# USING COMPUTER VISUALISATIONS TO EDUCATE AND COMMUNICATE VOLCANIC HAZARDS TO AT-RISK COMMUNITIES.


**BY**

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# AUTHOR'S DECLARATION

At no time during the registration for the degree of Doctor of Philosophy has the author been registered for any other University award without prior agreement of the Doctoral College Quality Sub-Committee.

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# ABSTRACT

**Using computer visualisations to educate and communicate volcanic hazards to at-risk communities.**

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With an increase in the number of people living in proximity to active volcanic centres worldwide, there is a greater need to provide effective and engaging education and outreach programmes to reduce vulnerability and prepare exposed communities for potential future volcanic eruptions. The finalisation of the Sendai Framework (UNISDR, 2015a) has also cemented the need for disaster risk managers to engage at-risk communities with education and outreach programmes, to reduce the number of deaths and injuries caused by volcanic eruptions worldwide.

Education and outreach programmes are already commonplace for disaster risk reduction, with many taking the form of traditional presentations, maps, diagrams, TV and radio broadcasts. In recent years, there has been a shift towards the use of more creative media to communicate volcanic hazards and engage populations in outreach activities. These have included films, comic strips, puppet shows, board games and video games. However, to-date there is little empirical evidence for the use of these media with at-risk communities. This research seeks to address this issue by providing evidence for the effective use of creative media for volcanic hazard education by adopting the use of video games (or serious games).

To assess how effective serious games could be as an education tool, a bespoke video game (*St. Vincent's Volcano*) was developed collaborative with disaster risk agencies and communities on the Eastern Caribbean island of St. Vincent and then trialled with adults and students from across the island. A range of outreach sessions were adopted to compare and contrast the applications of the game and to identify the most effective method of its delivery. These sessions included a traditional outreach presentation used as a control, and a group of UK students for a cohort comparison. Data were collected through a mixed-methods approach.

Overall the results of the study demonstrate how successful the game can be as an education tool, promoting knowledge improvement in players. The results also demonstrate how the role of the outreach instructor is important to encourage engagement and can result in higher levels of overall positive engagement exhibited by the students. The game was also successful at promoting knowledge gain and engagement with adult participants. The results also demonstrated promise for games in promoting longer-term knowledge retention and for improving awareness of existing outreach materials.

This research provides a foundation for the increased integration of emerging technologies within traditional education sessions. The work also shares some of the challenges and lessons learnt throughout the development and testing processes and provides recommendations for researchers looking to pursue a similar study or to adopt the use of serious games.

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| | |
|---|---|
| CDEMA | Caribbean Disaster Emergency Management Agency |
| DRR | Disaster Risk Reduction |
| GDP | Gross Domestic Product |
| GFDRR | Global Facility for Disaster Reduction and Recovery |
| IPCC | Intergovernmental Panel on Climate Change |
| MOE SVG | Ministry of Education for St. Vincent and the Grenadines |
| NEMO | National Emergency Management Organisation |
| Net Gen | Net Generation |
| PU | Plymouth University |
| SIDS | Small Island Developing State |
| SMU | Soufriere Monitoring Unit |
| SRC | Seismic Research Centre |
| STREVA | Strengthening Resilience in Volcanic Areas |
| SVG | St. Vincent and the Grenadines |
| UNDP | United Nations Development Programme |
| UNISDR | United Nations International Strategy for Disaster Reduction |
| UWI | University of the West Indies |
| VAW | Volcano Awareness Week |
| VEI | Volcanic Explosivity Index |
| VEMP | Volcano Emergency Management Plan |

# CHAPTER 1: Introduction

## 1.1. Rationale

Latest figures suggest that 12% of the world's population (over 570 million people) live within 100 km of a volcano classified as having had an eruption in during the Holocene epoch (approximately 11,700 years) (Siebert *et al.*, 2010). These numbers are continually rising with an increase in population density close to volcanic centres and particularly around the Pacific 'Ring of Fire'. In Indonesia alone, the entire population of the island of Java (130 million people) live within 100 km of a Holocene volcano. The reasons why people live in proximity to active volcanic centres are multi-faceted, with some populations choosing to accept the risks of living so close to an active volcano in return for the rich fertile soils of which that volcano affords. However, living close to an active volcanic centre is not always a choice; due to population growth and lack of space, more and more people find themselves living in these potential vulnerable locations.

With ever increasing numbers of people living in such potentially dangerous locations, awareness raising activities, such as education and outreach programmes are more essential than ever to work with vulnerable populations to reduce risk from a future eruption. The importance of public education and outreach is highlighted by the Sendai Framework for Disaster Risk Reduction (DRR) (UNISDR, 2015a), which aims to reduce the number of deaths, injuries and impacts caused globally by disasters (human and natural). To address that goal, the Sendai Framework identifies the need for participating countries to *"strengthen public education and awareness in disaster risk reduction",* specifically promoting the use of social media, community mobilisation campaigns and encouraging the education of all at-risk communities (UNISDR, 2015a).

Education and communication plays a vital role in improving the resilience of vulnerable populations at risk from natural disasters (Johnston *et al.*, 1999; Paton *et al.*, 2000;

Ronan & Johnston, 2003; Paton *et al.*, 2008). Conventionally, such awareness-raising activities are delivered in a number of guises - typically leaflets, posters, presentations, maps, TV and radio broadcasts. Often these educational products are aimed at school-aged children, in part due to ease of access and in part reflecting current thinking that children filter information through to their parents through informal conversations (Ronan & Johnston, 2003; Carlino *et al.*, 2008; Sharpe & Izadkhah, 2014). However, it is becoming increasingly important to evolve existing education and communication techniques to better engage with a new generation of learners. It has been argued that, with advancements in technology, individuals today learn in ways different to their predecessors (Prensky, 2001; Annetta, 2008; Bekebrede *et al.*, 2011). A fresh generation of learners - sometimes called the Net-Generation or Net-Gen (Tapscott, 1998) - are accustomed to a digital age in which information, news and entertainment are obtained instantaneously and delivered directly to them on personal devices (e.g. mobile phones, tablets and laptops). This has led to a rise in innovative teaching techniques in the classroom, such as the use of video games, in an effort to better motivate this new generation to learn (Prensky, 2001).

This thesis focuses on how educational video games can be used as a tool for public outreach around raising awareness of volcano hazards with at-risk communities. It reflects a recent surge in the application of so-called 'serious games' - video games whose primary purpose are educational, not entertainment - for the purposes of learning and training (Michael & Chen, 2005; Zyda, 2005; Djaouti *et al.*, 2011), ranging from applications in medicine to military training, and spanning everything from personal health to curriculum education. This thesis considers the emergence of serious games in the realm of natural hazard education, and critically examines their role for communicating volcanic hazards. Highlighting a lack of empirical evidence to demonstrate that geohazard-related serious games promote effective learning, this thesis presents the development and testing of a serious game specifically designed to test volcanic hazard awareness among school children and adults on the Caribbean island of St. Vincent. The study provides a preliminary assessment of the effectiveness of virtual environments as a learning tool and discusses the practical issues and challenges encountered when conducting this type of research.

### 1.2. Aims of the research

The primary aim of this research is to **establish how effective serious games can be when used as an education tool with public education and outreach programmes for volcanic hazards**. With many researchers choosing to adopt creative media for education and outreach programmes, this research aims to evaluate the effectiveness of serious games and to provide insight into the most effective method for them to be used. The overarching aim of this research can be broken down into the following main objectives:

I. To establish the state of the art for creative communication in natural hazards education and the current role of serious games for this purpose.

II. Identify the key characteristics of existing serious games that make them successful as tools for promoting learning.

III. To provide insight into the process involved in designing and developing a bespoke serious game for volcanic hazard education.

IV. To design an effective evaluation strategy for implementation testing that adopts quantitative and qualitative data collections in order to examine how effective serious games are at improving participants' knowledge of volcanic hazards in both, the short- and longer-term.

V. Using the data obtained through implementation testing, to compare and constrain how effective video games are as an outreach tool when compared with more traditionally used education techniques (e.g. presentations) and how best they may be implemented.

VI. To provide recommendations and share issues and challenges encountered during the design, development and implementation phases of this research to inform other researchers considering pursuing a similar study.

## 1.3. Thesis structure

This thesis is presented in chronological order to fully document the process undertaken as part of the research. Chapter 2 of this thesis comprises a literature review which defines some of the common terminology used within this thesis and examines the techniques and approaches currently used for natural hazard outreach and education. The literature review also looks at the current uses of serious games across a broader education platform and seeks to identify methods and features which can be adopted within the design of the game developed as part of this research.

Chapter 3 introduces the study location for this research – the eastern Caribbean island of St. Vincent. It provides justification for the selection of St. Vincent as the study location by explaining its violent volcanic history, exploring its unique vulnerabilities to volcanic hazards and identifying the methods and approaches currently used for outreach and education for volcanic hazards.

Chapter 4 covers the design and development phase of the *St. Vincent's Volcano* game, providing a detailed step-by-step methodology. This includes detail of how user requirements were established, considerations made for the game content, how the game was storyboarded, and finally how the game was created. The final section of this chapter includes the results of the first formal testing of the game for functionality and robustness with students from Plymouth University. The finalised game is introduced within Chapter 5, with each of the scenes of the game described in detail.

The methodology for the game's implementation within outreach sessions on St. Vincent is described in Chapter 6. It details how participants were selected, the quantitative and qualitative data collection methods used to establish learning and engagement, and justifications for each method adopted. The final results established from this testing in St. Vincent are then presented within Chapter 7. This chapter is broken down into sections to present the data collections to assess the impact on knowledge and learning gain, including a longitudinal study; participant engagement; the outcomes of in-built game analytics; and the ability of the game to communicate existing outreach materials.

Chapter 8 discusses the results obtained through the study and puts them into context to establish how effective video games are for volcanic hazard outreach and communication. This chapter also critiques the final game design, outlines key issues and problems encountered during the study and provides recommendations for other researchers. Finally, Chapter 9 draws overall conclusions from this study, outlines the key findings and presents areas for potential future research

#### *1.3.1. Thesis terminology*

This research adopts the phrase 'serious game' to define the developed and tested *St. Vincent's Volcano* game. The game produced is primarily designed as an education tool with aspects of interactivity and input from the player providing the 'game' aspect. However, the primary aim remains education; therefore, it is considered appropriate that the phrase 'serious game' is used throughout this thesis, rather than video game or computer game.

# CHAPTER 2: Review of literature: creative communication and video games in natural hazards education.

This chapter presents a review of the academic literature relating to techniques and approaches adopted for disaster risk reduction (DRR), with particular interest in the creative approaches currently employed for natural hazards outreach and education. The first section of this chapter defines natural hazards, vulnerability, exposure and disaster risk in the context of this research and outlines the adoption of the Sendai Framework, which has been developed to encourage disaster managers to work towards building more resilient populations, through improved DRR practices.

The second part of the chapter explores the methods currently adopted for DRR practices at the community level to raise awareness and encourage adoption of preparation measures. This section includes an overview of how the depiction of maps for natural hazard communication is evolving and critiques some of the other creative communication practices in play. This includes the use of films, comic strips, puppet shows and board games currently used in natural hazards education.

The final section of the chapter discusses the general benefits and limitations of using serious games for volcanic hazard education whilst critiquing existing uses both within natural hazards and in the wider education and training sectors. This section examines existing serious games and seeks to identify the common factors that make them successful in their aims of improving knowledge. Finally, the chapter provides justification for the selection of serious games in regards to the aim and objectives for this research.

## 2.1. Terminology: natural hazard, disaster risk, vulnerability and exposure

In this section, each of the terms 'natural hazard', 'risk', 'exposure', 'vulnerability' and 'resilience' are defined using recently updated (February 2017) definitions from the United Nations International Strategy for Disaster Reduction (UNISDR).

### *2.1.1. Natural hazards (geological or geophysical hazards)*

The UNISDR (2017) defines a hazard as *"a process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation."*

The term 'natural hazard' is used across many disciplines and has a wealth of, often contradictory, definitions within published literature. One of the earliest definitions provided for natural hazards was by Burton and Kates (1964, p.413), who suggested *"natural hazards are those elements in the physical environment, harmful to man and caused by forces extraneous to him."* The definition strictly covers the nature of the hazard and does not propose an explanation for why natural hazards are indeed hazardous to man. A further definition provided by Alexander (1993) in *Natural Disasters* defines natural hazards as: *"A physical event which makes an impact on human being and their environment. The hazard involves the human population placing itself at risk from geophysical events"* (Alexander, 1993, p.4). This definition describes the nature of the hazard and their potential impact on man in more detail than Burton and Kates (1964). The UNISDR adds to the definition of a hazard to further define a natural hazard as *"predominantly associated with natural processes and phenomena"* (UNISDR, 2017*).*

Of particular relevance to this research, the UNISDR (2017) provides a further definition for geological or geophysical hazards, of particular relevance to this research. Geological or geophysical hazards *"originate from internal Earth processes"* and include earthquakes, volcanic activity and emissions, landslides and debris or mud flows. The definition also states that hydrometeorological conditions may also have an impact on geological or geophysical hazards (e.g. rainfall on mud flows).

For this research, the UNISDR (2017) definition for hazards, natural hazard and geological or geophysical hazards are adopted.

### *2.1.2. Vulnerability*

Due to the broad application of the term 'vulnerability' across natural hazards and social science, an array of definitions exists. Typically, vulnerability relates to the characteristics of a person or community and their circumstances that can affect their ability to cope with and recover from a natural hazard event (Wisner *et al.*, 2003; Hicks, 2012).

The UNISDR (2017) definition of vulnerability comprises *"The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards."*

Factors to assess social vulnerability are often: population, age, race, income, employment, and health; with victims of natural hazards often encompassing marginal groups such as people with disabilities, women, children and the elderly (Cutter *et al.*, 2003; Gaillard, 2008). Frequently, in relation to vulnerability to volcanic hazards, communities increase their vulnerability by living close to a volcanic centre and farming the land around active volcanoes. One such example of this behaviour is on the Eastern Caribbean island of St. Vincent where many young farmers are adopting land on the high flanks of the La Soufriere volcano, despite its well-known violent eruptive history. Often, natural hazards are seen as an amplifier of vulnerability and Gaillard (2008) expresses the need to understand the social, political and economic nature of vulnerability for communities considered at-risk, to reduce impacts (USAID, 2011). For the purpose of this study the UNISDR (2017) definition of vulnerability is adopted.

### *2.1.3. Exposure*

Exposure is another key component of disaster risk reduction. The UNISDR (2017) defines exposure as *“The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas”.* Where a hazard occurs in an area of no exposure, there can be no risk (GFDRR, 2014). For example, if a natural hazard event such as a landslide occurs in an unpopulated area, then there is no risk to people, housing or infrastructure as defined by UNISDR (2017), therefore, there can be no problems relating to disaster risk (IPCC, 2012).

Exposure and vulnerability are often used interchangeably, however, they are distinct. It is possible to be exposed to a natural hazard but not vulnerable. For example, people living within active seismic zones are exposed to the risk of earthquakes; however, they may have taken provisions such as building retrofitting and other measures to mitigate potential loss. This therefore means they are exposed to a future earthquake event but not vulnerable to the impacts.

Drivers of exposure can include, but are not exclusive to, population growth, migration, badly planned and managed urban development and poverty (UNISDR, 2015b). One such example is the movement of populations due to conflict and/or environmental change to areas of refuge which can have greater exposure to natural hazards.

### *2.1.4. Risk and Disaster risk*

‘Risk’ is a concept that is more challenging to provide a definitive definition for due to its varying use across multiple disciplines, particularly social science. Further, much disagreement exists over the exact use of the phrase ‘risk’, with some believing risk to be “a *concept that human beings have invented to help them understand and cope with the dangers and uncertainties of life.”* (Slovic & Weber, 2002, p.3-4). A more accurate definition of ‘risk’ for the Disaster Risk Reduction (DRR) community was provided by the United Nations Development Programme (UNDP), who defined ‘risk’ as “*the probability of harmful consequences — casualties, damaged property, lost livelihoods, disrupted economic activity, and damage to the environment — resulting from interactions between natural or human-induced hazards and vulnerable conditions”* (UNDP, 2010).

Within the natural hazards and DRR arena, the term ‘risk’ was also defined by numerous authors; for example:

- Paton et al. (2008, p.179) - “*a product of (a) the likelihood (probability) of a hazard event occurring, (b) the consequences of hazard activity.”*
- Wisner et al. (2003, p.49) - “*a compound function of the natural hazard and the number of people, characterised by their varying degrees of vulnerability to that specific hazard, who occupy the space and time of exposure to the hazard event.”*
- National Institute of Water and Atmospheric Research (2016) - *“In the context of natural hazards, "risk" not only represents the possibility that a hazard event could occur, but also its likelihood and consequences. There are many ways it can impact a community, from the destruction of property and infrastructure, through to injuries and casualties, to influencing economic activity.”*

In 2017, the UNISDR terminology bank was updated to provide a more detailed and encompassing definition of risk relating specifically to DRR, instead using the phrase ‘Disaster Risk’. Disaster risk is defined by UNISDR (2017) as *“The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or community in a specific period of time, determined as probabilistically as a function of hazard, exposure, vulnerability and capacity”.* Based on this definition, disaster risk can only be possible if there are elements of hazard, exposure and vulnerability. For this research, the term ‘disaster risk’ and the definition provided by UNISDR (2017) is adopted.

## 2.2. Hazard communication and education

As the global population increases, so does the number of people living in proximity to volcanic centres (Siebert *et al.*, 2010). This increased exposure of populations to volcanic hazards, has led to increased motivation to strengthen resilience of exposed and vulnerable communities to volcanic hazards. This is often approached through the instigation and improvement of awareness-raising programmes to try and encourage communities to adopt preparation measures to reduce their vulnerability.

This increased motivation for improved resilience was cemented with the formalisation of the Sendai Framework for Disaster Risk Reduction in 2015. The Sendai Framework aims to reduce the number of deaths, injuries and impacts caused globally by disasters (human and natural). To address that goal, the Sendai Framework identifies the need for participating countries to continue working toward substantial disaster risk reduction practices building upon work undertaken under the former Hyogo Framework for Action (UNISDR, 2015a). The Sendai Framework reflects on the importance for "*strengthening public education and awareness in disaster risk reduction*", specifically promoting the use of social media, community mobilisation campaigns and encouraging the education of all at-risk communities (UNISDR, 2015a, p.15).

Within the DRR arena there is broad acceptance of the role of education and outreach programmes for improving knowledge and awareness of natural hazards (McKay, 1984; Johnston *et al.*, 1999; Paton *et al.*, 2000; Ronan & Johnston, 2001; Paton *et al.*, 2008). These education and outreach programmes, often primarily focused on school-aged children, take the form of presentations, posters, leaflets and table-top activities. School children are the easiest audience to access to deliver outreach sessions with at-risk communities and there is current thinking that children often reflect on their learning at school with parents and relatives. This could potentially lead to a transfer of knowledge through to adults as a result (Ronan & Johnston, 2003; Carlino *et al.*, 2008; Sharpe & Izadkhah, 2014).

One such example for the successful implementation of an education programme for improving knowledge of natural hazards with school children is from Shaw *et al.* (2004). The authors used secondary-school students (aged 15-16 years) in Japan to demonstrate in-school education sessions of earthquake hazard were able to stimulate students' interests in the subject and led to a positive improvement of knowledge around the subject. However, much of the debate around the role of education and outreach programmes with at-risk communities relates to how knowledge and understanding of natural hazards can motivate a community or population to adopt preparation measures, thus reducing their vulnerability.

The process for at-risk communities to adopt preparative measures is multi-faceted and some studies have shown that increased awareness does not lead to adoption of preparative measures. Some studies have even shown that communities actually reduced their preparation measures after educational intervention. One such example was from Paton *et al.* (2008), who demonstrated that after the deployment of an education and outreach programme in the Auckland area of New Zealand, 28% of residents actually wanted to reduce their levels of preparation for future events. Paton *et al.* (2008) attributed this finding to the strong links between people's perception of risk and preparation measures; arguing that as people began to learn more about their environment and the monitoring network in place at the volcanoes, they began to feel safer and thus, their risk perception reduced. As participants' levels of perceived risk dropped, so did their motivations for adopting preparation measures.

A similar trend was also demonstrated by Johnston *et al.* (1999), who used exposed communities to volcanic hazards in New Zealand to examine whether direct experience of the 1995 Ruapehu eruption led to improved resilience of local communities. Although participants were able to demonstrate an improved knowledge of the threat of volcanic hazards to their communities, there was no increase in the level of preparation measures adopted by the communities. Similarly, Fişek *et al.* (2002) observed a similar trend when studying risk perceptions of two communities in Turkey affected by the 1999 Marmara earthquake. They observed that although there was a high level of awareness and perceived risk within the communities, this did not lead to improved preparation measures, commenting that a key factor controlling the adoption of preparative measures was financial.

An added complication in the understanding of the interplay between education and preparation comes in the levels of perceived risk by exposed communities. Research has shown that the probability of a major hazardous event occurring, such as a volcanic eruption, posing a threat to exposed communities is relatively low, this can lead to reduced perceptions of risk (Paton *et al.*, 2008). This low threat from imposing hazards can often result in communities becoming demotivated to adopt preparative measures and further, increasing reliance on scientists to give enough warning before an event occurs to prepare themselves (Johnston *et al.*, 1999; Shaw *et al.*, 2004; Paton *et al.*, 2008). Additionally, communities that may find themselves exposed to multi-hazards, such as the Caribbean islands whom are often exposed to hurricanes, landslides and volcanic eruptions, may prioritise their preparation activities. Perry and Lindell (2008) looked at the effect of volcanic risk perception in two Californian (USA) communities prone to wildfire, earthquakes and volcanic hazards. The recurrence intervals of these hazards is variable; wildfires recurrence can be annual and last for prolonged periods of time (months); compare to the last volcanic eruption of Mt. Shasta (the most proximal volcano) which occurred in the 1700s and now with a low likelihood of explosive eruptive activity in the next 50 years. Further, seismic activity in the area is relatively low (0.50 probability of an earthquake in the next 50 years). The study demonstrated that communities were more likely to adopt preparative measures for the more-frequently occurring wildfires than for either volcanic or seismic hazards.

The literature shows that there is a disassociation between education and outreach programmes and their ability to reduce community vulnerability through the adoption of preparation measures (Paton *et al.*, 2008). This has now led to a corresponding shift in the approaches adopted to try and improve education and outreach materials and programmes with exposed communities.

A recurring theme presented within the academic literature supporting the use of education and outreach as a tool for DRR is that education alone does not necessarily lead to action. However, some studies showed that if a collaborative approach is adopted for the development of DRR tools with exposed communities and the agencies tasked with developing the materials, then the willingness to adopt preparative measures can be increased (Paton *et al.*, 2008; Hicks *et al.*, 2017).

One such example of a collaborative approach is by Hicks *et al.* (2017) who developed community-based films used for volcanic hazard education is a series of films developed by the Strengthening Resilience in Volcanic Areas (STREVA) project, for the Caribbean island of St. Vincent (also the study location for this research) and for the area close to Nevado del Ruiz, Colombia. STREVA developed 2 series of films for St. Vincent: one series of 3 episodes of islanders talking about their experiences of the 1979 eruption and a series of 6 films presented by Dr Richard Robertson (Seismic Research Centre), who explains the various volcanic hazards and their potential effects on the island based on La Soufriere's historic eruptions. Three films made with communities at Nevado del Ruiz show residents talking about their experiences of the devastating 1985 eruption. The films were developed with the primary aim of raising awareness of volcanic hazards and the potential effect of a future eruptions with the hope that they would empower communities to adopt preparation measures for a future volcanic eruption (Hicks *et al.*, 2017). The films were developed uniquely in collaboration with local communities and key DRR agencies in both locations and then showcased to communities across St. Vincent in April 2016 (200 participants) and Colombia in March 2016 (700 participants). Feedback data was gathered at screenings through post-film surveys and focus groups. The results from the final evaluations demonstrated that the films were successful in their aims to motivate people to actively seek hazard information, to encourage at-risk communities to adopt risk-reducing measures and to ultimately strengthen resilience at the individual, community and risk management levels (Hicks *et al.*, 2017). This study provides an indication of the effectiveness of participatory development of education materials with key agencies and communities. Further, with large numbers of people engaged in the showcases, it also indicates the potential for creative media to encourage communities to engage with hazard education.

