.' The participants could answer several preliminary questions despite their age, especially the 11-year-old children from the second group. The high level of seismic hazard in Chile and the fact that almost half of the participants had experienced earthquakes, participated in preparedness activities and/or been witnesses of reconstruction processes may explain their knowledge.

The competitive aspect of the puzzle activity sparked participants' interest, even among teenagers. The similarity of the puzzle with a city in the reconstruction process after an earthquake was easy to understand. In previous applications of this methodology, the metaphor between doing puzzles and reconstructing a city was easily recognised only by participants who worked in disaster management. For example, before the puzzle exercise, participants were only aware of relief or emergency as a post-disaster phase but could not identify the other post-disaster phases. Answers from the participants according to gender indicate that girls are more aware of protection techniques during earthquakes than boys, while boys are more mindful of terminology and engaged in decision-making activities.

At the beginning of the exercise, participants did not identify the role and importance of roads for returning to normality and business continuity after an earthquake. In previous applications of the methodology, participants quickly identified the vehicles related to the relief phase. However, they had difficulty identifying the vehicles related to the other post-disaster phases because there is less information dissemination about the activities in those phases. Nevertheless, these children and teenagers managed to identify vehicles related to the relief phase as well as some vehicles related to recovery and early recovery. Some vehicles can be used in more than one or two post-disaster phases. The idea of using vehicles from the development phase for evacuation during an emergency reflects that citizens feel empowered enough to respond to the emergency by themselves, thereby enabling authorities to support the most vulnerable. This ludic activity also engaged all the participants, including the teenagers.

The interactions among the participants depended on their background and the degree of familiarity between them. As such, teams with participants who knew each other before the exercise performed better than teams working together for the first time. All the ludic activities included in this methodology were new to and well-received by the participants. The design and application of this methodology are empirical, modified to match participants' experiences and contributions. It is essential to state that this methodology is still under development and can be improved based on participants' experience and feedback.

7. Recommendations

It is necessary to include disaster risk management in school curricula [70] using game sciences to teach children and teenagers about the risk of CIs, interdependencies, environmental impact, economic losses, prevention, preparedness, response and recovery [70]. Such ludic activities must emphasise the importance of evacuation in case of a tsunami, particularly in coastal states located in seismic hazard zones, and underline to children and teenagers - especially boys - that damages to buildings during earthquakes can produce injuries and casualties. Children and teenagers must be made aware of other secondary effects of an earthquake beyond landslides and fires, such as explosions, leaks and spills. It is important to familiarise children and teenagers with terms such as 'lifelines' and 'urban facilities' in preparedness activities. Mixing age groups is not recommended because teenagers avoid participating while children do so actively. It is necessary to empower girls to go beyond implementing protection techniques during earthquakes and participate in decision-making to respond to emergencies.

In this ludic activity to represent how world heritage (WH) buildings are affected by earthquakes, I would not include one or three pieces of each puzzle according to their complexity. The aim of excluding some puzzle pieces was to demonstrate how difficult it is to reconstruct these buildings and their significance for the community and the city's historical memory [71,72]. The metaphor of the puzzle and the city could be improved by using puzzles based on satellite or aerial images or orthophotos of cities affected by earthquakes. Additionally, 3D scale models could be used, such as a computer game. It is necessary to use cars with the same scale for the 'learning with vehicles and construction machinery' activity because participants were initially reluctant to use the van since its model was on a different scale.

Applying this methodology as a non-structural mitigation measure is suggested in areas where road infrastructure has been affected by earthquakes in the past. Another place to apply this methodology is where damage scenarios have indicated significant damage to road infrastructure or where no financial resources for structural mitigation actions is available. This methodology will help people understand the concepts and phases of post-disaster recovery and generate adaptation strategies. One area to implement this exercise is Coquimbo (Chile). The earthquake on January 19, 2019 generated an alert for a tsunami, and people used their cars to evacuate and reach a safe point, thus creating a traffic jam. If the tsunami had occurred, the waves would have reached the people stuck in their cars. Hence, one of the aims of this exercise is to teach people how to use roads and vehicles in case of an emergency and to give priority to emergency cars during the relief phase.

This methodology can also be applied in companies' business continuity awareness and training. This training makes companies aware of the importance of having a business continuity plan if a disaster blocks roads or tunnels or damages bridges, thus disrupting 'supply chains. The methodology could include a survey to determine preferred destinations, transport methods used by participants, and possible adaptation strategies after an earthquake. The survey could prioritise structural mitigation in Chile's urban and inter-urban road network.

It is also essential to clarify the concept of urban facilities in the first part of the methodology. Trips always have an origin and a destination, which is usually urban facilities such as schools, hospitals, stores, restaurants, pharmacies and so forth. The destination and the purpose of a trip determine the transport needed. The fact that destinations are open is a sign of recovery, return to normality and business continuity after an earthquake.

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