The study by Hicks *et al.* (2017) demonstrates an example of how education sessions can be successfully used to encourage the adoption of preparative measures for future volcanic eruptions, but also how the use of creative media can support these aims. This research shows that strong collaboration between exposed communities and DRR agencies can lead to reduced vulnerability to volcanic hazards. However, it also shows that through the adoption of technology and creative media (in this case films), education messages can be delivered more effectively to increase awareness and ultimately, increase adoption of preparation measures.

Another example of how creative technology is being used to enhance the way we present hazard information is hazard maps. The use of sophisticated GIS programmes has led to a shift from traditional 2D map depictions to 3D terrain models. The next section presents some of the recent developments for visualising hazard maps and how these are being used in education and outreach programmes.

### *2.2.1. Volcanic hazard maps*

Maps are one of the most common tools for education in hazardous areas, whether it be topographical maps to demonstrate landscape features or hazard maps to show areas most at exposed to a natural hazard event. A hazard map identifies zones of low to very high hazard based on historical data (e.g. eruption records) modelling, geology, topography and geographical locations (Donovan, 2010). In relation to volcanoes, they generally indicate the areas most likely to be impacted by volcanic hazards including: pyroclastic flows, lahars, ash fall and lava flows. Calder *et al.* (2015) explored the different types of hazard map that are currently produced within the volcanic hazards community and identified 5 different styles of hazard map currently employed to communicate volcanic hazard information (Figure 2.1)

Figure 2.1. has been removed due to Copyright restrictions

**Figure 2.1. The five types of hazard map currently used to communicate volcanic hazard information where a) geology-based maps, b) integrated qualitative maps, c) administrative maps, d) modelling-based maps and e) probabilistic maps. Taken from Calder *et al.* (2015).**

Each hazard map is selected based on the data available and the perceived needs of the end-users (e.g. at-risk communities). These 5 hazard map styles include:

a. *Geology-based maps* - where hazards are mapped based on their historical occurrence and extent. The map is produced based on field-based evidence of historic volcanic deposits. Therefore it is only as reliable as the data available and may not be full representative of all potential eruption magnitudes and intensities of eruption.

b. *Integrated qualitative maps* – integrating all geological hazard information onto one map. The overall effect is simple, often comprising concentric zones radiating from the source.

*c.* *Administrative maps* – maps that combine both the hazard information with the requirements for disaster management (e.g. areas that require quick evacuation based on access difficulties).

*d.* *Modelling-based maps* – maps developed using a scenario-based simulation of the impact of volcanic hazards on the surrounding area taking into account the magnitude and intensity of the eruption. For example, the areas affected by a small, medium or large pyroclastic flow deposit.

*e.* *Probabilistic maps* – takes into account historical data and models future potential hazard occurrence based on thousands of computer models and simulations. These maps can often be complicated to understand due to the data involved in the modelling procedure.

There is little empirical evidence to explain how volcanic hazard maps are used effectively to communicate information to exposed communities. However, volcanic hazard maps are widely known to have been published in books, phone directories or made available on public noticeboards and within schools. One example that does explain how hazard maps have been used was by Lowe (2010) who described the use of integrated qualitative-type maps printed within newspapers and used widely within public education and outreach sessions across the Caribbean island of St. Vincent.

Volcanic hazard maps are often produced by governmental organisations (such as volcano observatories) and frequently in close collaboration with the academic community (Calder *et al.*, 2015). However, they are rarely produced collaboratively with communities and people that the map is intended to communicate information to, forming disconnect between those trying to communicate information and those who need to receive it. Additionally, high levels of illiteracy commonly encountered within exposed communities, additional language complications (for example in Indonesia, over 40 languages are spoken in proximity to Mount Merapi Volcano) and the use of complex terminology by those who develop the maps, mean that volcanic hazard maps are rarely suitable for the intended end-audience (Donovan, 2010).

A study undertaken by Haynes *et al.* (2007) tried to overcome some of these common issues by seeking to understand if advancements in technology for developing maps can be used to enhance map comprehension by lay populations. Haynes *et al.* (2007) sought to understand how peoples' comprehension of an existing 2D map (Figure 2.2), compared to newly developed 3D maps for volcanic hazard mapping on the Caribbean island of Montserrat. Two resident groups were used, with the first asked to locate themselves and landmarks on 2D maps and the second using 3D topographic maps. Both groups were also supplied with oblique aerial photographs. The results demonstrated that communities had difficulty interpreting the colours, features and topography of the 2D map and that although they could identify the boundary to the exclusion zone, were not able to identify the link between the exclusion zone extent and the topography. However, overall the study showed there was a minor improvement for the participants using the 3D maps in their ability to locate themselves. The most significant improvement was in the understanding of the relationship between hazard and topography using the aerial photographs. The results of this study provide positive signs that using more familiar type maps (e.g. using aerial photographs and realistic looking 3D maps) may enhance at-risk community comprehension of the information provided through maps

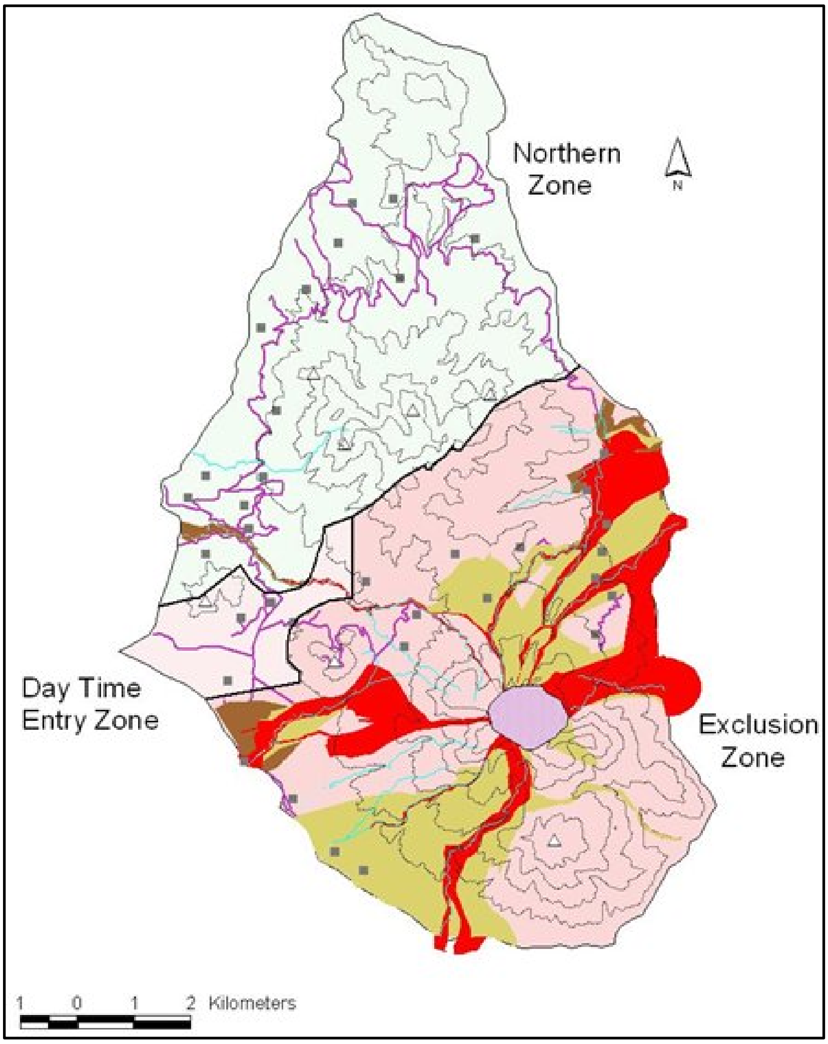



**Figure 2.2. The geology-based hazard map used by Haynes *et al.* (2007) with exposed communities to explore how well they understood the volcanic hazard map presented to them (taken from Haynes *et al.* (2007) adapted from Cole *et al.* (2002). Map comprises a contour map of Montserrat overlain with volcanic hazard information. Permission to reproduce this image has been granted by Springer Nature.**

In a similar study for lahar hazards at Mount Hood, Oregon, USA, conducted by Preppernau and Jenny (2015); participants were shown four maps and asked to complete activities for terrain interpretation, estimation of lahar travel times and evacuation routes. The results of the study revealed that most participants preferred the use of 3D maps, being able to interpret the terrain better and choose the more appropriate evacuation routes.

Both studies revealed that participants were better able to identify key features and make informed choices when using 3D hazard maps or aerial photography. A logical progression of this realisation is to consider how we may be able to improve hazard awareness using better resolved 3D representations of hazardous settings, something that is reflected upon in this study through the use of virtual gaming environments.

#### *2.2.2. Creative hazard and risk communications*

As an acknowledgement by the disaster risk reduction community of the importance of the development of effective and engaging outreach programmes, new and innovative education media have emerged. This boom in innovative education techniques builds upon research that suggests young people who grew up with accessible technology, now learn differently than generations before (Prensky, 2001; Annetta, 2008; Bekebrede *et al.*, 2011). A fresh generation of learners - sometimes called the Net-Generation or Net-Gen (Tapscott, 1998) - are accustomed to a digital age in which information, news and entertainment are obtained instantaneously and delivered directly to them on personal devices (e.g. mobile phones, tablets and laptops). This has led to a rise in innovative teaching techniques in the classroom, in an effort to better motivate this new generation to learn (Prensky, 2001). Within the natural hazards arena, these new innovative media have included films (as presented in Section 2.2), comic strips, puppet shows, board games and computer games, amongst many others. Some examples of the adoption of these creative media for hazard education are presented here.

Comic strips were used by Sharpe and Izadkhah (2014) to explore how effective they were for education of kindergarten students on earthquakes in Iran. The *Silly Timmy* comics (Figure 2.3) were developed with the aim of providing a simple education tool for communicating earthquake hazard. The comics include the main character 'Timmy' making a series of mistakes during an earthquake event with a 'Fairy' character also used to teach Timmy the correct information. The *Silly Timmy* comics, created by Justin Sharp of King's College, London, were used with 31 children in Tehran in December 2012. The results from the study, although small-scale, demonstrated that the comic strips were successful in engaging students in their learning, which led to a good knowledge retention when re-visited three weeks post-study. One significant finding was the ability of the students to re-teach each other the knowledge they had learnt about earthquakes but also their apparent transfer of knowledge to other classmates and family members (Sharpe & Izadkhah, 2014). The comics are simple, clear and to the point, presenting the information to the students within a few simple frames. Although the results from this study are not empirical, they demonstrate that there is a potential use and need for creative communication techniques in natural hazards education.


**Figure 2.3. An example of a *Silly Timmy* comic strip used to educate about earthquakes in Iran by Sharpe and Izadkhah (2014). Permission to reproduce this image has been granted by J. Sharpe.**

Another simple but creative approach to natural hazards education has been through puppet shows with at-risk communities. A charity – '*No Strings*' – have made a series of films using puppets to explain topics such as volcanic eruptions, earthquakes, hurricanes and even landmine safety and healthcare issues (e.g. HIV and gender awareness) (Watt, 2015). The films are simple and show characters undergoing a natural hazard scenario (e.g. a volcanic eruption). Through narration, the puppets take appropriate measures to protect themselves providing clear guidance to the audience. The films are both engaging and interesting to watch; however, to-date no evaluation has been completed to establish how effective the puppet shows are for improving knowledge of the topics presented. Nonetheless, the puppet shows demonstrate a diverse method of hazard communication currently used to engage students and young people in natural hazard education.

A final example of creative communications for natural hazard communication is a board game developed by Mossoux *et al.* (2016) called '*Hazagora: will you survive the next adventure?'*. Although not the first example of the use of board games for this application, the *Hazagora* game uniquely targets both secondary school students and disaster risk managers. The aim of the game is to improve knowledge of geohazards, risk and disaster risk reduction strategies amongst players by generating discussion. It was tested with students and adults in Europe and Africa, with evaluation collected through surveys and session observations. The results from the study showed that there was a notable knowledge improvement generally relating to geohazards, including their intensity, spatial distribution and their potential impacts on communities. However, the results also revealed that the game was difficult for some players to grasp, particularly those who had not previous played board games with complicated game rules. The advice from the authors is for the participants to play the game many times with the same group of players to enhance the learning experience (Mossoux *et al.*, 2016). However, the game duration is noted to be up to several hours, meaning that any repetitions of the game would be unlikely with their target audiences (e.g. time away from curricular studies in schools is often difficult to arrange). Nonetheless, the *Hazagora* board game is a good platform for collaborative outreach and education between communities and disaster risk managers. The results of this study demonstrate that the technique requires a significant input and engagement from participants and where possible, repetitive interventions in order to achieve the goal of improving knowledge and understanding of risk reduction practices.

This section has provided a brief overview of some of the most creative techniques currently employed in natural hazards education. Some of the examples provided have laid the foundations of providing a bank of empirical evidence for the adoption of more creative education and outreach media, whilst highlighting areas of success and weakness which can be built upon. Using these key examples of the use of creative media, this study seeks to establish if video games – or serious games – can be used for the same application and, to what extent they are effective. The following section of this chapter presents an overview of serious games and their rise in the education sector, explores some of their applications both in and outside of natural hazards research and provides a critique of their effectiveness. The overall aim is to provide justification for the use of serious games within this study as a creative media to communicate information relating to volcanic hazards.

### 2.3. Serious games

Serious games and virtual environments were considered a logical progression for this study that builds upon research demonstrating people's understanding of hazard maps is greatly improved when using 3D maps over more traditional representations (Haynes *et al.*, 2007; Preppernau & Jenny, 2015). Additionally, with a shift towards the use of more creative media for education and outreach practices and towards the use of virtual environments, serious games were considered to be an ideal platform for this research to explore how they could be used.

Serious games may provide an understanding whether we can use virtual reality environments to foster effective spatial thinking. Computer games are increasingly offering that potential, hence the emergence of ‘serious games’, defined by Michael and Chen (2005) as a game in which *“education is the primary goal, not entertainment, with the intention of improving a specific aspect of learning.”* Serious games focus on specific learning outcomes to achieve changes in performance and behaviour which can be sustained (Derryberry, 2007). Zyda (2005) added further to the definition of serious games, suggesting that they needed to include a sound pedagogical underpinning to enable learning and knowledge transfer.

The popularity of serious games has increased in the last decade with more bespoke games being developed across a broad range of subjects (e.g. military, health, advertising, economic and corporate training). The earliest example of a serious game was *America’s Army* launched in 2007 by the U.S. Army. The game was developed as a recruitment tool and was designed to simulate, with accurate detail, what it is like to be a soldier in the U.S. Army; proving highly successful (Michael & Chen, 2005; Zyda, 2005). Building from *America’s Army*, serious games have now widely been applied to curricular subjects (e.g. maths, geography and science) and have been integrated into school teaching around the world. However, one of the most widely used application of serious games is within the medical sector, with games used to educate new doctors on surgical procedures and even to educate communities about hygiene and disease prevention (Ricciardi & De Paolis, 2014; Mellor *et al.*, 2016).

It is becoming more important to integrate new technologies and interactive media into education to keep the audience motivated and engaged in their learning experience (Bekebrede *et al.*, 2011). Prensky (2001) argues strongly for the emergence of a new generation of learner – the Net Gen or Net Generation – who are considered to have a different way of interacting and learning in general, favouring video, audio and interactive media when compared to their parents’ generation (Prensky, 2001; Carlson, 2005; Annetta, 2008; Bekebrede *et al.*, 2011; Sharp, 2012). Prensky (2001) suggested that the

Net Gen live in a digital media saturated environment and treat the use of technology as a second language (Digital natives), opposed to their parent's generation who have had to adopt a technological way of life (Digital Migrant or Digital Immigrant). With the evolution of this new generation of learners, technology is becoming increasingly adopted within education practices, particularly the use of video games to try and actively engage learners in their education.

In recent years, there has been significant publicity relating to the negative influence of video games on behaviour however, strong evidence is now emerging to demonstrate that video games can also have a positive impact on behaviour and learning. Ball (1978) was a pioneer at identifying a link between how video games can aid education. He surmised that video games can be used to enhance children's spatial abilities and intellectual skills, including reading comprehension and assimilations of number concepts, as well as promoting reading (Aguilera & Mendiz, 2003). Further research suggests a link between video games and knowledge acquisition, cognition, behaviour, motivation, and physiological and social outcomes (Aguilera & Mendiz, 2003; Boyle *et al.*, 2011; Connolly *et al.*, 2012; Sharp, 2012). This link between the benefits of video games and education has led a new revolution into the development of video games built specifically for a research purpose known as 'serious games'.

### *2.3.1. Serious games for natural hazard education and disaster risk reduction*

The potential for serious games in natural hazard education and outreach is highlighted by the fact that one of the first purpose-built serious games was created by the UN International Strategy for Disaster Reduction (ISDR) as part of the Hyogo Framework for Action (UNISDR, n.d.). The ISDR game, *'Stop Disasters!'*, (Figure 2.4) was designed to educate children about preparing for a natural disaster by building adopting preparations measures for a number of hazards (e.g. hurricanes, earthquakes, wildfires and flooding). Players are required to prepare their towns for an impending natural hazard by retrofitting buildings, creating physical defences and establishing early warning systems. The game was supported by a website of teaching materials and has been used in education programmes by the Seismic Research Centre (SRC) in the Caribbean region (Pers. Coms. SRC, 2015). The concept of the game, although simple, is effective at providing contextualised information to the player (e.g. when a building is upgraded, it explains why this is important). The length of game play can be tailored to suit the user and the content of the game is relevant for localities that can be affected by more than one natural hazard scenario. However, to-date there has been no research into the most valuable application of the game or as to how effective it is as an education tool. One particularly successful aspect of this game is the simple approach to progression and achievement through the game that motivates the user to continue playing (Griffiths, 2002).


**Figure 2.4. Screenshot from the earthquake scene of the UNISDR *Stop Disasters!* game. Permission to reproduce this image has been granted by UN ISDR.**

A similar approach was taken by UNESCO and the government of Japan in designing '*Sai Fah: The Flood Fighter*' (*Sai Fah*) (Figure 2.5), a bespoke game built as a response to devastating floods in Thailand in 2011. Like *Stop Disasters!,* the game is a simple platform aimed at young children, intended to educate them about how to recognise when flooding is likely and about the actions they should take to prepare. The game is freely available for a number of devices (e.g. mobile and computer) and, to-date, has been translated into several languages for use in education programmes around the world. Each scene of the game is highly interactive, encourage the player to explore the extent of the game scenes. In some levels of the game, there are short tasks to complete with the player receiving a reward for each task completed.


**Figure 2.5. Screenshot of the *Sai Fah: The Flood Fighter* game from UNESCO and the Japanese Government. Permission to reproduce this image has been granted by OpenDream.**

*Sai Fah* possess common characteristics that makes it engaging for the player, including: high levels of interactivity (through clickable icons and activities), a clear game objective, and reward-based activities (e.g. point-scoring and upgrades). Similarly to the *Stop Disasters!* game, no evaluation has been completed to-date using the *Sai Fah* game with its intended audience – at-risk children from flooding in Central Asia. Therefore no real conclusion can be drawn on the how effective the game is at its intended purpose of preparing communities for flooding events.

### *2.3.2. Justification for the use of serious games*

Bespoke designed video games such as *Sai Fah* and *Stop Disasters!* allow for a more interactive, engaging and tailored educational experience for the players. One of the desired outcomes of this research is to provide education for volcanic hazards to students in a fun and engaging way, which encourages them to remember the information over a longer-term purely due to the novel nature of their interventions. The thought is, that the more novel and memorable the intervention session, the more likely the students are to remember the information during a time of crisis, which may be many years in the future. This more active-type engagement for students through the use of serious games may promote learning and motivation to learn (Wouters *et al.*, 2013).

There is a wealth of academic literature relating to the benefits associated with the use of serious games in education and providing empirical evidence for their effectiveness for this use (Long & Long, 1984; Griffiths, 2002; Connolly *et al.*, 2012; Guillén-Nieto & Aleson-Carbonell, 2012). One key advantage of serious games is they can simultaneously stimulate audio-visual sensors whilst proving a kinaesthetic, hands-on learning experience (Gee, 2005). The result of serious games being able to engage with a broad range of learning styles, is that they can be used with all types of students, no matter how they prefer to learn, something not often considered in more traditional outreach interventions.

Serious games typically adopt a problem-based learning approach (Clark, 2007; Kiili, 2007), which means that players must use problem-solving to progress and reach the end of the game. This style of learning is demonstrated within the *Sai Fah* game, which requires players to complete each level before progressing to the next. This problem-based approach to the games is designed to motivate the player to continue their progression through the game and, ultimately, the learning experience. This problem-based learning is often approached through ‘level ups’ and rewards-based challenges as demonstrated with both the *Stop Disasters!* and *Sai Fah* games. Rewards, whether intrinsic or extrinsic, can result in increased motivation levels for players to continue engagement with their learning experience (Wang & Sun, 2011).

One of the most interesting benefits of using serious games for this research is their ability to provide instantaneous feedback to the player as they completed challenges, levels and problems. This feedback is useful for providing continued motivation for players and reinforcing the learning message, but also as a method to overcome misappropriation of knowledge and the development of misconceptions at an early stage in the learning cycle (Lee *et al.*, 2004; Johnson, 2008). Building on this unique benefit, serious games can also have analytics integrated within them to collect data on how well students are performing, as well as strengths and weaknesses in their knowledge (Serrano-Laguna & Fernández-Manjón, 2014; Serrano-Laguna *et al.*, 2014). The combination of instantaneous feedback and the use of game analytics present a unique opportunity of outreach practitioners to gather evidence that learning has occurred from their interventions and to quantify it, with little input.

However, there are some limitations associated with the use of serious games for education. One of the most significant limitations is the high costs involved for the development of serious games for education use (Clark, 2007). On top of the initial development costs, games require maintenance and iterative improvements, further increasing the costs associated with their use. To-date there is little evidence available that demonstrates significant improvements in learning through the adoption of serious games compared to more traditional education techniques (Clark, 2007). Within disaster risk reduction and hazard education, there may be challenges associated with the use of games in areas where there may be lack of facilities and equipment available to run games of this calibre.

There are significant advantages and a strong evidence base for the use of serious games as an education tool. Serious games are already currently being used to educate various audiences about natural hazards, but to-date little empirical evidence has emerged as to their effectiveness for this application. With a rise in the number of games emerging for hazard education and disaster risk reduction, it seems timely to establish how effective serious games may be for this function and to investigate the most effective methods for their implementation.

## 2.4. Summary

In recent years following on from inception of the Hyogo Framework and its predecessor, the Sendai Framework, there has been increased motivation to understand how to make education and outreach practice as effective and engaging as possible with at-risk communities. This has led to a rise in the use of creative media such as films, books, puppet shows, comic strips and board games emerging within the natural hazards education and disaster risk reduction arenas (Section 2.2.2).

Studies completed by Haynes *et al.* (2007) and Preppernau and Jenny (2015) sought to understand the most effective methods of communicating important hazard information with lay communities through maps. Both studies identified the need for an evolution from traditional 2D maps which were often found to be too difficult to understand by at-risk communities or poorly interpreted. The studies focused on the integration of new technologies comprising the depiction of maps in 3D, resulting in a positive increase in their comprehension and in the ability of communities to take appropriate risk-reducing decisions (e.g. evacuation routes). This approach to hazard maps proved to be successful in improving people's understanding of the maps content and ultimately their knowledge of the natural hazards they faced.

Building upon this research, serious games were selected as a logical progression in natural hazard communication, enabling players to become immersed in their education experience. Further, a wealth of empirical evidence from the use of serious games in the education sector adds weight to the justification of their use for natural hazards education and DRR. Examples presented of the use of serious games in natural hazards education and DRR (*Stop Disasters!* and *Sai Fah)* provide a platform for consideration of the use of games, identifying key features and interactions that make them potentially successful as education tools. However, to-date there is a lack of evidence for the application of serious games in natural hazards education and DRR.

With serious games proving, when used in an education context, that they provide significant benefits when used as learning tools and with an increasing interest in their use in natural hazard education and DRR, it seems timely to provide a critical appraisal of their effectiveness for this application. Considerations also need to be made for the adoption of serious games over other media for education and outreach programmes, to ascertain whether some of the limitations of their use (e.g. high cost of development and limitation for facilities required to support them), outweigh the benefits.

# CHAPTER 3: Study Location - St. Vincent, Lesser Antilles.

This chapter introduces the field location chosen for this study – the Eastern Caribbean island of St. Vincent. The first half of this chapter introduces the geographical and geological setting of St. Vincent. It then provides descriptions of the previous eruptions of the La Soufriere volcano and frames the risks a future eruption might pose to communities living close to the volcano.

The second part of this chapter describes the key agencies responsible for monitoring the volcano and for preparing communities for potential future eruptions. Further, it discusses the pathways for dissemination of information during a crisis situation and the techniques and approaches already employed to reduce vulnerability of at-risk communities. This chapter concludes with an overall justification for the selection of St. Vincent as the study location for this research.

## 3.1. Geographical and geological setting

The island of St. Vincent is the largest island in a chain of islands making up St. Vincent and the Grenadines (SVG) in the Lesser Antilles archipelago. The Caribbean region is a volcanically active location with active volcanoes present on Martinique, Guadeloupe, Montserrat, Dominica, St. Lucia, Saba and St. Kitts as well as St. Vincent (Figure 3.1). However, St. Vincent has been specifically chosen as the location for this study due to its recent history of explosive volcanic eruptions and vulnerability to future volcanic eruptions.

### *3.1.1. Geographical setting*

St. Vincent is approximately 29 km long and 17.5 km wide located some 160 km west of Barbados and 97 km north of Grenada (Figure 3.1). According to the last Census conducted in St. Vincent in 2012, the islands population was 109,991 with over a quarter of the population (> 26,000) living in the capital Kingstown, to the south of the island (Ministry of Finance and Economic Planning, 2012).

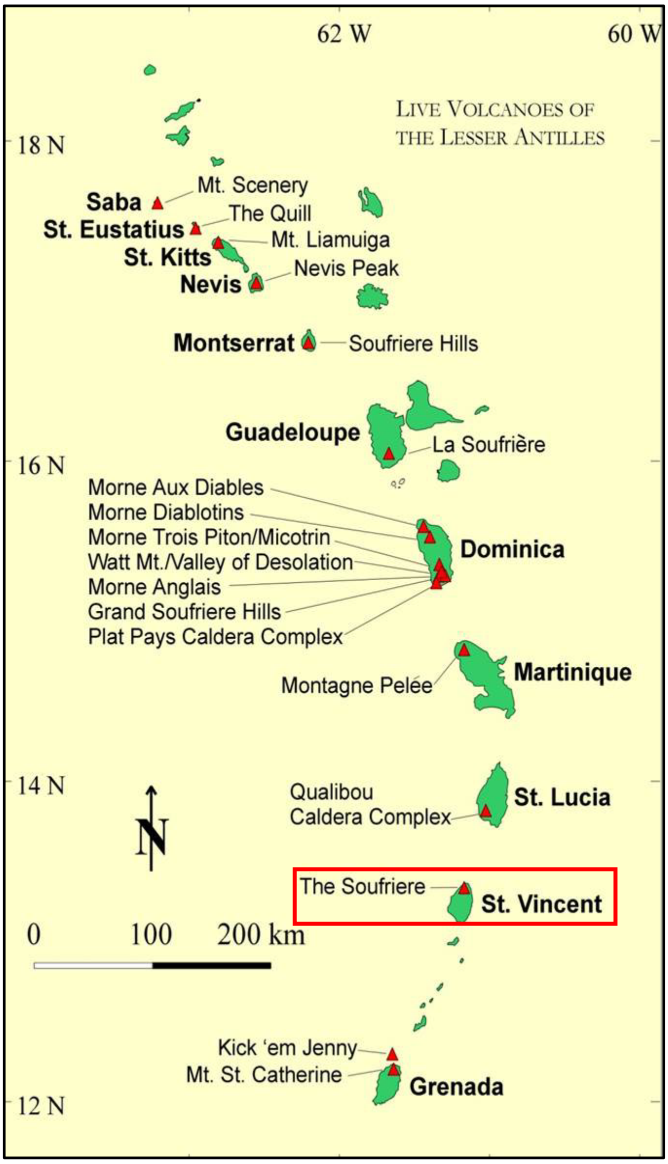



**Figure 3.1. Islands forming the Lesser Antilles with St. Vincent outlined with a red box. All volcanoes on each island indicated by a red triangles and associated volcano names (Seismic Research Centre, 2009). Permission to reproduce this image has been granted by R. Robertson.**

In the north of St. Vincent lies the La Soufriere volcano which has been the source of significant explosive volcanic eruptions documented in 1718, 1812, 1902 and 1979. Although these historical eruptions are the only examples documented, La Soufriere has had many other significant eruptions (Volcanic Explosivity Index [VEI][1] 3+) prehistorically, based on the presence of extensive volcanic deposits across the island.

**[1]Volcanic Explosivity Index (VEI) is the scale derived by Newhall and Self (1982) used to measure the explosive magnitude of a volcanic eruption.**

Present thinking is that La Soufriere could have had significant eruptions every 100 years over the past 4000 years (Robertson, 2005). Scenarios considered likely during a potential future volcanic eruption are discussed in Section 3.4.

Due to St. Vincent's steep, rugged and densely vegetated interior, much of the population resides on the lower-lying, more gently-sloping coastlines. The rugged and steep interior comprises the remnants of prehistoric volcanic centres forming a ridge stretching from Mt St. Andrew in the south to the modern active centre of La Soufriere to the north (Figure 3.2). The flatter coastlines have been formed from ancient volcanic deposits dating back an estimated 3 Ma (Robertson, 2005) creating fertile soils which now support extensive banana plantations and flat land on which communities have been built. One such example of a town built on volcanic deposits is Orange Hill which is located on Lower Pleistocene pyroclastic flow and surge deposits dated at >2000 BP (Robertson, 2005; STREVA, 2016b) . The windward (east) side of the island is more gently sloping than the leeward (west) side and therefore supports many larger communities, such as Georgetown, Sandy Bay, Orange Hill and Owia (Figure 3.2).

Currently, it is estimated that 15,406 people are living within the high hazard zone close to the La Soufriere volcano (Ministry of Finance and Economic Planning, 2012) which includes several large towns: Georgetown, Orange Hill, Sandy Bay, Owia and Fancy. Additionally, over half the population (56%) are aged under 36 years, meaning there are a high number of people who did not experience the most recent (1979) eruption and therefore have no first-hand experience of volcanic activity on St. Vincent.

### *3.1.2. Natural hazards facing St. Vincent*

The Lesser Antilles archipelago formed due to the subduction of the North American tectonic plate and/or South American plate beneath the Caribbean plate on which the islands are situated and continues to do so at an estimated rate of 2 cm/year (Bouysse *et al.*, 1990; Bachmann, 2001). Although the complex process that formed the islands is not fully understood, the region is tectonically active and prone to frequent earthquakes, with at least 14-recorded events over a magnitude of 6.9 since the 1500s (Seismic Research Centre, 2009).


**Figure 3.2. A relief map of the island of St. Vincent (adapted from Seismic Research Centre (2005)). The labels in blue show where the river valleys leading from La Soufriere are located. Permission to reproduce this image has been granted by R. Robertson.**

Although there have been no significant earthquakes to directly affect St. Vincent in documented history (since 1500s), many larger earthquakes occurring close to nearby islands have been felt on St. Vincent (Seismic Research Centre, 2011). In 2007 a large magnitude 7.4 earthquake struck off the north-west coast of Martinique with strong shaking felt across many of the Caribbean islands, including St. Vincent. More recently, swarms of low (<5.0) magnitude earthquakes were recorded off the north coast of Barbados in July 2015 that were felt on St. Vincent.

The Lesser Antilles are regularly exposed to other natural hazards including flooding, landslides and tsunamis. However, one of the most significant natural hazards the islands face is the annual hurricane season which occurs between 1 June and 30 November. The last major hurricane to affect St. Vincent was Hurricane Tomas in 2010. Although tropical storm warnings had been issued by the National Emergency Management Organisation (NEMO), many of the islands' residents were ill-prepared as the storm intensified and eventually hit land. The Category 1 hurricane struck St. Vincent at 20.00 UTC on 30 October, with the eye of the hurricane sweeping across the northern tip of the island bringing sustained winds of over 75 mph (120 km/h). Between 30 October and 7 November, St. Vincent received over 150 mm of rainfall (NASA Earth Observatory, 2010), where typical average rainfall for the whole of November is 190 mm (The World Bank Group, 2017), causing widespread landslides due to loose volcanic deposits and steep hillsides (CDEMA, 2010). The areas between Park Hill (close to Colonarie) and Owia on the windward coast and between Belle Isle (close to Richmond) and Fitz Hughes (close to Chateaubelair) on the leeward coast (Figure 3.2) were declared 'disaster areas' after Hurricane Tomas struck (CDEMA, 2010). Although no deaths were associated with the hurricane, 458 people were displaced with over 1,300 homes damaged (International Federation of Red Cross and Red Cresent Societies, 2011) and 20 homes completely destroyed. However, the most significant effect on the island was the loss of 98% of the banana plantations (International Federation of Red Cross and Red Cresent Societies, 2011) in the affected areas, estimated to have cost the economy USD$24.8 million. Further, CDEMA (2010) estimated the total damages sustained to St. Vincent and the Grenadines to be over US$166.7 million.

A further example of St. Vincent's exposure to natural hazards was the low-pressure (trough) system that swept across the island on the night of 24 December 2013. The trough system, described as a 1 in 100 year event, brought with it intense rainfall, with over 300 mm falling in northern parts of the island over a 24 hour period. At its most intense, some areas to the north of St. Vincent received approximately 280 mm rainfall over the 3 hour period 9 am - 12 pm on 25 December (Government of Saint Vincent and the Grenadines, 2014). This intense rainfall fell on ground already waterlogged from normal levels of rainfall, leading to the maximum potential surface run-off conditions. This surface run-off led to flash-flood events in the major river valleys and tributaries leading from the mountainous interior to coastal areas on the north of the island where many roads and bridges were destroyed (Plate 3.1). Further, the intense rainfall resulted in numerous landslides across the island which blocked roads, took out power lines and contaminated water sources. In total, 12 people were killed during the trough system (9 confirmed dead and 3 still missing), with a further 225 people evacuated to 7 emergency shelters due to the partial or complete loss of their homes. Associated flooding from the trough system led to the damage of critical infrastructure including both the Milton Cato Memorial Hospital and the E. T Joshua airport (International Federation of Red Cross and Red Cresent Societies, 2011). Total damages to the island were estimated at US$103.9 million – equivalent to 15% of the country's gross domestic product (GDP) (International Federation of Red Cross and Red Cresent Societies, 2011; Government of Saint Vincent and the Grenadines, 2014).

Both Hurricane Tomas in 2010 and the 2013 Christmas trough system demonstrate the type of natural disasters that regularly pose a threat to the St. Vincent. Multiple natural hazards may occur simultaneously, as evidenced by the extensive landslides triggered during and after both Hurricane Tomas and the Christmas trough system. This reinforces the need for resilient communities prepared for multi-hazard crisis.

**Plate 3.1. Photograph taken during fieldwork in January 2014 showing the damage to a bridge in the town of Georgetown on the windward coast. This bridge is part of the Windward Highway which is the main access road along the eastern coast of the island, from Kingstown to Fancy.**

## 3.2. Historical volcanic activity

As the only active volcanic centre on St. Vincent, La Soufriere is considered to be the only potential source of any future volcanic activity. All documented historical eruptions (post-1700) have occurred in the modern-day summit crater, which is approximately 2.5 km in diameter. Today a large lava dome, approximately 870 m wide and 130 m high, lies within the summit crater, the only signs of activity are fumaroles situated on the south side of the lava dome (Plate 3.2). Volcanic hazards are introduced in Section 3.3.


**Plate 3.2. Photograph showing the La Soufriere summit crater as seen today, measuring 2.5 km in diameter. The large lava dome extruded post-1979 is still present in the centre of the crater and is some 870m wide by 130 m high. A fumarole field is present to the south side of the lava dome and is the only sign of activity within the summit crater. A recent landslide can be seen in the northern crater wall, associated with stabilisation activity. Photograph courtesy of Paul Cole, taken in January 2014.**

In documented history, there have been 4 significant explosive eruptions of La Soufriere in 1718, 1812, 1902, and 1979, with a further effusive style (lava dome forming type) eruption documented between 1971-72. These eruptions have varied in magnitude with the most significant (VEI 4) eruptions occurring in 1812 and 1902. Effusive eruptions, such as that in 1971-72 are expected to have occurred throughout the history of the volcano leading to the formation of lava domes, as currently seen within the La Soufriere summit crater.

Although records only exist as far-back as the 1718 eruption, analysis of volcanic deposits across the island suggest that La Soufriere has had an extensive explosive history, with a 100 year recurrence interval for such an event (Robertson, 2005). Documented historical volcanic eruptions (occurring within the last 250 years) have been dominated by two contrasting styles of eruption: explosive (1902 and 1979) and effusive dome forming eruptions (1971-72) (Aspinall *et al.*, 1973; Robertson, 2005), with Aspinall *et al.* (1973) observing a cyclic pattern between these two eruptive styles over the last 250 years. Figure 3.3. comprises a chronogram which demonstrates the relationship between effusive (dome-forming) and explosive eruptions for the documented historical eruptions of La Soufriere.

### *3.2.1. 1718 eruption*

The first documented historical eruption of La Soufriere was included within Mist's *Weekly Journal* on 5 July 1718. The account, thought to have been written by Daniel Defoe and then later reproduced in Anderson and Flett (1903), brings together reports from various ships and telegrams from the region at the time.

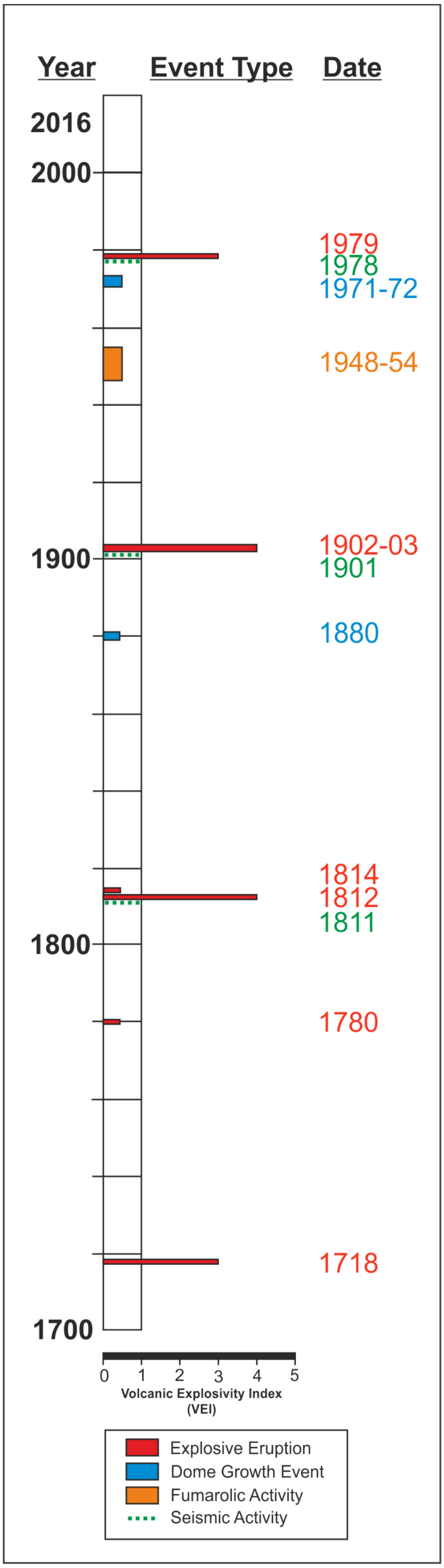



**Figure 3.3. Chronogram of the recent historic volcanic activity of Soufriere, St. Vincent. Adapted from Robertson (2005); Barberi *et al.* (2008).**

The article begins with a report of an encounter with local seamen who described feeling frightened by intense earthquake activity for at least one month prior to the eruption at the volcano. The eruption itself is then described in accounts from passing ships who detail the onset of the main explosive activity on St. Vincent:

> …they saw in the night that terrible flash of fire, and after that they heard innumerable clashes of thunder… (Defoe, 1718)

The article goes on describe how heavy ash fall 'up to one foot thick' was experienced by passing ships on 27th March. Heavy ash fall was reported on other Caribbean islands including Barbados, Martinique, and Hispaniola, and as far away as Venezuela. The descriptions indicated the eruption lasted one to two days with the author describing the event as "*the entire desolation of the island of St. Vincent, in the West Indies, by the immediate hand of nature".*

These accounts compiled in Mist's Weekly Journal should be treated with caution. Volcanoes had been little studied in the 1700s and so the accounts provided may be prone to exaggeration, linked to peoples' fear of not understanding what was happening at the time. For example, it is likely that the thickness of ash on the decks of passing ships is over-estimated due either to the lack of accurate measuring techniques, or guessing the thickness of ash rather than actually measuring it (LondonVolcano, 2014). Nonetheless, the accounts provide confirmation of a significant explosive eruption occurring in 1718.

### *3.2.2. 1812 Eruption*

A greater number of accounts exist for the 1812 eruption as St. Vincent was a British Colony at the time, with a more literate population. Over 90% of the island's residents (26,000) were slaves in sugar plantations (Smith, 2011). The island experienced 11 months of seismic activity prior to the eruption beginning on 27th April 1812. Aspinall *et al.* (1973) provide a brief description of the observed activity which included pyroclastic flows, lahars (mudflows) and ash fall. Accounts of the event collated by Smith (2011) include descriptions by Hugh Perry Keane, a barrister and plantation owner at the time, which describe explosions, dark clouds and *'vomiting black sands'* (referring to heavy ash and lapilli fall) during the initial days of the eruption. Further accounts published in British newspapers and journals at the time of the eruption suggest some of the most intense activity was experienced on the 30 April, after a loud *'incessant thunderous noise'* was heard (Smith, 2011). Descriptions from Hugh Perry Keane continue to describe projectiles fired from the summit crater, quickly followed by lava flows into the Rabacca river valley (Smith, 2011). Ash and lapilli fall continued into the following day with ash fall also experienced on nearby Barbados. Volcanic activity at La Soufriere ceased by 9 June by which time an estimated 56 people had been killed (Aspinall *et al.*, 1973), with estimated losses equalling 14% GDP (Smith, 2011).

### *3.2.3. 1902-03 eruption*

The eruption of 1902 was the deadliest recorded, with 1,565 people losing their lives (Robertson, 1995). After nearly 14 months of continuous low-magnitude (<5.0) earthquake activity, La Soufriere eventually erupted on 6 May and continued to erupt intermittently until 30$^{th}$ March 1903 (Aspinall *et al.*, 1973). This eruption (a VEI 4) comprised pulses of pyroclastic flows, heavy ash fall, projectiles and lahars. Northern sections of the island were heavily impacted and covered with a thick blanket of ash after the eruptions. At the time two English researchers – Tempest Anderson and John Flett - were commissioned to visit St. Vincent as part of a Royal Society expedition. They produced detailed accounts and descriptions of the volcanic activity and the devastation that ensued. Their report, published in 1903, states that *"as yet the Soufriere had shown no symptoms of actual eruption"'* prior to the 6$^{th}$ May, other than a prolonged period of earthquake activity. However, by the afternoon of the 6$^{th}$ May, La Soufriere was in eruption.

The following summary of the 1902 event is based primarily on the account of Anderson and Flett (1903). After intensified earthquake activity on the morning of the 6th May, many of the Carib population began to move south towards Chateaubelair from Morne Ronde in anticipation of an eruption. Later that morning, news travelled fast of steam emitting from the summit crater, and by the afternoon a loud explosion was heard and an eruption column seen, towering high above the volcano. At this point, many of the residents on the eastern coast were unaware of the heightened activity at the volcano due to a low cloud bank above the summit with many believing the loud explosions to be thunder clashes.

By 6am on 7th of May, activity at La Soufriere had increased and the eruption had commenced. Some of the first reports of the activity were provided by Mr McDonald, a plantation owner in Richmond Vale, who described how, at approximately 7am, a thick vapour cloud appeared which turned heavy and dark in colour and then subsided back into the crater. This is likely to be the first mention of ejected materials from the volcano. Later that morning Mr McDonald described seeing a plume of white vapour ascending over 30,000 feet (over 9 km) and that "*outbursts took place now at shorter intervals and now at 10.30 am the eruption became continuous"* (Anderson & Flett, 1903, p.384).

During the early stages of the 7th May activity, residents in Georgetown had no idea of the unfolding activity at the volcano due to a low cloud bank covering the mountain. Around 10.30am on 7th May residents in Georgetown began to hear continued loud rumblings and cracking sounds (like lightning cracks) coming from the mountain, followed at 11.15am by sulphurous, material laden rainfall. However, ash and lapilli began to rain down earlier than this in closer proximity to the volcano, with the sugar mill at Wallibou closing due to "*steady showers of dust*" (Anderson & Flett, 1903, p.385).

At 12.30pm the Wallibou river valley to the west of the La Soufriere was observed to be in flood between 30-40 feet (9-12 m) high and comprising steaming water, despite there having been no rainfall that morning (Anderson & Flett, 1903). There were also additional reports from Georgetown of many river valleys steaming, suggesting a large discharge of water from the summit crater (a crater lake was present prior to the eruption).

Anderson and Flett (1903) describe the climax of the eruption as '*the descent of the Great Black Cloud'*, referring to pyroclastic flows and surges that occurred at 1.55pm on 7th May. Mr McDonald describes how, after a period of rumbling, "*a terrific huge reddish and purplish curtain"* was released from the volcano and advanced towards the Richmond Estate. This great back cloud "*poured from the crater and swept down the valleys to the sea"* (Anderson & Flett, 1903, p.392). At the time of the cloud's descent, a group of local men were on a boat just off the coast of Chateaubelair when the cloud struck them. They described the intense heat, the sound of hot material dropping into the sea making hissing sounds, and the intense sulphurous smell that began to suffocate them. A witness also at sea at the time of the pyroclastic flows described seeing them travel down the Larikai, Wallibou and Baleine valleys (Figure 3.2) before continuing out over the sea for at least 7 miles (11 km) to his position. Similar reports from the leeward side of the island also describe the pyroclastic flows descending the Rabacca valley and other valleys towards Owia in the north. This pyroclastic flow was the main cause of death from the eruption, with anyone exposed to the flows instantly killed. Additionally, hot mudflows and material descending down the Rabacca river valley prevented residents from fleeing to Georgetown, leaving them to perish during the pyroclastic flows.

Anderson and Flett (1903) describe how, after the pyroclastic flow event on 7th May, minor earthquakes and intense lightning persisted, whilst ash and lapilli also continued to fall. Towards the end of 7th May activity began to cease, although minor ash plumes continued throughout the day. In the days following the eruption, some steaming lahars were noted to continue to flow down river valleys and there were sporadic explosions and associated ash plumes released from the crater. The activity continued to slow until its ultimate cessation from 29th April, by which time 1,565 people had been killed, and extensive damage caused to the north of the island including to farmland where large numbers of animals also perished (Anderson & Flett, 1903; Robertson, 1995) (Plate 3.3).

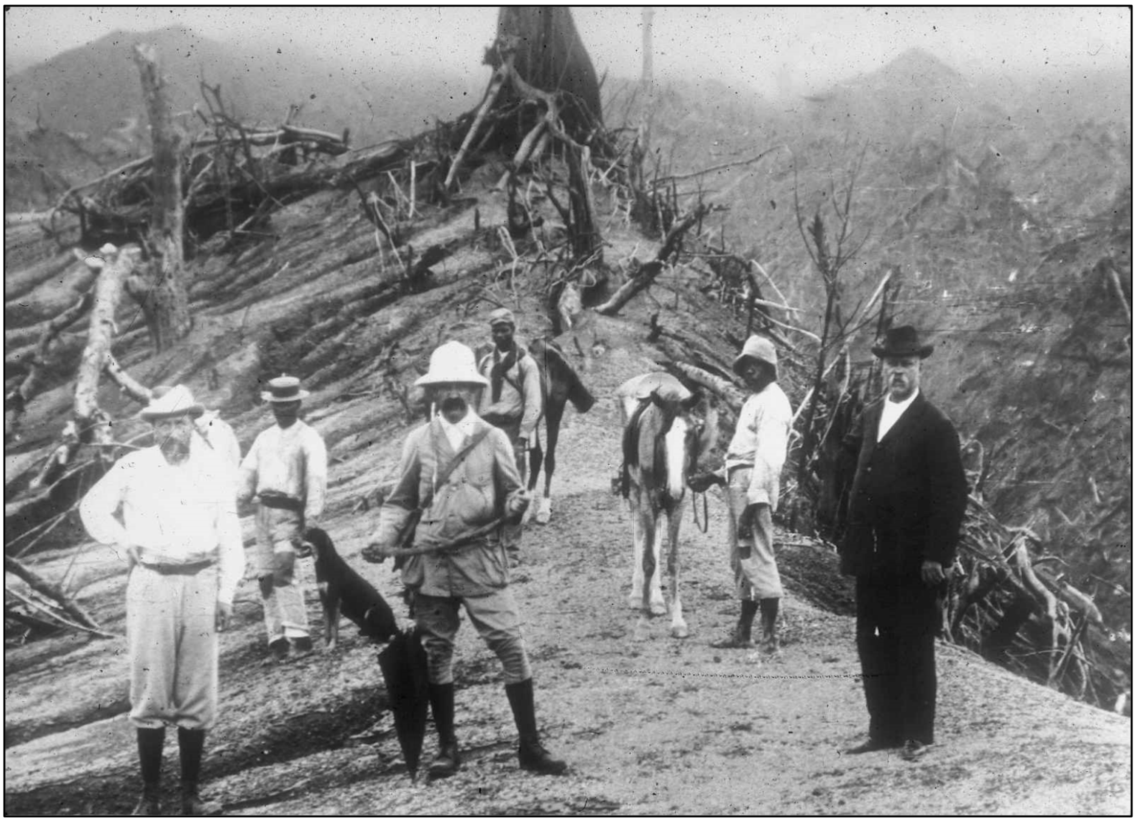


**Plate 3.3. Photograph taken in the aftermath of the 1902 eruption, showing Tempest Anderson and John Flett investigating the damage caused in close-proximity to La Soufriere (Anderson & Flett, 1903). The image shows trees that have been burnt and completely flattened during the eruption and thick layers of ashy deposits covering the ground.**

### *3.2.4. 1971-72 eruption*

In October 1971 an effusive eruption began at La Soufriere, forming a lava dome some 295 m high in the summit crater during six months of activity which ceased in March 1972. Before this effusive eruption, the summit crater of La Soufriere contained a crater lake formed after the 1902 eruption. During small localised earthquake swarms between November 1945 and February 1946 the lake’s average temperature was observed to increase by 4°C, returning to its ambient temperature of 24°C by 1954 (Aspinall *et al.*, 1973).

No specific date is recorded for the onset of the 1971-72 eruption, but it was estimated to be between 19th September 1971, when an experienced observer visited the crater and observed normal conditions, and 17th October 1971 when a group of tourists had visited the summit crater, noting the lake to be steaming and giving off a sulphurous smell. During their visit to the summit crater on 3rd November Aspinall *et al.* (1973) observed the crater lake surface temperature to be 81.5°C and the water level 26 m above normal. Small tremors were felt close to the volcano, peaking in December 1971 at up to 100 per day, before decreasing gradually until their cessation in March 1972.

At the time of the 1971 eruption the island's population had increased to 96,000 of which some (i.e. those over 75 years) had directly experienced, or were extremely aware of, the devastation caused by the 1902 eruption. This resulted in a more cautious population who had been exposed to stories passed down through generations of the 1902 eruption events and subsequent consequences; so when the volcano began to exhibit signs of life at the beginning of November, people immediately began evacuating from areas close to the volcano (north of the island) (Aspinall *et al.*, 1973), although an official evacuation order was not given until 7th December (Robertson, 2005).

On 20th November, extruded lava breached the lake's surface creating a central island, which was observed to grow by 2-3 m per day. Monitoring of the activity (extrusion and growth of the lava dome and degassing) continued, but by 20th March 1972 activity had ceased within the summit crater without any loss of life, or significant damage to the local environment. By cessation of the extrusion, the volcano had erupted some 80 x $10^6$ $m^3$ of lava into the crater creating a lava dome approximately 295 m high (Robertson, 2005).

### 3.2.5. 1979 Eruption

The most recent eruption of La Soufriere began on 13th April 1979, occurring after a period of measured changes at the volcano but with no strong indications of when an eruption may occur. The precursory activity detected prior to and the events of the 1979 eruption are detailed in this section.

The information provided within this section is taken from Shepherd *et al.* (1979) unless otherwise specified. After the 1971-72 volcanic eruption, the temperature of the crater lake was continually monitored. Between August and November 1976, the lake temperature was observed to fluctuate between 23-30.5°C at irregular intervals, but by 1977 had stabilised at a higher than ambient temperature of 25°C. However, by August 1978 the lake's temperature had begun to increase once more, peaking at 31°C.

In June 1978, a short-period seismograph was installed at Belmont (~9 km south-west from the summit crater) to detect minor seismicity around the volcano. It detected the occurrence and magnitude of earthquakes which arrived in swarms of up to 20 events at any one time between June and July 1977. On 30th July 1977 a peak reading of 40 events over the period of one day was recorded. Due to the consistently recorded seismicity and increase in lake temperature, the government of St. Vincent were warned of an abnormal situation at La Soufriere by scientists at the Belmont observatory and the Seismic Research Centre (SRC). However, little change in activity occurred until between September 1978 and April 1979 until an increase in seismic events < 3.0 magnitude (too small to be felt) were detected from 12th April, recording over 50 events per day (Shepherd *et al.*, 1979).

On 13th April 1979, the recorded earthquakes increased in intensity (magnitude and frequency) with over 70 events recorded between 02.04 and 04.30 UTC, before a continuous seismic signal made distinguishing events too difficult. This increased in intensity indicates heightened activity at the volcano. A warning was issued to the St. Vincent government by the SRC late on 12th April that a highly abnormal situation was developing at the volcano but by the morning (4am local time) the volcano was already in full-eruption with loud rumbling heard across the entire island and on neighbouring islands.

Without an official evacuation warning, many of the local residents began to self-evacuate as ash began to rain-down up to 5 km away from the volcano. An official evacuation warning was given on the morning of 13th April at 09.30 UTC for the immediate evacuation of people north of the Rabacca and Wallibou rivers (Figure 3.2), which was completed by 20.00 UTC (Shepherd *et al.*, 1979). In total, over 15,000 people were evacuated from the north of the island towards the south (Shepherd *et al.*, 1979; Lowe, 2010).

From 09.30am on 13th April, a series of loud explosions were heard from the volcano accompanied by an ash cloud reaching 8 km above the crater. Ash and lapilli fall began in Georgetown and Chateaubelair as explosive activity continued through until 14th April. Pyroclastic flows were observed flowing into the Rabacca and Wallibou river valleys on both 13th and 14th April leaving a trail of destruction and lahar (muddy and rocky) deposits up 1.5 m thick. Towards the end of this eruption (14th-17th April), intermittent explosive activity continued with another phase of pyroclastic flows in the upper river valleys of the Larikai and Wallibou on 17th April. Ash and lapilli fall continued around the flanks of the volcano as the ash plume ascended to 18.7 km (Shepherd *et al.*, 1979). The intensity of the explosive phases began to reduce after 22nd April with the final explosions observed on 26th April.

Due to the speed with which evacuations were carried out by the government and the preparation measures adopted on the island following previous volcanic activity, no lives were lost as a direct result of the eruption. However, many homes were destroyed in the northern part of the island and extensive damage to crops and livestock was recorded, with a total economic cost estimated to be US$5.2 million (Robertson, 1995). Many people were allowed to return to their homes just three weeks after activity ceased, but many families had to remain in emergency shelters for up to four months due to the complete destruction of their homes.

### *3.2.6. Present day activity*

Today, La Soufriere lies in apparent quiescence. The large lava dome in the summit crater (Plate 3.2), which was extruded at the end of the 1979 eruption, is prone to rock falls as it begins to stabilise. This has led many islanders to believe the dome is still growing however, no growth has been detected since its initial expulsion ending in 1980.

The only visual sign that the volcano remains active is a fumarole field close to the southern edge of the lava dome (Plate 3.2). There are currently two groups of high-temperature fumaroles which emit steam and gases of up to 100°C (STREVA, 2016a), but these have noticeably reduced in strength and temperature since their initial formation after the dome emplacement between 1979-1980 (Robertson, 2005).

Other than these gas emissions the volcano infrequently had small magnitude earthquakes (<3.0), of which few are rarely felt. Also, in the last decade landsliding has occurred in the crater walls which is thought to be linked more to rainfall and over-steepening of the crater walls than with seismic activity (STREVA, 2016b). A crater lake has not been present in the summit crater since 1979, although small pools of stagnant water are often observed (Plate 3.2).

## 3.3. Volcanic Hazards

Any future eruption of La Soufriere will likely subject the island to a range of hazardous phenomena including ash fall, ballistic projectiles, pyroclastic flows and surges, and volcanic mudflows (lahars). This section further describes these hazards in terms of their formation, and behaviours that may pose a viable threat to communities close to the volcano.

### *3.3.1 Ash fall and ballistic projectiles*

Tephra is a collective term for pyroclastic (literally meaning 'fire-broken') fragments of varying sizes ejected from a volcano during an eruption that fall back to Earth (Fisher, 1964). Tephra is categorised by grain size into ash (< 2 mm), lapilli (2-64 mm) and blocks and bombs (>64 mm) (Fisher, 1961). Pyroclasts are juvenile particles formed by the process of magma fragmentation – when liquid phase magma with bubbles is transformed into a gas phase with magma particles (Cashman & Scheu, 2015). Bubbles are an important factor in magma fragmentation and are formed when water (and/or volatiles) exsolves from the magma under pressure at depth. As the bubbles rise up through the volcano in the magma, they can grow and/or coalesce to cause fragmentation of the magma. As the bubbles grow, due to more water (and/or volatiles) exsolving from the magma, they increase the overall magma volume, accelerating the mixture towards the Earth's surface (Mangan *et al.*, 2004; Carey & Bursik, 2015; Cashman & Scheu, 2015).

When the foam-like mixture of magma and bubbles reach the Earth's surface, the gas escapes as outgassing. In some cases, such as that of La Soufriere, St. Vincent, the volcano conduit (throat of the volcano) is blocked by a lava dome. This leads to a build-up of pressure within the volcanic system and can lead to an explosive eruption (Francis & Oppenheimer, 2004).

Once ash is expelled from a volcano during an eruption it forms a volcanic plume. Ash plumes are a hot mixture of volcanic ash, aerosols and gases expelled from the volcano at velocities of hundreds of metres per second, which then begin to rise upwards through convection (Bonadonna *et al.*, 2015; Carey & Bursik, 2015). As the volcanic plume ascends through the atmosphere it begins to slow under gravity and resistance against the surrounding air. However, the hotter air within the plume heats the surrounding atmosphere, entraining more air as it develops, causing expansion of the column and ultimately, buoyancy. This enables the plume to continue rising (Carey & Bursik, 2015) and volcanic plumes can reach up to 40 km above the vent. Eventually the volcanic plume will ascend to a point where the density of the surrounding atmosphere and the plume and equal and the plume is no longer buoyant. As a result, the plume begins to move laterally forming an 'umbrella region', often under the influence of atmospheric winds (Bursik, 2001). Eventually, volcanic ash from the plume begins to fall back to Earth under gravity and due to lateral movement of the plume, volcanic ash can be spread over hundreds of kilometres from the vent.

During the 1979 eruption of La Soufriere, volcanic plumes were recorded up to 18.7 km above the volcano which left a thick layer of ash deposits over a 9 km radius from the vent (Brazier *et al.*, 1982). Volcanic ash deposits up to 2 cm thick were even recorded on Barbados, over 160 km east of St. Vincent (McClelland & Fiske, 1979; Shepherd *et al.*, 1979; Brazier *et al.*, 1982).

Volcanic ash can blanket a landscape after deposition and is hazardous for a number of reasons. Firstly, ash can contaminate water courses, polluting potable water sources and unbalancing the aquatic environment (Jones & Gislason, 2008). Volcanic ash is also hazardous to human health, causing respiratory problems if breathed in, particularly during long sustained ash fall periods (Horwell *et al.*, 2003). One of the more documented potential effects of volcanic ash is to machinery such as cars and aeroplanes (Guffanti *et al.*, 2010; Webley, 2015). Volcanic ash can become welded to hot engine parts causing them to stop working and can also cause short-circuiting of electric systems leading to failure (Prata & Rose, 2015). Other potential impacts associated with volcanic ash include damage to crops and vegetation, harm to livestock and damage to infrastructure.

Ash and lapilli fall were experienced during the 1979 eruption of La Soufriere, St. Vincent, which, for some, was the first evidence that the volcano had erupted. During fieldwork on the island, residents from the north coast town of Fancy recalled their experiences of the ash falls, describing how it irritated their skin and blanketed the town. Some residents also described how ash mixed with rain water clogged the windscreen of the evacuation bus meaning the driver had to smash the windscreen to proceed (Pers.Com, Residents of Fancy, St. Vincent, 2015).

During explosive eruptions, ballistic projectiles can also be expelled from a volcano. Ballistic projectiles are more frequently referred to as blocks and bombs and comprise volcanic rock fragments >64 mm in size of lava or solid rock. Ballistics can reach velocities of hundreds of metres per second and land up typically up to 5 km from the vent (Fitzgerald *et al.*; Blong, 1984; Bonadonna *et al.*, 2015). Ballistic projectiles pose a risk to life and can cause significant damage to infrastructure and the surrounding environment due to their mass and ferocity of impact (high kinetic energy) (Fitzgerald *et al.*). Anderson & Flett (1903: 468) document how 56 people were killed with many more injured due to *'falling hot stones'* and subsequent collapse of dwellings during the 1812 eruption of La Soufriere.

### *3.3.2 Pyroclastic flows and surges*

Pyroclastic flows are avalanches of hot ash, gases and volcanic rock fragments that can travel quickly under gravitational influence down the flanks of a volcano, typically following the course of river valleys (Brown & Andrews, 2015). They differ from pyroclastic surges, which often have a much more dilute particle concentration and are unconfined by topography (Cole *et al.*, 2015). Pyroclastic flows and surges typically occur simultaneously (Druitt, 1998). The term Pyroclastic Density Current (PDC) is now commonly used as an umbrella term to describe both these phenomena (Cole *et al.*, 2015).

Pyroclastic flows and surges are able to travel at high velocities, reaching tens of hundreds of kilometres per hour and can be very hot, often resulting in temperatures of hundreds of degrees centigrade (Brown & Andrews, 2015). These high velocities and temperatures coupled with the difficulty volcanologists have in predicting when and where they may occur make pyroclastic flows and surges the most dangerous volcanic hazard. Pyroclastic flows and surges are the cause of the most significant loss of life during volcanic eruptions, accounting for one third of all volcano related fatalities (Auker *et al.*, 2013). One famous example of the deadly nature of pyroclastic flows and surges was the total destruction of the towns of Pompeii and Herculaneum during the AD 79 eruption of Mount Vesuvius, Naples (Sigurdsson *et al.*, 1982). During the eruption of Mont Pelée, Martinique in 1902, a pyroclastic flow descended rapidly from the volcano summit to the town of St. Pierre destroying the town and killing over 29,000 people (Anderson & Flett, 1903). More recently, 31 people were killed on the flanks of Mount Ontake volcano in Japan after they were struck by a pyroclastic flow whilst out hiking in 2014 (BBC, 2014).

PDCs can be formed in a number of ways but are commonly formed by either; the collapse of an eruption column, gravitational collapse of a lava dome or lateral blasts (such as that seen at Mt. St. Helens in 1980) (Druitt, 1998; Calder *et al.*, 2002; Francis & Oppenheimer, 2004). The distance and speed at which a PDC travels is dependent on the intensity of the volcanic eruption; the more intense the eruption, the further and faster the PDC can travel. Where PDCs are erupted close to the coast, they can continue to travel over water for many tens of kilometres, posing a threat to marine life and boats (Brown & Andrews, 2015). During the 1979 eruption of La Soufriere, PDC travelled up to 10 km across the sea (Anderson & Flett, 1903).

As described in Section 3.2.3, PDCs were produced during the 1902 eruption of La Soufriere due to the collapse of an eruption column. This eruption produced a surge deposit that reached to the top of Richmond Peak, some 1,079 m high and nearly 5 km from the La Soufriere summit crater. These PDCs destroyed much of the north of the island, flattening trees and killing livestock; they were also considered to be the cause of the majority of deaths during the 1902 eruption (Anderson & Flett, 1903).

### *3.3.3 Lahars (Mudflows)*

The term Lahar is an Indonesian word which is commonly used to describe mudflows triggered at volcanic centres. Lahars typically comprise a mixture of rock, debris (often entrained as it flows) and water which combines to produce a rapid flow of material down the flanks of a volcano under the influence of gravity (Vignaux & Weir, 1990; Vallance & Iverson, 2015). As water mixes with the loose debris (such as ash, lapilli, block and bombs erupted from the volcano and human-made debris), it can begin to flow rapidly down the flanks of the volcano taking advantage of topographic features (river valleys and channels), similarly to pyroclastic flows. Primary lahars – the largest type of lahar – occur during a volcanic eruption; whilst secondary lahars may be formed post-eruption after period of heavy rainfall or snow melt (Gudmundsson, 2015). The speed at which lahars travel is dependent on the slope steepness, but they have been observed travelling up to 90 km/h, over distances of up to 100 km (Francis & Oppenheimer, 2004). Due to the interaction of water with freshly erupted PDC deposits during an eruption, lahars may be very hot with some lahars having recorded temperatures close to boiling (Gudmundsson, 2015).

One of the most devastating examples of a lahar occurred during the eruption of Nevado Del Ruiz in Colombia on 13th November 1985. The eruption of Nevado Del Ruiz was a short-lived magmatic eruption which produced PDCs (Voight, 1990). At the time of the eruption the volcano had a snow and ice cap, which began to melt when contacted by the PDCs. The meltwater began to flow down the valleys leading from the volcano mixing with loose pyroclastic material as it travelled. The mixture began to entrain more loose debris as it descended the volcano eventually reaching speeds of between 6-10 m/s (Gudmundsson, 2015). The largest lahar struck the town of Armero located over 70 km from the volcano summit, burying the entire town, crushing buildings and destroying everything in its path leading to the deaths of over 23,000 residents (Barberi *et al.*, 1990; Gudmundsson, 2015).

Lahars are known to have previously occurred on St. Vincent, with an observation made by Mr Robertson during the 1902 eruption of La Soufriere. Mr Robertson noted *"a raging flood of hot water tearing down the valley"* which he estimated to be up to 20-40 feet high (9-12 m high) (Anderson & Flett, 1903, p.387). These lahars occurred in all the major river valleys and tributaries leading from the La Soufriere summit crater, destroying bridges and infrastructure in their path, eventually depositing their materials when they reached the sea.

Lahars can occur not only during and immediately after an eruption, but months or years after an eruption has occurred, typically after periods of heavy rain of snow melt (secondary lahar) (Vallance & Iverson, 2015). These secondary lahars pose a significant threat on St. Vincent as the island is prone to annual heavy rainfall during the wet season (June to November), which can lead to the formation of a lahar, when the waters mix with loose ash deposits and soils.

## 3.4. Potential future volcanic activity

Any future eruptions at La Soufriere are expected to be equivalent to the styles of volcanism previously experienced. The volcano is believed to erupt in a two-phase cycle of activity (as demonstrated in Figure 3.3), characterised by either:

- *Phase-one* - a slow quiet effusive phase (expulsion of lava similar to 1971-72) or;
- *Phase-two* a more explosive activity comprising pyroclastic flows, ash plumes and fallout (similar to 1979 and 1902) (Aspinall *et al.*, 1973; Robertson, 2005).

The cycle comprising both phases of eruption is estimated to span around 100-years based on the documented historical eruptions and prehistoric volcanic deposits across the island (Aspinall *et al.*, 1973).

In the St. Vincent chapter of the *Volcanic Hazard Atlas of The Lesser Antilles* developed by the University of the West Indies (UWI), Robertson (2005) considers the potential future eruptive scenarios that may be experienced on St. Vincent to include both phases of activity. The scenarios are categorised by their duration, short-term/most-likely scenarios (effusive or dome-forming and explosive eruptions) and a long-term/worst case scenario (catastrophic explosive eruption). This section summarises the potential future eruptive scenarios on St. Vincent based on information from Robertson (2005) unless otherwise stated. Figure 3.4 demonstrates the potential extent of volcanic hazards during a short-term eruption scenario (both explosive eruptions and dome-forming effusive eruptions).

### *3.4.1 Short-term eruption: Effusive or dome-forming*

This style of eruption comprises the extrusion of a viscous basaltic-andesite magma into the summit crater through the central vent. Based on the current configuration of the summit crater, without a lake, this type of eruption is likely to produce a lava dome, similar to those produced in 1971-72 and 1979-80. Activity is likely to occur only within the summit crater, with fumarole temperatures expected to increase as a precursor with some minor changes in ground deformation (inflation of the volcano flanks as previously experienced in 1979). The expected volumes of magma extruded per day, based on historical eruptions, is likely to be between $10^5$ $m^3$ and $10^6$ $m^3$ per day (Robertson, 2005). As this style of activity is likely to only occur within the summit crater, there is considered minimal risk to the population, with the exception of volcanic gases which may reach proximal communities (dependent on wind direction and strength). Historically, there has been little to no impact of gas emission from La Soufriere on the surrounding population, however there have been instances where normal levels of gas emissions have been smelt in local communities due to strong winds, leading to rumours of an imminent eruption (Pers. Coms., Richard Robertson, 2015). Increased volumes and toxicity of the gas emissions mixed with strong winds may pose a risk to proximal communities to La Soufriere.

### *3.4.2 Short-term eruption: Explosive eruption*

This style of eruption would begin with the formation of a lava-dome, plugging the central vent of the volcano and allowing pressure to build-up. Eventually, an explosion will occur indicating the start of the explosive phase of the eruption, accompanied by large ash plumes up to 18 km high (as in 1902). An eruption of this style is expected to last between a few days to several months, dependent on the discharge rate of magma.

During an eruption of this style, many hazardous volcanic phenomena are likely to be produced, including pyroclastic density currents, lahars, ash fall and ballistics. These hazards will pose a significant threat to communities living close to the volcano, particularly close to river valleys (e.g. Georgetown, Orange Hill and Overland) as they act as the path of least resistance, funnelling lahars and pyroclastic flows down towards the coast. The reach of these hazards will be largely dependent on the magnitude of the eruption; for example, an eruption of VEI 4+ would potentially lead to the inundation of river valleys leading to Fancy and Owia by pyroclastic flows and lahars that may otherwise not be seen during a lower magnitude eruption.

Secondary-hazards (hazards not originated from the volcano but formed as a result of the eruption) may also be triggered from the eruption such as lightning and landslides which could further pose a significant threat to the population. If the eruption is on a similar scale to 1902, much of the northern-part of the island will see near total destruction of vegetation, agriculture, animals and infrastructure.

### *3.4.3 Long-term eruption scenario*

A longer-term eruption scenario for St. Vincent was considered by Robertson (2005). The scenario comprises a VEI 4+ explosive eruption which could cause pyroclastic density currents, sustained ash plumes and thick air fall deposits. This style of eruption would cause near complete devastation of major towns and villages to the north of the island (likely the entire Red Zone [Figure 3.5]) and lead to permanent enforced exclusion zones, or even total evacuation from the island, as was the case on Montserrat after the eruption of the Soufriere Hills Volcano. This long duration eruption was considered by Robertson (2005) to be a worst-case scenario. However, prehistoric volcanic deposits located across the island (thought to date back to ~ 1500s) indicate that the La Soufriere volcano is capable of large-scale, devastating eruptions (Robertson, 1995).

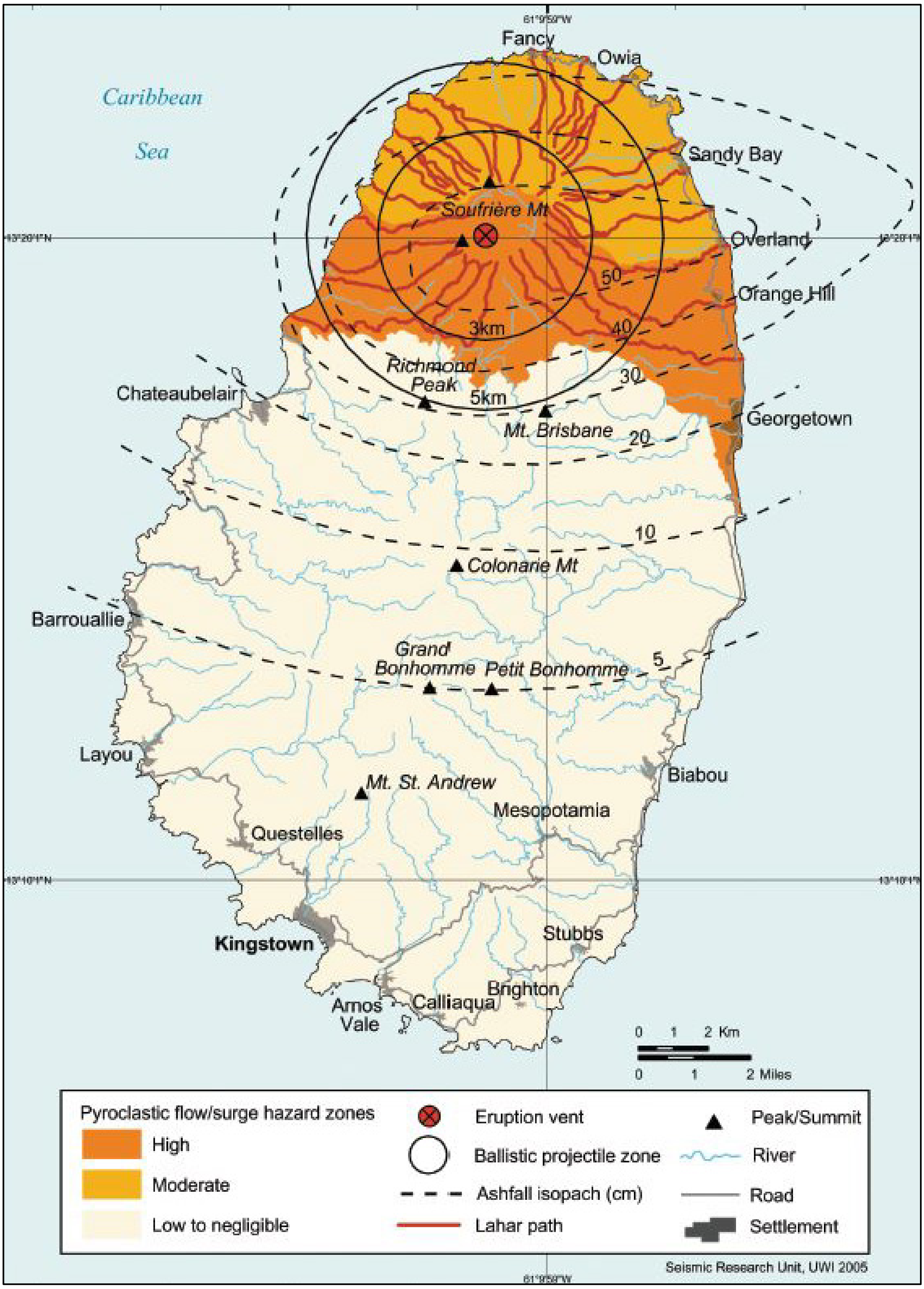
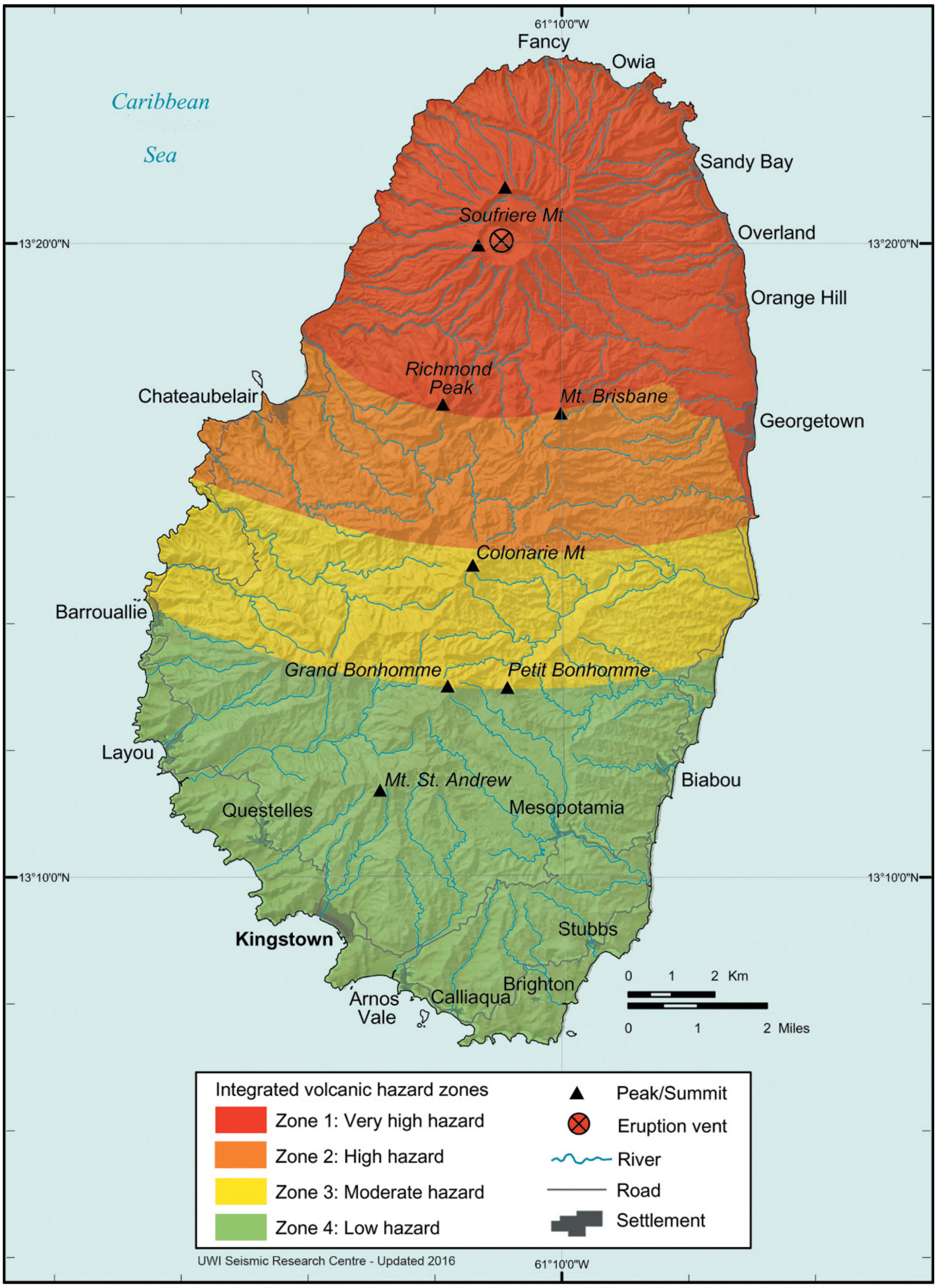



**Figure 3.4. Map taken from Robertson (2005) showing the potential extent of volcanic hazards that may be experienced during a future eruption of La Soufriere. The map includes both eruption phase activity: effusive dome-forming and explosive eruption scenarios. Permission to reproduce this map has been granted by R. Robertson.**

### *3.4.4 Volcanic hazard map*

The volcanic hazard map (Figure 3.5) was first produced in 2005 by Richard Robertson of SRC. The integrated hazard map is a summation of information relating to areas that are likely to be affected by the various volcanic hazards (pyroclastic flows, ash fall and lahars) based on predictions for potential future eruptions established through analysis of historic data and volcanic deposits, as detailed in this section.

The island is split into four ‘traffic light’ categories of risk ranging from ‘Red Zone’ – very high hazard to ‘Green Zone’ – low hazard. The areas within the ‘Red Zone’ are the most proximal to the volcano, or are most exposed to the effects of volcanic hazards through topographic features (e.g. the Rabacca river valley leading from the volcano to Georgetown). These are the areas that will be advised to evacuate first as they are the most at-risk. A summary of the definitions behind each hazard zone is provided in Table 3.1, which also presents information on the largest communities in each hazard zone and provides detail on the effects that may be seen during an eruption in each zone.




Source: Lindsay, Jan M., ed. Volcanic hazard atlas of the Lesser Antilles. Seismic Research, 2005.

**Figure 3.5. The integrated volcanic hazard map produced by Robertson (2005). The map uses historical data and predictions for future eruptions to categorise the island into four parts based on their exposure to the hazards. The red zone is the most proximal to the volcano and is the Very high hazard zone which comprises several large communities (Fancy, Owia, Sandy Bay, Orange Hill and Georgetown). Permission to reproduce this map has been granted by R. Robertson.**

| Hazard Zone | Communities | Potential Impacts |
| --- | --- | --- |
| **Red Zone – Very high hazard** | Fancy, Georgetown, Owia, Sandy Bay, Overland, Orange Hill. | • Maximum damage in the short-term.<br>• Impacted by all volcanic hazards at their highest potential.<br>• Pyroclastic flows and lahars will cause total devastation.<br>• Expected ash fall of >30 cm.<br>• Area of immediate evacuation during an eruption. |
| **Orange Zone – High hazard** | Chateaubelair, Petit Bordel, Richmond, Rose Hall, Troumaka. | • Similar effects as Red Zone during a large explosive eruption.<br>• This zone would experience less ash fall – 10-30 cm.<br>• Topographic highs would protect some areas from the effects of pyroclastic flows and surges and lahars.<br>• Area only likely to be affected during a significant explosive eruption. |
| **Yellow Zone – Moderate hazard** | Barrouallie, Byrea, Gordon Yard, Cumberland, Colonaire, North Union and South Union | • Free from the effects of flows and surges but will receive ash fall, earthquakes and lightning.<br>• Ash fall expected up to 10 cm.<br>• Minor damage caused to infrastructure, but secondary hazards may make life difficult. |
| **Green Zone – Low hazard** | Mesopotamia, Biabou, Layou, Questelles, Kingstown, Callaqua, Arnos Vale, Vermont | • Receive only minor impacts from an eruption.<br>• Ash fall >5 cm which may affect water supplies and crops but minimal physical damage.<br>• Area that will receive most evacuees and so social disruption may be high with increased demand on schools and resources. |

**Table 3.1. A summary of the potential impacts that may be experienced during a future eruption of La Soufriere based on the hazard zones as categorised by Robertson (2005). The largest towns included within each hazard zone are also included. Permission to reproduce this table has been granted by R. Robertson.**

It should be noted that the volcanic hazard map for St. Vincent was updated in 2016 to encompass Fancy within the Red Zone (previously Orange Zone). It was considered that, although Fancy has some topographic protection from pyroclastic flows and surges, people would delay their evacuation, believing it to be a safer location during an eruption rather than passing through the Red Zone to reach safety in the south of the island (Pers. Coms., Richard Robertson, 2015).

Robertson's volcanic hazard map is one of the main communication tools used on St. Vincent to educate about volcanic hazards and is printed annually within the national newspaper and telephone directory (Lowe, 2010). Crosweller (2009) surveyed 109 residents across St. Vincent after the map had been printed in the newspaper and asked them to identify the hazard zone in which they lived. The results showed that 43% (where *N* = 120) of respondents identified the correct zone but 36% of those surveyed overestimated their exposure to hazards compared to their actual exposure and, more concerning, 21% of those surveyed underestimated their exposure, meaning that over half of individuals surveyed incorrectly estimated their exposure. Although there is no indication from Crosweller (2009) to identify why this is the case, the study alludes to the fact that when those surveyed were asked if they had seen the volcanic hazard map only 29% (*N* = 121) had. Despite the volcanic hazard map forming the primary education tool used to teach about volcanic hazards and exposure, this research suggests that the channels used to share this information (through the newspaper and telephone directory) do not penetrate far enough into the population.

### 3.5. Public perceptions of volcanic risk on St. Vincent

Several studies have attempted to explore public perceptions and awareness of volcanic hazards amongst the general population of St. Vincent (Crosweller, 2009; Lowe, 2010; Ferdinand *et al.*, 2012; Armijos & Few, 2016). The findings from these studies provide insight into the potential vulnerabilities that may exist within at-risk communities on St. Vincent; including large populations living close to La Soufriere who are also exposed to other, more frequently occurring natural hazards (e.g. earthquakes, hurricanes and flooding).

A study undertaken by Armijos and Few (2016) comprising household surveys (*N* = 400), semi-structured interview (*N* = 46) and group interviews (*N* = 41) sought to establish the vulnerability to volcanic hazards on St. Vincent. The study identified that of the households surveyed in proximity to La Soufriere - Owia, Langley Park, Troumaka, Rose Bank, Petit Bordel, Chateaubelair and Fitz Hughes – 77% had experienced the 1979 eruption. These people are still residing in these at-risk communities exposed to future volcanic eruptions and their associated hazards. This has led to a population living close to La Soufriere which possess a good level of awareness of the volcano as stories of 1979 are passed from generation to generation (Crosweller, 2009).

However, Robertson (1995) identifies several factors that may affect an individual's actions and reactions relating to an eruption including: economic status, recollection of past eruptions, proximity to the volcano and knowledge of volcanic processes. During the 1979 eruption, residents living within the areas most likely to be affected by volcanic hazards (Red Zone) (Figure 3.5) close to the volcano (north of the Rabacca and Wallibou rivers) began to self-evacuate prior to official government advice (Robertson, 2005). Robertson interprets these actions as a population that possesses a good level of awareness of volcanic threat. Despite this, Robertson still suggests that Vincentians have a poor knowledge of volcanic processes due to a considerable amount of education efforts focusing largely on volcanic risk and preparedness, over the actual volcanic processes. As a result of their poor understanding of volcanic processes, many residents have acquired misconceptions relating to the volcano and its activity. Examples of misconceptions include many islanders refer to 'lava' for any product released from the volcano (e.g. ash, lava and mudflows) (Crosweller, 2009) and residents believe that the 1979 lava dome is still growing (referring to rock falls associated with stabilisation) despite it having ceased in 1980.

Armijos and Few (2016) also identified 93% of the most at-risk communities ($N$ = 401) indicated that they knew where to go in the event of a volcanic eruption, with 97% of those respondents saying they would go to a shelter. However, when the same participants were asked whether they had adopted a self-developed emergency plan, 92% said they had not ($N$ = 401). Many of the participants expressed their willingness to evacuate during a future eruption, but some also indicated they would not be willing to evacuate, as they would worry about leaving behind personal items and property. These attitudes may be associated with the significant levels of poverty in some of the more proximal towns including Chateaubelair, Georgetown and Sandy Bay, where the poverty rate ranges between 43% and 56% of the total population, exceeding the 30% national average (KAIRA, 2008; Armijos & Few, 2016).

The results of these studies demonstrate that there is a good level of awareness of volcanic hazards among St. Vincent residents, particularly those in proximity to the volcano, but this awareness has not led to increased adoption of preparation measures. These outcomes strongly reflect the findings from the academic literature, demonstrating the lack of connection between awareness and taking action. However, what both Robertson (1995) and Crosweller (2009) do identify is the lack of knowledge of the behaviour, nature and spatial distribution of volcanic hazards which may pose a threat to communities in proximity to the volcano.

### *3.5.1 Acceptable risk*

The levels of risk that people are willing to assume when confronted with a specific hazard is called acceptable risk (Peterson, 1988). In many volcanic regions populations accept higher levels of risk as they also receive benefits from residing in those areas (e.g. fertile soils). On St. Vincent, Robertson (1995) suggests, some people are willing to except a relatively high level of risk from any volcanic activity, demonstrated by the refusal by some islanders to evacuate during the 1979 eruption, despite a governmental evacuation warning being in place. However, many of the most vulnerable population did evacuate during the 1979 eruption (>15,000 people in emergency shelters), demonstrating that a large portion of the most vulnerable population had low levels of acceptable risk or, that their acceptance of risk is short-lived when confronted with a volcanic eruption.

As the time interval between volcanic eruptions increases, and no activity or potential activity is expected by either vulnerable communities or policy makers, governments begin to feel more at ease with decision making for town planning and development (Robertson, 1995). As there is more pressure to provide housing for increasing populations and less land available for development, St. Vincent has seen an increase in the amount of development within the Red Zone (Figure 3.5) (Robertson, 1995; Wilkinson *et al.*, 2016). Further, in recent years there has been a shift in the number of Vincentians now illegally farming marijuana directly on the slopes of La Soufriere due to the fertile soils and plentiful land. The number of illegal marijuana farmers is currently not known, but their willingness to farm these fertile soils on the flanks of an active volcano demonstrates high levels of acceptable risk, although it is assumed that many of the farmers would evacuate during a future eruption of La Soufriere.

## 3.6. Agencies involved in disaster risk reduction on St. Vincent

There are a number of agencies responsible for the monitoring of La Soufriere, communication of hazard information, disaster management, mitigation and resilience of communities for a future volcanic eruption on St. Vincent. In this section, the role of each of the key agencies in preparing for and managing a volcanic crisis is defined.

### *3.6.1 Monitoring of La Soufriere*

The University of the West Indies, Seismic Research Centre (SRC), first established in 1952, is responsible for the monitoring of all volcanoes in the English-speaking Eastern Caribbean (Seismic Research Centre, 2011), including La Soufriere, St. Vincent. Their role is to analyse all incoming data from monitoring equipment placed around La Soufriere (tiltmeters, seismometers and GPS) and to interpret the data to assess whether the volcano is exhibiting signs of unrest (precursory activity such as inflation and increased gas release). It is also their responsibility to disseminate this information to the local governments to enable them to take action if an eruption is deemed imminent. The SRC are also responsible for investigating historical eruptive centres that are currently not active to determine if there is potential for a future eruption, and to establish the type of activity that may be experienced if it does occur (Section 3.4) (Robertson, 2003). One of the more important roles of the SRC is extensive community education and outreach programmes covering all geological hazards in the Eastern Caribbean (e.g. tsunami, landslides, earthquakes and volcanoes).

The Soufriere Monitoring Unit (SMU) was established in 1987 and is based on St. Vincent within the Ministry of Agriculture, Industry, Forestry, Fisheries and Rural Transformation. They work in collaboration with SRC to maintain a 24-hour monitoring network of La Soufriere. Their role is to maintain and service the monitoring equipment around the island including the observatory at Belmont (Government of Saint Vincent and the Grenadines, 2014) and to provide further information to SRC in a time of crisis (i.e. observations of activity at the volcano). Their role also includes taking measurements from within the crater on a regular basis, including temperature readings from the fumaroles, taking photographs and making visual observations. The role of the SMU extends beyond volcano monitoring as they also engage in other geohazard-related work including landslide investigation, coastal flooding, and education and outreach with island residents (Robertson, 2003).

### *3.6.2 Disaster management*

The Caribbean Disaster Emergency Management Agency (CDEMA, formally CDERA) are the main organisation responsible for disaster management across the Caribbean region. Their main function is respond to disastrous events (human or natural) in a coordinated effort with national disaster agencies, as was the case in the aftermath of

Hurricane Tomas in 2010. Other key roles of CDEMA include: providing information to Caribbean states of potentially hazardous phenomena (e.g. hurricanes), and organising and mobilising disaster relief efforts including aid and funding. CDEMA also provide tools for education and outreach in the Caribbean and, in 2010, launched their latest tool *weready.org*. This online resource provides information relating to many different types of hazards, including why they happen and how the Caribbean Community (CARICOM) can prepare (CDEMA, 2010). This project was also partly funded by USAID (United States aid agency), European Union and the University of the West Indies.

CDEMA work closely with national disaster management organisations (governmental and non-governmental) to coordinate their response effort. On St. Vincent, CDEMA work with the National Emergency Management Organisation (NEMO), a government organisation, to manage disasters if, and when they happen. NEMO are responsible for disaster preparation, mitigation and management for St. Vincent and the Grenadines. Established in 2002, NEMO's role is to mitigate and manage disasters such as hurricanes and volcanic activity. NEMO have helped develop the National Disaster Plan for St. Vincent in collaboration with the police, fire department, coast guard, Red Cross and other key agencies and governmental departments. In the case of a disastrous event on St. Vincent, such as a volcanic eruption, NEMO will be some of the first responders who will:

- provide and disseminate information to the public (e.g. changes in volcanic activity alert level),
- organise appropriate action (e.g. evacuation to shelters)
- and provide emergency supplies (e.g. food and bottled water), where appropriate (National Emergency Management Organisation, 2015).

Another important role of NEMO is their community education and outreach programmes. Every year NEMO launches educational campaigns for issues such as the upcoming hurricane season, and their annual 'Volcano Awareness Week' (VAW) to coincide with the anniversary of the 1979 eruption. Their campaigns are often a collaborative effort with other organisations such as the Red Cross and/or SRC, and often include television and radio broadcasts, a programme of school sessions, open community sessions and the distribution of information materials such as leaflets and posters (Lowe, 2010).

## 3.7. Communicating volcanic hazards

Disaster risk reduction agencies on St. Vincent work to improve resilience of communities living close to the volcano in a number of ways. The volcanic hazard map (Figure 3.5) for the island is one of the most important and extensively distributed materials about volcanic hazard, along with the volcanic activity alert levels. Education and outreach is also extensively utilised across the island in a number of guises further described in this section.

### *3.7.1 Education and outreach*

One of the main methods of improving resilience and preparedness of communities for a potential eruption of La Soufriere is through extensive education and outreach programmes conducted across the island. This is undertaken through both the national curriculum, and through targeted education and outreach programmes conducted annually as part of Volcano Awareness Week (VAW).

The topic of volcanoes is included within the national school curriculum for CXC Geography (equivalent to UK GCSE) secondary education. The curriculum covers the formation and distribution of volcanoes in the Caribbean region along with the basics of tectonics and the various volcanic hazards (Caribbean Examinations Council, 2005). However, this is only taught within the Geography course which is optional for students at CXC level. No information about volcanoes is provided as part of the national curriculum to primary schools or students outside of Geography classes.

**Plate 3.4. Primary school students making model volcanoes during Volcano Awareness Week 2016 activities conducted by SRC, NEMO and SMU. Photograph courtesy of Clevon Ash (SRC) taken in April 2016.**

To counter this, each year NEMO, SRC and SMU embark upon an intensive programme of education and outreach for volcanic risk (hazards, preparation measure and response) with primary and secondary school students on St. Vincent (Plate 3.4). VAW is run to coincide with the anniversary of the 1979 eruption, during April of each year. The programme includes presentations and activities within schools and communities and culminates with a volcano hike to the La Soufriere summit crater to encourage public engagement at the end of the week's activities. During the week, over 1000 students from the most at-risk communities on the island receive outreach sessions. Additionally, NEMO also run education sessions with at-risk communities living in proximity to La Soufriere and host a meeting for key agencies to revise the Volcano Emergency Management Plan (VEMP).

### 3.8. Study location justification

St. Vincent was selected as the study location for this research based on its unique relationship with volcanic hazards. The La Soufriere volcano has a long history of explosive eruptions occurring on an approximate 100-year cycle, with the last eruption in 1979 leading to the evacuation of over 15,000 people to emergency shelters where they stayed for up to four months. Since then, the La Soufriere volcano has remained in a state of quiescence.

Today, over 15,000 people continue to live within the Red Zone close to La Soufriere, considered to be the most exposed to volcanic hazards during future eruptions at the volcano (Richardson, 2005). In some these exposed communities, poverty levels range between 43-56% particularly within Georgetown, Chateaubelair and Sandy Bay (KIRIA, 2008) meaning that some of the most vulnerable people may not have a choice about where they reside, placing themselves in areas particularly exposed to volcanic hazards. Vulnerability of these communities is exacerbated by poor access routes with only one highway (windward or leeward highway) connecting towns within the Red Zone with safer, less exposed areas to the south. Further, as the time interval increases since the 1979 eruption, policy makers and government become more relaxed with decisions for town planning and urban development within these exposed areas, potentially leading to an increase in the number of people residing in proximity to La Soufriere (Robertson, 1995).

As a small Caribbean island, St. Vincent is also prone to many other natural hazards in addition to volcanic eruptions; experiencing hurricanes, flooding, earthquakes and landslides on a much more frequent basis. This has led to the island’s residents tending to prioritise preparedness for short-term threats over longer-term volcanic threats, which are deemed to pose less of a risk to day-to-day life. This is a phenomena also previously noted in other areas prone to multiple natural hazards (e.g. Shaw *et al.* (2004); Perry and Lindell (2008).

Despite many of the island's residents having a good knowledge of, or having experienced the 1979 eruption, over half (56%) of the population are under the age of 35 (Census, 2012), meaning they have no direct experience of volcanic eruptions on the island. This younger generation are more vulnerable to the impacts of an eruption and have little or no knowledge of the potential effects. To this end, significant efforts are being made to raise awareness about volcanic hazards, which is vital to ensure the population is motivated to prepare for a potential future eruption of La Soufriere, which could occur with little warning. This awareness raising is undertaken by NEMO and SRC through their annual education and outreach programme – Volcano Awareness Week. This existing platform for volcano education provides an ideal backdrop to appraise the efficacy of using serious games in volcanic hazard education, also enabling for comparison with conventional techniques.

Both the high levels of potential hazard and exposure associated with a future potential eruption of La Soufriere, combined with a strong existing education and outreach programme provide an ideal setting to establish how effective serious games can be when used for volcano education.

### 3.9. Summary

The high likelihood of an eruption occurring in the next 100-years and with many communities in proximity to the volcano, many people are potentially exposed to future volcanic hazard. This is the most significant justification for adopting St. Vincent as the testing location for this study. Additionally, due to an extensive network of agencies involved in disaster risk reduction and the programme of education and outreach, in particular VAW, St. Vincent is considered to be an ideal location to host this research.

This well-established education and outreach programme allows for detailed comparisons to be established for the effectiveness of different types of education techniques (e.g. presentations and video games). Further, with the islands primary language being English and an already well-established relationship between key agencies on St. Vincent (NEMO, SMU and SRC) and the research team (Lara Mani and Paul Cole), St. Vincent was chosen as the study location for this research.

# CHAPTER 4: *St. Vincent's Volcano* game design and development.

This chapter describes the design and development of the *St. Vincent's Volcano* game, including initial establishment of the game concept, translating the concept into a feasible design, creation of the game and initial functionality testing (Figure 4.1).

The first part of this chapter describes how the game design was established through a three-stage process: 1) establishing user requirement for community groups and agencies on St. Vincent, 2) extracting historical information from literature and 3) considerations for the four-dimensional framework for learning (learner specifications, mode of representation, pedagogy and game context). Once these three-stages were complete, the game design and concept were translated into a series of storyboards which depicted the concept, flow and look-and-feel of the game. The process behind creating the storyboards is outlined in this section of the chapter and includes examples of the completed storyboards together with an explanation of their importance for the game building phase.

The second part of this chapter describes the functionality testing undertaken with undergraduate students at Plymouth University. This allowed the game to be tested and checked for robustness and the identification of any issues (e.g. glitches and technical issues). Results from participant feedback are presented in this section. Weaknesses identified during the game enabled modifications to be made before the game was finally implemented on St. Vincent.

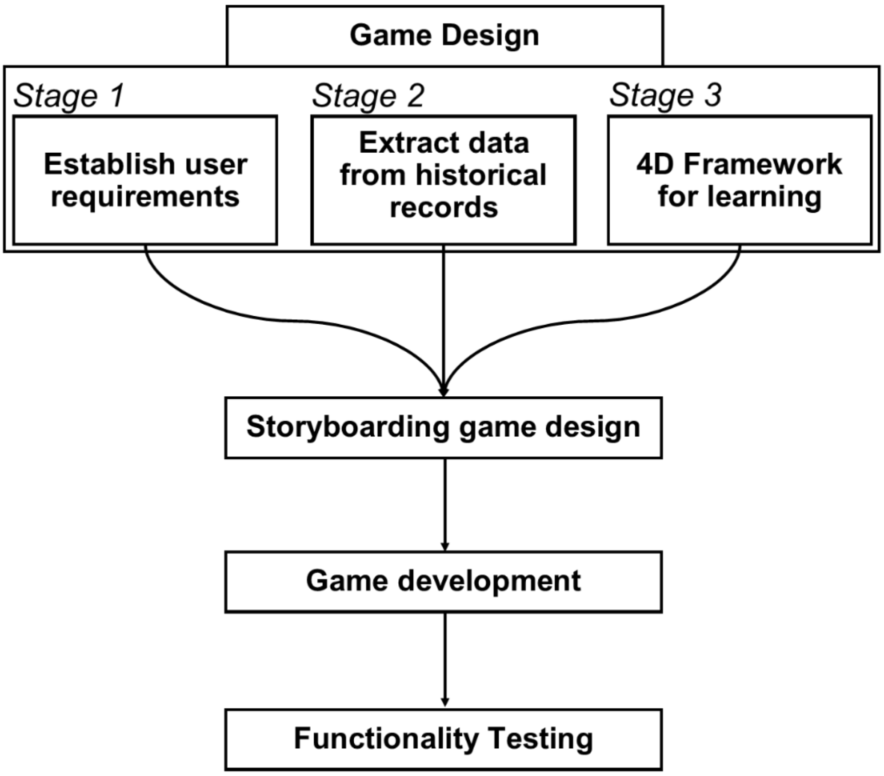



**Figure 4.1. The process undertaken to develop the *St. Vincent's Volcano* game.**

## 4.1. Game design stage 1: establish user requirements

The first stage of the game design was to establish what the end-users of the game (agencies on St. Vincent and community groups) required it to include and to understand how they might use it in education and outreach sessions. This was considered essential in ensuring that a level of collaboration with both communities and agencies was integrated into the game development. Collaboration was highlighted as a key component in developing effective DRR tools (Paton *et al.*, 2008; Hicks *et al.*, 2017). User requirements information was gathered during August 2014 through online questionnaires for agencies and focus groups with community groups.

### *4.1.1 Online agencies questionnaires*

To establish the user requirements from perspective of agencies involved in DRR, a detailed questionnaire was designed. The questionnaire comprised questions asking about existing methods and techniques employed for volcano education and outreach and questions to gauge opinions on the game content and specifications. Questions also asked agencies how they envisaged the game could be integrated into existing outreach activities. Ethics approval was sought to deliver the questionnaire to agencies and the final questions approved by Dr Stephanie Lavau (a former social science lecturer within the School of Geography, Earth and Environmental sciences at Plymouth University) who acted as an advisor. The online questionnaire is included in Appendix A.

The online questionnaire was then emailed directly to six key agencies involved with volcano education and outreach on St. Vincent, including members of SRC, NEMO and The Red Cross. This method of delivery was selected as it was considered the simplest method to distribute to agencies who were based throughout the Caribbean region. Of six agencies contact to provide input for the game design, one respondent, a key and central education provided in the Eastern Caribbean, completed the online questionnaire. Within social science literature, it is commonly understood that a low response rate to questionnaire indicates that the responders may not fully represent the survey populations, resulting in study bias (Bowling, 2005; Fincham, 2008). Although one respondent in this case, does not allow for key ideas and themes to be identified across multiple agencies, the responding stakeholder is a key decision maker and influencer in the coordination and deliverance of all education and outreach session for natural hazards across the English speaking Eastern Caribbean, including St. Vincent. The respondent works closely with all agencies invited to participate in the questionnaire and is considered to have a good understanding of the potential needs and requirements of these agencies. This respondent also originates from St. Vincent and was able to give a thorough response to the online questionnaire based not only on their experiences of working in the field, but also from growing up on the island. A summary of the requirements outlined by the key stakeholder are included in Table 4.1.

Many of the requirements outlined by the respondent to the online questionnaire validated many of the themes emerging from informal conversations with agencies including members of NEMO, SRC and the Red Cross, during a reconnaissance trip to St. Vincent in January 2014. Key themes included the need for strong Caribbean links within the game (e.g. use of local town names and identifiable locations), the ability to use the game during VAW and integration of existing education materials (e.g. the volcanic hazard map) (Pers. Coms. S. Edwards and C. Ashton, January 2014).

#### *4.1.2 Focus groups with community groups: Owia and Petit Bordel*

Focus groups were used to provide a forum to establish user requirements but also to encourage discussion and the expression of opinions about the game among community members (lay population and community leaders). As attendance on St. Vincent was not possible during August 2014, questions relating to the game were integrated into focus groups being conducted across St. Vincent by the Strengthening Resilience in Volcanic Areas (STREVA) project. The STREVA project has aimed to work towards building more resilient communities through raised awareness of volcanic hazards amongst communities and agencies. The focus groups hosted by the STREVA project aimed to record people's stories from the 1979 eruptions and determine levels of perceived volcanic risk and preparedness at both family and community level. The focus groups were facilitated by Teresa Armijos Burneo, a researcher from the STREVA project who integrated the questions relating to the game into the end of her focus groups in the towns of Owia (windward), and Petit Bordel (leeward) (Figure 3.2). These towns were targeted due to their high populations and proximity to La Soufriere, with both towns falling into the Red Zone (Figure 3.5). The integration of the user requirement questions into the STREVA project focus groups was advantageous in reducing the number of times local residents are exposed to volcano research on St. Vincent. This reduces the stress on communities who may become concerned that an eruption is imminent when frequently questioned about the volcano by scientists/researchers. In total, 18 participants were involved in the focus groups, six from Petit Bordel and 12 from Owia.

The participants were recruited through community leaders who invited participants to attend.

User requirement questions integrated into the focus groups were carefully designed and once completed, approved by Dr Stephanie Lavau. They comprised open-ended questions designed to provoke discussion and allow participants to share thoughts and opinions about the game requirements. Questions related to what people thought of the idea of creating a serious game, specifications for the final design and what content communities believed should be included. The user requirement questions issued in the focus groups are included in Appendix B.

The focus group questions were designed to help improve understanding of who the game should be targeted at, how it might be used, what would be desirable from a potential end-user's perspectives in terms of content and to identify any other content or specifications not previously considered. The questions were then designed to follow-on from each other in order to maintain a good flow and engagement for participants, based on Breen (2006). Prior to the questions being posed, Teresa was asked to read a statement to the participants explaining the idea behind the research to place the questions in context. Little steer was given to the participants to influence their thoughts or opinions, with only guidance provided by Teresa to ensure the discussions stayed on track and were relevant.

All focus groups were audio recorded and then transcribed for ease of data analysis. The transcripts were then examined to draw the key ideas and opinions, particularly where repeated across focus groups. The comments were grouped into categories based on the questions posed to participants comprising: game duration, target audience, content and any other key specifications.

### 4.1.3 Summary of user requirements

The key themes relating to game specification and suggestions of content from both the online stakeholder response and the focus groups are summarised in Table 4.1.

| Topic | Questionnaire response | Community responses |
|---|---|---|
| ***Duration*** | 15-30 minutes. | No longer than 1 hour. |
| ***Platform*** | Stand-alone application on mobile devices and laptop/PC. | All available platforms (PC/laptop, mobile devices, internet, social media). |
| ***Target audience*** | Primary audience for current outreach activities is secondary school aged 10-19 but also with primary school children. | Primary and Secondary school children. |
| ***Content*** | Volcanic phenomena (ash fall, pyroclastic flows and lahars), historical eruptions. | The hazards associated with the volcano, historical eruptions and how communities were affected (socially and physically). |
| ***Other*** | Game should be used in current outreach sessions. | Game should be freely available and easy to use for all computer capabilities. |

**Table 4.1. Summary of the recurring themes identified from the community focus groups and stakeholder online questionnaire.**

There was a difference in the duration that was suggested by both questionnaire respondent and the community groups, with the questionnaire respondent suggesting the game should last somewhere between 15 and 30 minutes and community groups suggestions of up to 1 hour. This difference is likely to be due to a misunderstanding amongst the community groups of the games intended use and purpose and/or whether participants have experience of education and outreach sessions. The questionnaire respondent, who has regularly undertaken outreach sessions, notes a shorter duration and follows it up with the comment:

> *"It could be used with our current outreach program [sic] in schools… The games can be used as an activity that goes along with the existing outreach activities undertaken by SRC during our focused week on the island as well as period visits."*

The questionnaire respondent's justification for the short game duration is aligned with their intended use of the game – to be integrated within an existing outreach programme as a supporting tool. The programme of outreach undertaken by SRC on St. Vincent during VAW often includes a diverse range of engaging activities including TV and radio broadcasts, presentations, games and practical activities. The game is designed to be integrated within outreach activities which includes these other education approaches However, the communities suggest a much longer duration of one hour, which is thought to be due to a misunderstanding of the intended final use of the game, with many believing it will be a stand-alone application for general release (many participants suggest it should be made available through Facebook). This misunderstanding is considered to have occurred due to a lack of a clear statement of intention for the game (i.e. its use in existing education and outreach sessions) being provided by the facilitator prior to the community focus group discussions.

General consensus from both the questionnaire respondent and the community groups was that the game should be made available across a range of platforms, in particular mobile devices and PCs/laptops as these are the most accessible forms of technology across the island. The questionnaire respondent suggested that the game should not require the internet as this is often either unavailable or unreliable across the island. Further, both groups also agreed that the game should be targeted to primary and secondary school children, with emphasis on secondary school children, although wider age demographics should also be considered. Schools children were identified as the obvious target audience due to ease of access and because all secondary school students on St. Vincent are provided with a laptop to support their studies, facilitating the use of the game within a classroom setting.

When asked about the content of the game and what the participants believed to be the most important information to include, there was mutual agreement between all participants for the inclusion of information about volcanic hazards (ash fall, pyroclastic flows and lahars) and of historical eruption information (1902 and 1979). Both groups of participants indicated the need for information on preparation measures and evacuations; however, the community groups also had a strong emphasis on the inclusion of social aspects (living in shelters and psychological effects). The questionnaire respondent expressed the need to include existing communication tools such as the existing volcanic hazard map and alert levels and suggested that the game may be effective in disseminating this information to more hard-to-reach demographics (working-age men and women) on St. Vincent.

Additionally, the questionnaire respondent provided further ideas and suggestions that are relevant to the game design. When asked *"What do you think are the main challenges in effectively communicating volcanic hazard information?",* they stated:

> *"Reaching the entire population with the various [pre-existing] outreach techniques – some people are either not attending or are not adequately covered by the current methods. Enabling the target audience to accurately visualize the hazards and their impact. Bringing the reality of volcanic hazards to someone who have [sic] never experienced them. Sustaining the effort in a region with limited resources and many competing demands."*

Some of the key issues they raise here can be overcome through the use of the video game. For example, enabling people to accurately visualise hazards and their impacts, and bringing the reality of volcanic hazards to those who has never experienced them. This can be achieved through high levels of realism of visualisations of the various volcanic hazards and by integrating accurate information based on accounts of the 1979 eruption.

The questionnaire respondent further suggests alternative applications for the game. In response to the question *"How do you envisage a video game, such as this being integrated into volcanic hazard activities?"* they state:

> *"…It would be useful to have an application that can help in outreach to decision makers and other government officials who would have to manage future emergencies…"*

Although this is not the primary design consideration for the end-use of the game, by making the game realistic and integrating accurate data such as digital elevation models of the island, this could be a secondary outcome for the game besides education. This was an approached adopted by the *Hazagora* board game, using the interventions as a way to help inform disaster risk managers (Mossoux *et al.*, 2016). However, this potential end-use by decision-makers and government did not change the games overall design.

During the Petit Bordel focus group, one participant raised concern for the use of a video game for this purpose relating to the sensitivity of the content:

> *"We have to mindful when developing these games because some people may take it from a moralistic standpoint. So it is important to educate people as to what the game is really about and what you are trying to accomplish. Otherwise, you will always have opposition to such things. People in the community think differently. You might see it as a game which is just trying to uplift, other might think the game is mocking."* ***Participant,*** *Petit Bordel.*

This comment reflects the importance of involving both agencies and communities in the game design and development phases to avoid issues relating to lack of sensitivity relating to the volcano. One other point for consideration raised by a participant from the Owia focus group suggested that the game should be made simple to use as the older generations may have a low computer literacy level.

The responses from both the questionnaire respondent and the community focus groups provided a list of requirements and specifications (Table 4.1) that were integrated into the final game design. This proved essential in ensuring that the finished game was suitable for its intended use in existing education and outreach sessions.

## 4.2. Game design stage 2: extract data from historical records

For the second stage of the game design, information relating to the formation and behaviour of volcanic hazards (ash fall and explosions, pyroclastic density currents and lahars) during both the 1979 and 1902 eruptions was extracted from the literature. This included information relating to the height of ash plumes, wind directions during the eruption (to establish the direction plumes moved), the sequence of events experienced and the locations on the island that were affected. This information was extracted from journal articles, witness accounts and newspaper articles from the time. The extracted information and sources are summarised in Table 4.2.

<table>
<tr><th>Information extracted from literature</th><th>Relevance to game design</th><th>Source of information</th></tr>
<tr><td>Precursory activity</td><td>Shows precursory activity (e.g. gas emissions and flank inflation) prior to large eruption</td><td>McClelland and Fiske (1979); Shepherd et al. (1979).</td></tr>
<tr><td>Ash plume height</td><td>Allows production of a to-scale model of the ash plume; ensuring high fidelity.</td><td>Krueger (1982)</td></tr>
<tr><td>Ash fallout locations</td><td>Allow for accurate visualisations of the eruption events</td><td>Brazier et al. (1982)</td></tr>
<tr><td>Wind directions during eruption</td><td>To produce accurate visualisations of the eruptions.</td><td>Krueger (1982); Phillips and Jenkins (2013).</td></tr>
<tr><td>Sequence of eruption events (1979)</td><td rowspan="2">Used to depict an accurate timeline of the eruption events during both the 1902 and 1979 eruption to add high realism and fidelity.</td><td>McClelland and Fiske (1979); Shepherd et al. (1979); Shepherd & Sigurdsson (1982);</td></tr>
<tr><td>Sequence of eruption events (1902)</td><td>Anderson & Flett (1903); Robertson (1992)</td></tr>
<tr><td>Information on formation and behaviour of volcanic hazards</td><td>To include accurate and detailed information on the observable hazards throughout the game.</td><td>Francis & Oppenheimer (2004); Seismic Research Centre (2011)</td></tr>
</table>

**Table 4.2. Summary of the information extracted from the historical literature for the 1979 and 1902 eruptions and an explanation of how it was used within the *St. Vincent's Volcano* game.**

## 4.3. Game design stage 3: four-dimensional framework for learning

Stage three of the game design was to ensure all aspects of the game had been considered by adopting a well-established framework for learning games. However, there is a current lack of robust methodologies and frameworks for learning games enabling effective design, with the most adopted framework currently comprising the 'four-dimensional framework for learning' (4D framework) (Westera *et al.*, 2008). Therefore, in line with current standard for developing learning games, the 4D framework was adopted for this research. The 4D framework was first devised by de Freitas and Oliver (2006) and comprises a table of questions, broken down into four categories – or dimensions - for consideration: learner specifics, context, pedagogic consideration and mode of representation (de Freitas *et al.*, 2010) (Table 4.3). Each of the four categories of consideration are described in detail in the following sections.

#### *4.3.1 Learner specifics*

The learner specifics aspect of the 4D framework encompasses profiling and modelling of the target learners to understand how to best encourage them to learn through engaging with the game. The learner profile was established through the responses generated by the community focus group sessions and the stakeholder online questionnaire (Section 4.1).

Both the communities and questionnaire respondent identified that the target demographic should be secondary school-aged children (aged 12-16 years) but also suggested that the rest of the population (6-90 years) should be considered. The experience level of volcanic hazards (e.g. have they previously experienced 1979) of the population of St. Vincent is largely dependent on age profile. For example, secondary school children (the primary target audience) have little to no first-hand experience of volcanic hazards as La Soufriere has not erupted in their lifetime. However, some children may have been exposed to a volcano outreach session during their primary school education as part of the VAW activities, particularly likely in the northern communities on the island where outreach events have previously been focused (due to their higher associated risk). Where students have not received an outreach session, they will have no knowledge or experience of volcanic hazards as it is not covered as part of the national curriculum; except as part of the optional CSEC Geography course (Caribbean Examinations Council, 2005). Some older demographics (45+ years) may have experienced the 1979 eruption, and therefore have a basic knowledge of the various volcanic hazards. However, it is expected that most players of the game will be children with no experience of volcanic hazards through either first-hand experience or education sessions, therefore allowances for this were included within the game design (e.g. simplified definitions).

It was assumed that the expected end-users would have had varying preferences of learning styles, either visual (e.g. watching how something is done in order to learn), audial (e.g. listening to someone explain how something is done in order to learn) or kinaesthetic (e.g. trying to do something themselves in order to learn). Video games can be used to engage all three of these learning styles, meaning they are compatible for use with students of any learning style. Engagement with all learner-types was achieved in the *St. Vincent's Volcano* game through the inclusion of voice-overs and sound effects (audial learning), vivid and realistic looking visualisations (visual learning) and through interactions with the game (hands-on learning).

The game was designed to be embedded within an existing outreach and education programme, allowing users to be supported throughout their learning experience through class discussions, opportunities to ask questions and instructor assistance. Some advantages of the game being embedded into an existing outreach sessions rather than being stand-alone is that the learning message can be reinforced by the instructor, further information and assistance can be provided to the learner, and any misunderstanding or uncertainties can be rectified at an early stage in the learning process.

| 1. Learner Specification | 2. Context | 3. Pedagogic Considerations | 4. Mode of Representation |
|---|---|---|---|
| **Who is the learner?**<br>Population of St. Vincent between ages 6-90; primarily aimed at secondary school children (14-16).<br><br>**What is the background and learning history?**<br>Varying history, basic knowledge delivered in schools and outreach programmes, older community members may have first-hand experience but otherwise children have little to no experience.<br><br>**What are the learning styles/preferences?**<br>Game will provide visual, audial and kinaesthetic features capable of supporting a range of learning styles. Learners can engage with the game according to their own preferences.<br><br>**How can the learner group best be supported?**<br>The learner group can be supported through active discussions, opportunities to ask questions and involvement in all activities.<br><br>**In what ways are the groups working together? What collaborative approaches could support this?**<br>The game is designed to be played individually but could also be completed in small groups of 2-3 or as a larger class group. | **What is the context for learning**<br>Outreach programmes, school classrooms and community centres.<br><br>**Does the context affect learning? (level of resources, accessibility),**<br>All secondary children have access to a laptop on St. Vincent.<br><br>**How can links be made between context and practice?**<br>Natural hazards currently taught in Grade 5 in schools and annual Volcano Awareness Week activities undertaken. | **Which pedagogical models and approaches are being used?**<br>Kolb's model for experiential learning and cognitive load theory.<br><br>**What are the learning outcomes?**<br>To improve knowledge of volcanic hazard formation and behaviour on St. Vincent.<br><br>**What are the learning activities?**<br>Interactive island model, historical eruption visualisations, interactive hazard training and a multiple-choice quiz.<br><br>**How can the learning activities and outcomes be achieved through specially developed software? (E.g. embedding into lesson plans)?**<br>Game embedded into an existing outreach programme with introduction and emphasis of the main learning objectives prior to gameplay. The game will be developed with the specific learning goals in mind.<br><br>**How can briefing/debriefing be used to reinforce learning outcomes?**<br>Will allow for greater engagement in the process. Allow for introductory information and a chance for reflection after gameplay. | **Which software tools or content would best support the learning activities?**<br>High levels of interactivity and freedom to explore the game.<br><br>**What level of fidelity needs to be used to support learning activities and outcomes?**<br>High level of fidelity for scenarios and visualisations to allow learners to have a connection with the game. The game incorporates a 'local feel' by using specific towns and island localities familiar to the learners.<br><br>**What level of immersion is needed to support learning outcomes?**<br>The game will need to be highly immersive to encourage learning and encourage the transfer of knowledge.<br><br>**What level of realism is needed to achieve learning objectives?**<br>Eruption scenarios used within the game will be based on historic events and modelled to look as realistic as possible.<br><br>**How can links be made between the world of the game/simulation and reflection upon learning?**<br>A more memorable way to learn and instant feedback can be provided to the users throughout to keep the message relevant. |

**Table 4.3. Four-dimensional framework for learning for the *St. Vincent's Volcano* game (adapted from de Freitas *et al.* (2010)).**

The game was designed to be played individually, however, it can also be played in small groups of 2-3 or as a larger class group. During the online user requirements questionnaire, when asked about their thoughts on how they believed the game may be played in practice the questionnaire respondent explained:

> *"Small groups [are preferential]. Given the current resource limitations it would be difficult to have everyone access the devices needed to the play the games individually. Also group participation helps reinforce the need for cooperation and community engagement in managing a volcanic crisis"*

The questionnaire respondent highlights a key advantage of allowing the game to be played in small groups – facilitating discussion, debate and cooperation. This level of interaction (active engagement) during gameplay may enhance the learning process and could be advantageous in enhancing learning. It is often found in literature that students who are visually more engaged with their learning experience (e.g. writing notes, discussing with friends or asking questions) are more likely to learn the information presented to them (Benware & Deci, 1984; Ryan & Deci, 2000; Prince, 2004; Vile Junod *et al.*, 2006). However, the questionnaire respondent also highlights that if the game was designed for independent play, this could be problematic where there may be a lack of appropriate facilities and resources available for the game to run. Based on this suggestion, considerations were made for the game to be played individually, in small groups and in larger classes, enabling a flexible use of the game for whatever scenarios are encountered.

### *4.3.2 Context*

The context aspect of the 4D framework refers to the environment in which the learning will take place (e.g. a school classroom or community centre) and considerations for the resources and facilities available to support learning.

As the target audience was secondary school children aged between 12-16 years (Section 4.3.1), the most likely locations for game sessions to be run was school classrooms. Additionally, the game was intended to be integrated into existing outreach sessions during VAW, where currently all sessions are undertaken during visits to various schools across St. Vincent. For the adult (18+ years) outreach sessions, these were thought likely to take place in community centres or the local schools.

In 2014, a government initiative was rolled out to provide all secondary school students with a free laptop to support their curricula studies (Ministry of Education St. Vincent and the Grenadines, 2016). Due to this programme, the expectation was that all secondary school sessions, if provided with enough notice prior to the sessions, should have sufficient access to the required facilities to ensure the game could be used. Although internet access is provided freely in all schools across the country, the questionnaire respondent noted that "*Not everyone have [sic] access to internet and if they do it is not permanent and/or reliable"* with them going on to suggest that *"a stand-alone application would be the best"* (Section 4.1.3). Therefore, the game was designed to be played without the need for internet access.

Currently students are only formally taught volcanic hazards at secondary school, between grades 4-5, if they choose to study Geography for CXC examinations (Section 3.8.2 and Section 4.3.1). The CXC Geography curriculum covers the formation and distribution of volcanoes around the world and specific to the Caribbean region and also the different volcanic hazards that can be produced during an eruption (Caribbean Examinations Council, 2005). Where students do not choose to study Geography for CXC, they will have no exposure to volcano education unless they have experienced an outreach session conducted as part of the annual VAW activities by NEMO or SRC.

Based on the context considerations detailed in this section, the game was designed to target secondary school students aged between 14-16 years, in full-time education. This meant that all students should have access to the computer equipment necessary to run the game, and have received some exposure to volcano education prior to leaving school at 16 years old, whether they studied Geography or not.

### *4.3.3 Pedagogic considerations*

As the end-goal of the game was that it should be used for an educational purpose, it required a robust pedagogical underpinning to ensure it was fit for that learning purpose. The first stage in selecting the appropriate learning theories was to establish the idealised learning outcome from the game. For *St. Vincent's Volcano,* this was to improve learners' knowledge about the formation and behaviour of volcanic hazards during a future eruption of La Soufriere. Two learning theories were selected to be embedded within the game design to support this learning outcome: Kolb's theory for *experiential learning* and Sweller's *cognitive load theory.*

The primary learning theory integrated into the game design was Kolb's theory for experiential learning*,* which is commonly used within teaching and learning games. Experiential learning is a theory that builds on the concept that experiences can be transformed into knowledge though a learning experience (Kolb, 1984). The learning model comprises a four-stage cycle, where a learner undertakes a *concrete experiences* upon which they reflect upon the experiences (*reflective observation).* The reflections made are then incorporated into abstract generalisations of concepts (*abstract conceptualisation)* which can then be applied through *active experimentation* to create new experiences and generalisations (Kolb, 1984; Vince, 1998; Bellotti *et al.*, 2013a; Konak *et al.*, 2014) ().

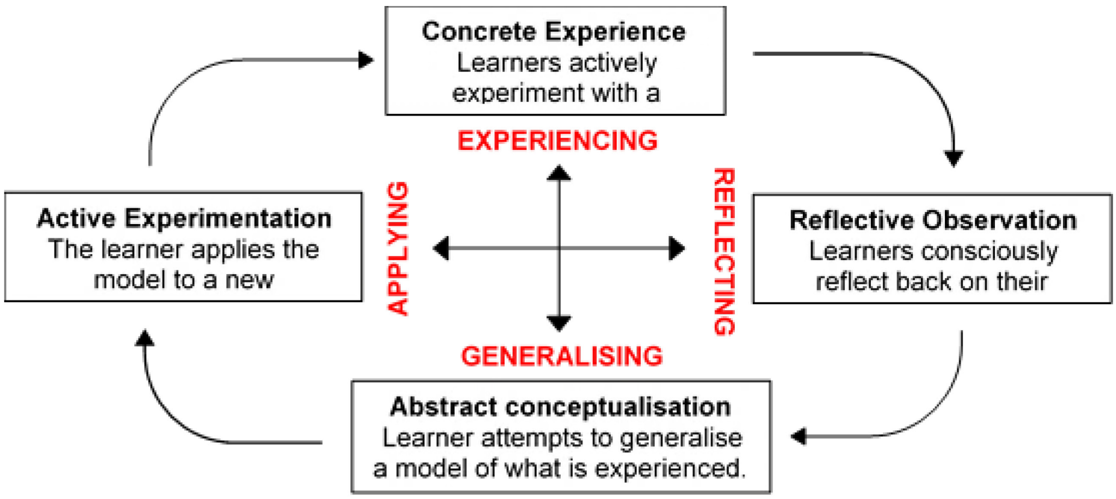



**Figure 4.2. Diagram to demonstrate the four stages that make up Kolb's theory for experiential learning. Adapted from Konak *et al.* (2014).**

Herz and Merz (1998) identified that some simulations games could follow the cycle of experiential learning better than traditional education methods, and suggested that serious games and experiential learning were compatible. Kolb's experiential learning theory has similarities with other active learning approaches but experiential learning was chosen for use in the *St. Vincent's Volcano* game due to its use of experience as the foundation for learning (Konak *et al.*, 2014).

Experiential learning is often incorporated into serious game design as the principal underpinning pedagogic logic. Kiili and Lainema (2006) suggested that experiential learning was compatible with serious game (or education games) and that it could easily be integrated into game design. Wang and Chen (2010) further expanded on this idea and supported the integration of experiential learning theory into game design as it could lead to a maintained learner motivation and facilitate knowledge construction through progressive challenges. Many educational games begin with the immediate introductions of a new concept; for example, the *St. Vincent's Volcano* game begins by defining each volcanic hazard. The introduction of a new concept provides a concrete experience for the learner, which can be reflected upon; thus initiating the experiential learning cycle (Egenfeldt-Nielsen, 2011).

In the context of the *St. Vincent's Volcano* game*,* experiential learning is integrated though learners being introduced to the key themes (volcanic hazards) early on in the game by watching historical eruption visualisations (concrete experience). The learner then interacts with scenes where the same visualisations of the volcanic hazards are used, but this time with added information and detailed descriptions of their formation and behaviour (reflective observation and abstract conceptualisation, ). Finally, the learners engage in a multiple-choice quiz, in which they can apply their knowledge. For each correct question the learner is awarded points and where questions are answered incorrectly, instantaneous feedback appears to explain the reason why the answer is incorrect (active experimentation). The game concludes with the learner being shown their overall scores and, dependent on their scores, awarded a medal (gold, silver or bronze).

Aspects of a secondary learning theory embedded into the game design are from Sweller's *cognitive load theory (CLT)*. This theory is commonly integrated into educational games as a way to reduce redundancy (e.g. through removing repetitive themes) and to streamline the learning experience. CLT works on the theory that a persons' cognitive capacity in working memory (conscious cognitive processing) is limited, so if the working memory becomes overloaded, this can affect the learning experience by reducing the cognitive capacity (Chandler & Sweller, 1991; Sweller, 1994; de Jong, 2010; Bellotti *et al.*, 2013a). Learning can be enhanced by eliminating repetitive information to reduce redundancy, and engaging both visual and auditory senses to increase the working memory capacity (Huang & Tettegh, 2010). The integration of CLT into the *St. Vincent's Volcano* game was limited to ensure it remained compatible with experiential learning - the principle learning theory. CLT was incorporated into the *St. Vincent's Volcano* in a number of ways including:

- Using visualisations and diagrams to introduce key themes (e.g. a sketch diagram was included into the lahar section of the *hazard training* scene to demonstrate how lahars were formed.

- Adding audio narration throughout the *historical eruption visualisation* scene to help learners build a deeper understanding
- Using the same language between the information presented in the game and the audio narrations.
- Cutting down the game content to the essentials to reduce redundancy of information and overloading of the working memory.

An additional consideration was how the game would be supported in terms of resources, to ensure it reaches its end goal of improving knowledge of volcanic hazards. As the game is designed to be integrated within an existing outreach session, support can be provided by an instructor who can introduce the session and its aims, answer learners questions throughout, debrief learners at the end of the activity and by allowing time for reflection at the end of the full outreach session.

#### *4.3.4 Mode of representation*

Mode of representation in the 4D framework relates to levels of interactivity and immersion (becoming physically or virtually a part of the experience itself (De Castell & Jenson, 2007)]) that the learning experience needs to incorporate for it to be effective as a learning tool. Applied to the *St. Vincent's Volcano* game, this includes considerations for interactivity, fidelity of visualisations, levels of immersion, realism and the how the learning can be reflected upon for application to the real-world (de Freitas & Oliver, 2006; de Freitas *et al.*, 2010).

The most important aspect of representation is the level of interactivity within the game, as this is the strongest method to ensure continued active engagement and subsequently motivation to play the game (Oblinger, 2004). With an identified link between interactivity and motivation to learn, the game design was made highly interactive in order to encourage learning. However, consideration also needed to be made for the potentially varying ability of end-users, such as their levels of general or computer literacy. During the community focus groups for user requirements held in Owia, one participant, when asked if they believe the development of the game to be a good idea, responded:

*"It must be easy to learn, so that the older ones can learn it too, because I am not too comfortable using the computer"* ***Participant,*** *Owia.*

This was a key consideration in the design of the game, ensuring that all end-users would be able to use the game with limited computer knowledge. To ensure this was the case, all movements throughout the game were completed using the computer mouse only. Further, support was provided throughout the sessions and guidance notes were developed and distributed to overcome any issues the users encountered (e.g. functionality of the game or understanding game content) (Appendix C).

Fidelity, when applied to video games, relates how exact the game can prepare a learner for the real-world version of the stimuli (McMahan *et al.*, 2012). For *St. Vincent's Volcano* a high level of fidelity was required to ensure the game exposed learners to an accurate and to-scale version of the volcanic hazards that they may experience during a future eruption. This was achieved through the integration of accurate information and data relating to the 1979 and 1902 eruptions extracted from historical records, such as plume heights and wind directions, to ensure the visualisations were as close to the previous eruptions' events as possible (Section 4.2). Fidelity can also be linked to levels of immersion, which relates to a learners feeling of 'being there' through gameplay (Jennett *et al.*, 2008). It was hoped that the accuracy to which the volcanic hazards were visualised may lead to higher levels of immersion. However, this was mainly achieved through the inclusion of local town names (Chateaubelair, Georgetown and Fancy) for the staging of the game. Local names were used throughout the game (e.g. names of river valleys and towns) in both audial and visual descriptions to connect with the learner.

A high degree of realism was required to maintain the integrity of the visualisations of the volcanic hazards. This was achieved by the integration of data (e.g. satellite overlays on the island model) and historical information (e.g. plume heights and sequence of events). Further, authentic audios (e.g. eruption sounds and bird sounds) were used to enhance the visualisations. An iterative approach was taken throughout the visualisation process for the volcanic hazards to ensure their behaviour and movement reflected reality. This involved the development of visualisations by the game developers which were then critiqued and compared to real-life examples by the research team. The feedback was then integrated into the development of the volcanic visualisations to ensure they were accurate and they looked as realistic as possible.

Application of the 4D framework during the game design phase ensured consideration for all aspects of the game that could lead to learning. The established user requirements (from community focus groups and stakeholder questionnaire), extracted volcanic hazard data from literature, and considerations made as part of the 4D framework were then all fed into the game design process which was completed through the development of a series of storyboards.

### 4.4. Game design stage 4: storyboarding the game design

The next phase of the game design process was to finalise the overall design concept and to pull-together all aspects of consideration (user requirements, historical data and 4D framework). To provide further understanding of the extent of information required by game designers prior to the development, a meeting was held with game designers from Bristol-based visualisation and game designers, *Shadow Industries.* Discussions provided comprehension on the capabilities of the gaming software, feasibility of desired game design, timescales for development, cost and the level of detail and information required by game designers prior to commencement. The importance of detailed storyboards was reiterated during the meeting and therefore considerable consideration and time was input during this phase of the game development.

Based on the established user requirements, extracted historical data, considerations from the 4D framework and the discussions with *Shadow Industries*, a series of 13 storyboards were drafted over a month-long period which collated:

- A scene-by-scene depiction of the game flow
- Detailed descriptions of the timeline of events for historical eruption visualisations
- Information relating to the general game look-and-feel
- Detail of learner interactions and engagement
- All textural and audial information
- Information to assist with the development of visualisations of volcanic hazards (e.g. diagrams of internal movements of ash plumes).
- Existing data and resources to be integrated

The complete set of storyboards completed throughout the game concept design are included as Appendix D.

The first storyboard developed was for the overall concept idea (Figure 4.3). This brought together pre-existing information currently used for volcano education on St. Vincent (volcanic hazards map & alert levels) as shown in the red box, data that can be used in the game development, shown in the green box (digital elevation model [DEM]) and detail of each volcanic hazard that should be included (e.g. pyroclastic flows and lahars are topographically controlled) presented in the orange box. A generalised concept for the game was then created using this information, along with the results of the user requirement sessions (community focus groups and stakeholder questionnaire), historical data gathering and completion of the 4D framework. This initial game concept comprised three scenes: information about the hazards, visualisation of the hazards and testing of knowledge (blue box).

Once the initial storyboards were completed, they were used in early discussions with the game developers – *iDAT* at Plymouth University. The storyboards enabled discussions around the feasibility of game design for their skill set, time and budget for the development and to highlight any potential issues. After these initial discussions, the game outline was given more consideration, the storyboards altered, and a detailed game flow was developed (Figure 4.4).

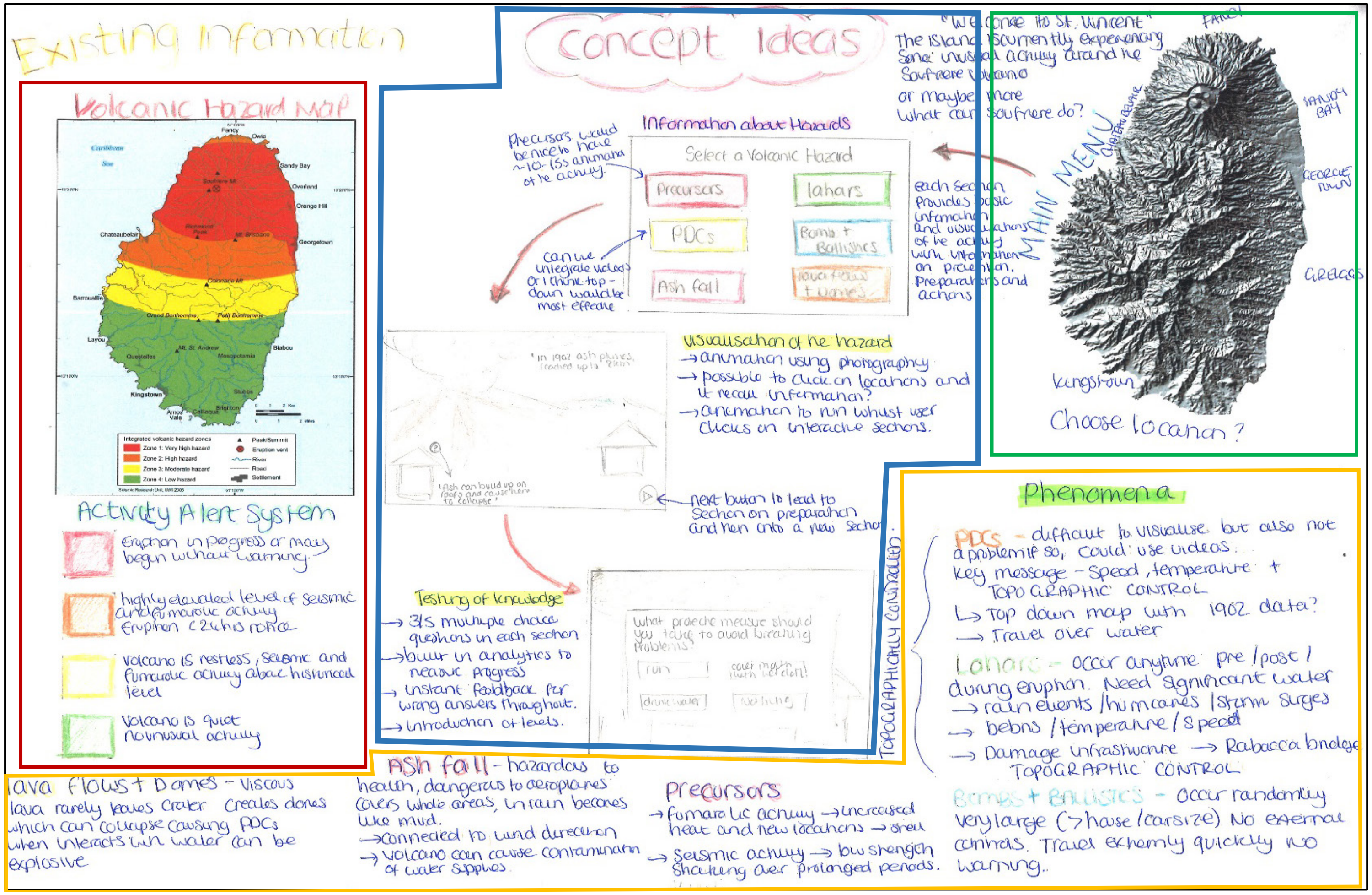



**Figure 4.3. Initial storyboard produced to establish the information required to be included within the final game (e.g. volcanic hazard map and alert levels (Red), DEM (Green) and information about volcanic hazards (Orange). The game flow was then designed in the centre of the storyboard which incorporates the established user requirements, historical data and 4D framework.**

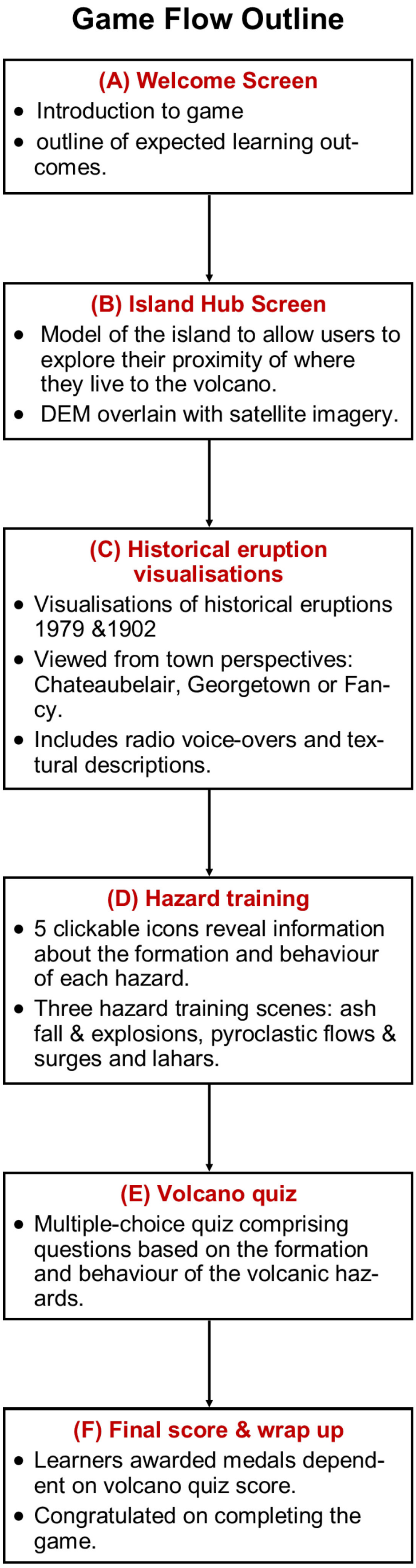



**Figure 4.4. Flowchart showing an overview of the six game scenes (A-F) within the *St. Vincent's Volcano* game and descriptions of each scene.**

The game overview flowchart comprises 6 scenes: welcome screen, island hub screen, historical eruption visualisations, hazard training, volcano quiz and final score & wrap up. The following section provides detail on how each scene of the game was devised and the justification for its inclusion within the game design, as defined on Figure 4.4.

**A. Welcome scene**

The *welcome scene* was included within the game design as a method to outline the learning outcomes before players begun their engagement with the game. This was integrated into the game to allow for CLT (Section 4.3.3) and to aid navigation and provide instruction for the player, whilst outlining the expected learning outcomes.

**B. Island hub scene**

The *island hub scene* was included within the game as a method to establish immersion by instantly exposing the player to a familiar image of their island (DEM model overlain with satellite imagery). To further enhance the connection between the game and the player, local town names and La Soufriere were labelled on the island model, allowing the player to visualise their towns in proximity to the volcano.

The *island hub scene* was also included as a platform to integrate existing volcano education material (in-line with suggestions made by the questionnaire respondent), in particular, the volcanic hazard map for the island (Figure 3.5). The volcanic hazard map can be overlain onto the DEM model to allow players to clearly visualise what volcanic hazard zone (Robertson, 2005) their town is within, either red, orange, yellow or green.

**C. Historical eruption visualisations**

The inclusion of visualisations of both the 1902 and 1979 eruptions enables the player to build an even stronger connection to the game by linking the visualisations to known locations (e.g. towns and river valleys), enhancing familiarity and immersion. These scenes were also designed to introduce volcanic hazards by exposing the player to a full eruption, accompanied with descriptions and voice-overs. This allows the player to see how the various volcanic hazards form and behave without being distracted through interactivity throughout the scene. This is the first integration of Kolb's experiential learning theory into the game and covers the 'concrete experience' () in which the player undergoes a learning experience early in the game from which they can then evolve their understanding as the game progresses.

### D. Hazard training

This section of the game is designed as the knowledge transfer phase, where players encounter information about the formation and behaviour of each of the volcanic hazards they witnessed in the historical visualisations (ash fall and explosions, pyroclastic flows and surges, and lahars). During both the community focus groups and agencies questionnaire, information about various volcanic hazards was deemed to be one of the most important themes to include within the game.

### E. Volcano quiz

The *volcano quiz* is designed to enable players to instantly apply their knowledge about volcanic hazards, re-enforcing the learning message, whilst also fulfilling the 'active experiment' stage of experiential learning. The quiz is designed to include questions relating to information and images that are provided throughout the game. Where a question is answered incorrectly, the player is instantly provided with feedback to correct any potential misunderstandings they may have. This quiz has been designed to be simple to use for all abilities, as specified by the community focus groups.

### F. Final score and wrap up

To provide a final round up to the game, learners are given a score for their responses during the volcano quiz and congratulated on completing the game.

## 4.5. Game development

Using the storyboards, the final game was developed by a group of in-house developers from the iDAT team - a research team who experiment with creative technologies within the School of Arts and Media at Plymouth University. The game was developed using Unity 3D; a freely-available, industry standard gaming engine and completed during September 2014 to March 2015.

The game development was approached iteratively and was informed by constant feedback and discussions between the game developers and the research team (Lara Mani, Paul Cole and Iain Stewart). During critical design phases of the game (e.g. setting behavioural characteristics of hazard visualisations), a collaborative approach was adopted, often comprising intense periods of discussion and development simultaneously. This approach ensured the game was delivered to the specifications detailed on the storyboards (as much as possible), looked as realistic and accurate as possible and was delivered within the time and budget constraints.

During January 2015, an incomplete but functional version of the game was shown to Dr Richard Robertson, Director of the Seismic Research Centre and coordinator of volcanic outreach in the English-speaking Caribbean region. At this time, the game comprised the completed visualisations of the volcanic hazards and the completed island models with integrated volcanic hazard maps. Feedback was sought to ensure that the game was consistently meeting end-user requirements, was suitable for use and to ensure the inclusion of key agencies with the design and development phase. Feedback from Dr Robertson was extremely positive and encouraging. Dr Robertson confirmed some aspects of the game he wished to be included and provided feedback on how to enhance visualisations. During this meeting, voice-overs were designed and recorded by Dr Robertson for inclusion within the game. The importance of these discussions is outlined by Paton *et al.* (2008) who identifies that a strong relationship exists between engagement and empowerment. They state that where communities are actively involved in the design and development of preparedness activities, they are more likely to be adopted. To this end, further feedback was sought from NEMO but was no response was received.

The finished game reflected most of the storyboarded game design. However, some aspects of the storyboarded design were omitted due to time constraints, developer capability and feasibility. One aspect of the game design that was altered was the hazard training scenes which were designed to integrate more imagery, videos and have a higher level of overall interactivity for the learners. The volcano quiz was also considerably different to the storyboarded design, which comprised much more visual type questions, drag and drop answers, interactive maps and a more engaging reward scheme. Despite the changes to these scenes within the game, the re-design was done in a way that ensured the scenes were still compatible with the learning theories and were able to achieve their stated aims, although they were less aesthetically pleasing. The effect of the changes to these scenes was considered minimal on the expected learning outcomes.

Once a working-version of the game was completed in March 2015, it was tested for functionality and robustness with a group of Geography undergraduate students at Plymouth University. The following section provides detail on this functionality testing and how the results from this testing informed the development of the final completed game.

### *4.5.1 Game functionality testing*

To ensure the finalised game was appropriate for use and to identify any potential issues with the game, a session was held with nine Geography undergraduate students at

Plymouth University. The students were recruited through Dr Stephanie Lavau and were asked to attend a game session within a computer room at Plymouth University. Ideally, students of a similar age (secondary-school age) range would have been used for the functionality testing however, due to time constraints, this was not possible to arrange, therefore the students used for functionality testing were not reflective of the target audience.

The students were asked to play the game independently (as was expected to be the condition with students in St. Vincent), with no guidance given throughout the session; although, participants were able to ask questions if they wished. At the end of the session, participants were provided with a feedback sheet to complete which included open-ended questions to ascertain:

- What they liked and did not like about the game
- If they encountered any issues whilst playing the game (qualitative)
- To provide a score for various aspects of the game (e.g. usability, navigation and content) on a Likert scale of 1 to 5 (quantitative).

Ethics approval was sought for the functionality testing session, with the final feedback questionnaire approved for use by both the ethics committee at Plymouth University and Dr Stephanie Lavau. The questionnaire was designed to specifically identify aspects of the game that may be the most successful and where last-minute improvement could be made prior to final use in St. Vincent. The testing session also provided useful information on how the game could be distributed and how the data that the game provides could be obtained at the end of the session.

The completed questionnaires were analysed by looking for repeated themes and patterns in the participants' responses. Each time an identified theme was mentioned it was scored with the total number of mentions then plotted.

When asked *"What did you like about the game?",* seven repetitive themes emerged from the participants' responses:

- It was interesting
- The game content
- Audio aspects
- Level of interactivity
- Simplicity
- It was informative
- The presentation/graphics.

Figure 4.5 shows the number of times each of these themes were mentioned. The two most commonly occurring themes were that it was informative (*N* = 6) and the graphics or presentation of the game (*N* = 6).

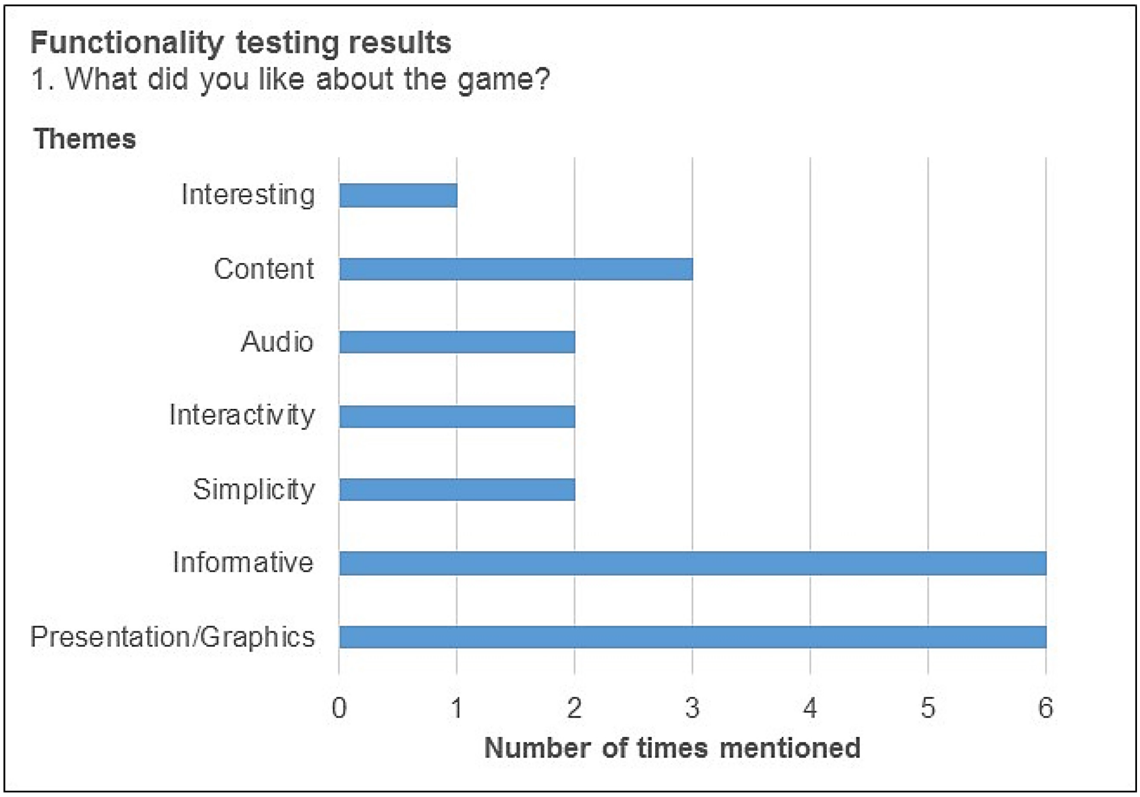



**Figure 4.5. Results of the thematic analysis for the question "*What did you like about the game?".***

The second question on the game feedback form was *"What did you not like about the game?".* The results show the aspects of the game least liked by the participants was the game navigation ($N$ = 5) and that the game was slow to respond ($N$ = 4) (Figure 4.6). Although the issue of the game being slow, in some instances, could be associated with a general issue with the computers being used during the trial. The game did lag in places and often took excessive amounts of time to load, particularly for the *welcome scene*. No guidance was provided to the participants to aid navigation through the game, therefore the responses indicated that the navigation was not intuitive enough when played without support.

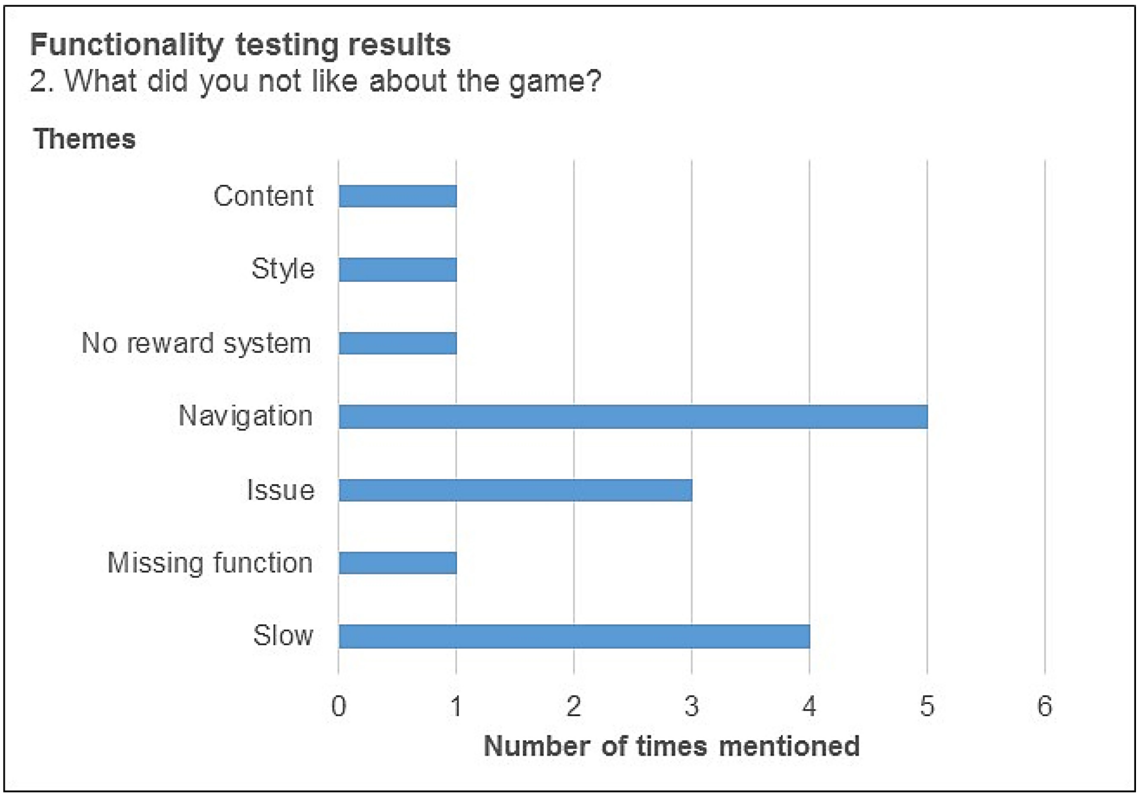



**Figure 4.6. Results of the thematic analysis for the question *"What did you not like about the game?".***

The participants were also asked to note any issues they encountered with the game. Three significant issues with the game were identified relating to the navigation, a sound issue and the game responding slowly to commands (Figure 4.7). Other issues identified related to the game crashing during play and low resolution of graphics (both considered to be related to the slow response issue), a spelling mistake within the games glossary, and lack of instruction (linked with the navigation issue).

An issue with the sound was identified by three of the participants. The issue arose where participants attempted to use earphones, which caused the sound from the game to stop. Also, when the sound worked for some participants, it was extremely loud.

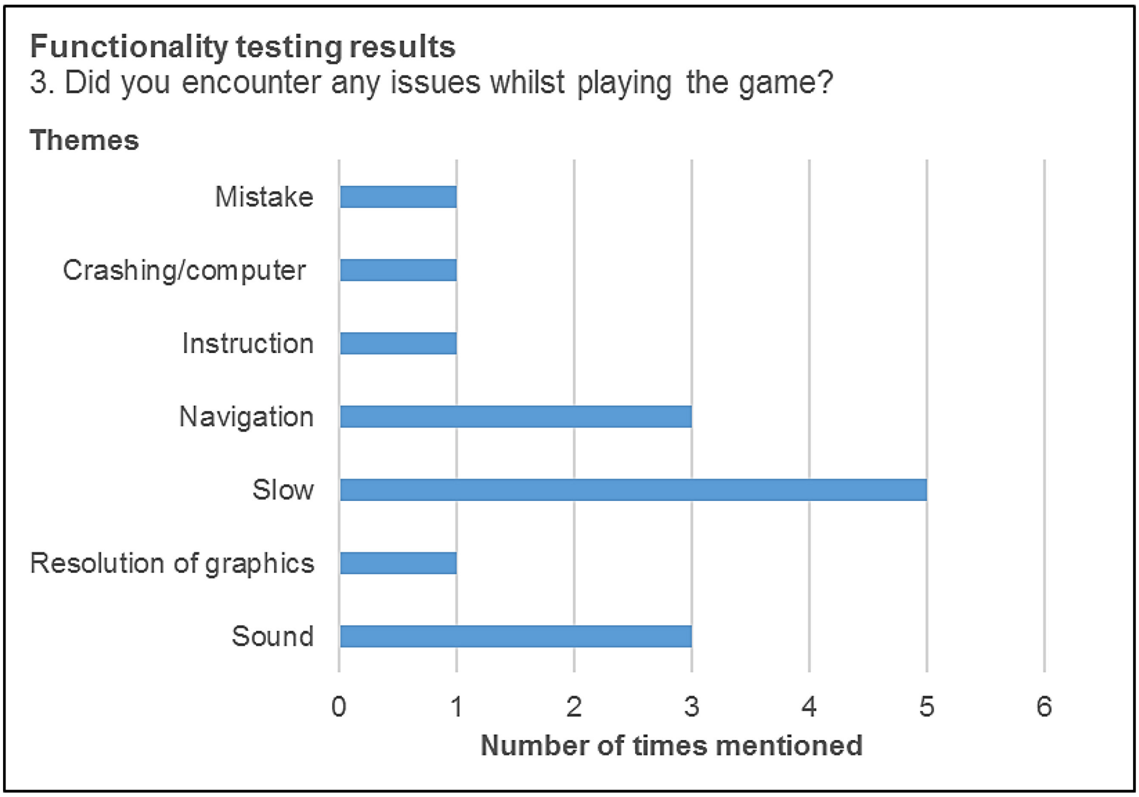



**Figure 4.7. Results of the thematic analysis when participants were asked to note any issues encountered when playing the game.**

The game was slow to respond for most of the participants, with the issue mentioned 5 times on the feedback responses. This issue was related to the pre-set graphics quality programmed into the game during development, which was too high in specification for the computers being used during the functionality testing. This was an important finding, as the game was required to work on computers of an even lower specification during the trials in St. Vincent.

Participants in the functionality trial were also asked to rank aspects of the game on a Likert Scale, a scale used to identify participant’s attitudes towards a topic (Johns, 2010) between 1 and 5 (where 1 is very poor, 2 is poor, 3 is neither good nor pool 4 is good and 5 is very good). These aspects included: navigation, realistic graphics, flow, usability, sound/audio, controls and content. The responses for each aspect were then averaged and plotted on a radar chart (Figure 4.8).

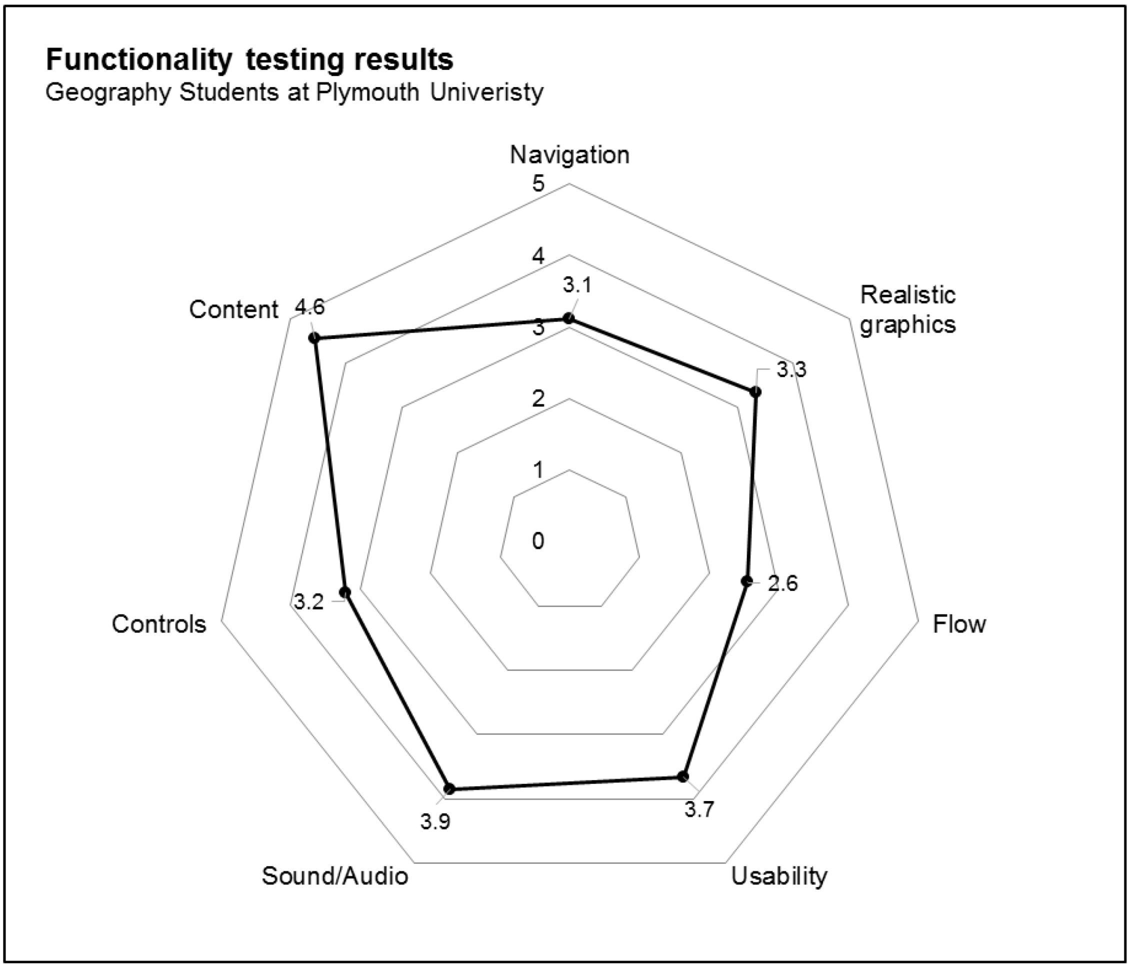



**Figure 4.8. Results of the feedback questionnaire Likert scales. The graph shows the average scores (where *N* = 9) for each of the categories based on a 1-5 scale (where 1 is very poor and 5 is very good).**

The participants demonstrated satisfaction with the content of the game, which achieved the highest average score of 4.6, but also with the sound/audio (3.9) and the overall usability of the game (3.7). The flow and navigation aspects of the game both scored low (2.6 for flow and 3.1 for navigation) indicating an area which required improvement. This also further reiterates the findings of Figure 4.7, which identified issues relating to the navigation through the game.

The results from the functionality testing provided clear indications of the aspects of the game that worked well or required further improvement. In general, the content, visualisations (graphics) and audio were considered to be good, with issues encountered relating to sound function and resolution of graphics. Issues with game resolution could have had serious implications when using the game in St. Vincent, where the computer equipment is of a lower specification. Both the resolution and sound issues were rectified during the next game iteration prior to testing on St. Vincent. Additionally, a graphics optimiser tool was added when the game loads which automatically selects the best graphics for the computer of which it is being used.

The main issues identified related to the navigation, instruction and flow through the game that, without guidance, proved difficult to understand for most participants. This issue proved more difficult to rectify but was overcome by the addition of instructions throughout each game scene and printed guidance notes (Appendix C). This issue is likely to be less significant when the game is used in context (i.e. during an outreach session) as it will be used in an environment where guidance and instruction can be provided by an education team.

### 4.6. Summary

The finalised *St. Vincent's Volcano* game was designed through a robust three-stage process, ensuring that all aspects of the game were considered prior to development. This was essential to ensure the game met all established user requirements and was able to meet its desired outcomes as a tool to enhance knowledge of volcanic hazards. Once all aspects of the game design were carefully considered (user requirements, historical information and 4D framework), the concept was detailed on a series of storyboards for use as a communications tool between game designer and game developers. The game development was an iterative process and involved collaborative input from a key agency in St. Vincent, which ensured that the game was optimised to meet user requirements. Constant discussion and close working during the development phase between the research team and the game developers ensured the visualisations produced were of high fidelity and realism, to further enhance the learners' experience.

Once the game was developed, it underwent functionality testing with a group of students from Plymouth University who highlighted issues and indicated aspects that worked well and those that required improvement. The results from this functionality testing were essential to enable modifications to be made to the game prior to its final implementation on St. Vincent. Once all the modifications were made the game was finalised. Unfortunately, there was little time available prior to field testing in St. Vincent to re-test the game once the modifications were made or to test with a group of similar age. The finalised version of the *St. Vincent's Volcano* game is detailed scene-by-scene in Chapter 5.

# CHAPTER 5: Overview of the *St. Vincent's Volcano* game

This chapter provides a detailed outline of the *St. Vincent's Volcano* game, scene-by-scene. Chapter 4 described the process of establishing the game design and the process of development undertaken after first establishing user requirements, gathering historical data records, considering the 4D framework for learning and assessing feedback from functionality testing. This chapter identifies how these aspects of the game design have been incorporated into the final game scenes in order to achieve the desired outcome of improving players' knowledge of volcanic hazards on St. Vincent.

The finalised game varies slightly from the initial storyboarded design, due to time and budget constraints or limitations of the software used, but without compromising the overarching concept or design (Section 4.5). The game comprises five main scenes: *island hub, historical eruption visualisations, hazard training, volcano quiz* and *reward* scene. This chapter provides descriptions of each of the game scenes including detail on the embedded interactivities and features, and describes how the player flows between each scene.

## 5.1 Island hub scene

The first scene encountered by the player is the *Island hub scene.* The scene begins with a menu option overlaying the *Island hub scene* (Figure 5.1), that provides the player with options to start playing the game ('start'), view credits for the game ('credits') or to quit the game ('quit'). This menu was added to replace the initially storyboarded *Welcome Scene* (Section 4.4.A), which caused the game to respond slowly as identified in the functionality testing.


**Figure 5.1. The first scene of the game that is opened after initiation. This 'main menu' scene allows the player to begin the game, view credits for the game (acknowledgements) and quit the game.**

When the *start* button is clicked, an information textbox appears designed to welcome the player to the game, provide instruction for the *island hub* scene, and explain what the player will encounter during the game (added to encompass cognitive load theory [CLT]). Once the player has read the instructions they can begin playing the game by clicking the *start* button leading them to the *island hub scene*. This textbox was added to the game, after the functionality testing, to alleviate some of the issues encountered with the speed of the game and the navigation and instruction throughout.

The i*sland hub* scene begins by showing a plan-view of the island model, built using a 15 m resolution Digital Elevation Model (DEM) of St. Vincent which is then overlain with satellite imagery (Figure 5.2). It was decided to make the model look as realistic as possible to integrate high-levels of realism and familiarity for the player. Three towns close to La Soufriere - Chateaubelair, Georgetown and Fancy - are labelled and highlighted by a blue light to add familiarity to the model. These towns were chosen as perspectives to view the historical eruptions from, based on their high populations and high vulnerability as indicated during the stakeholder online questionnaire.

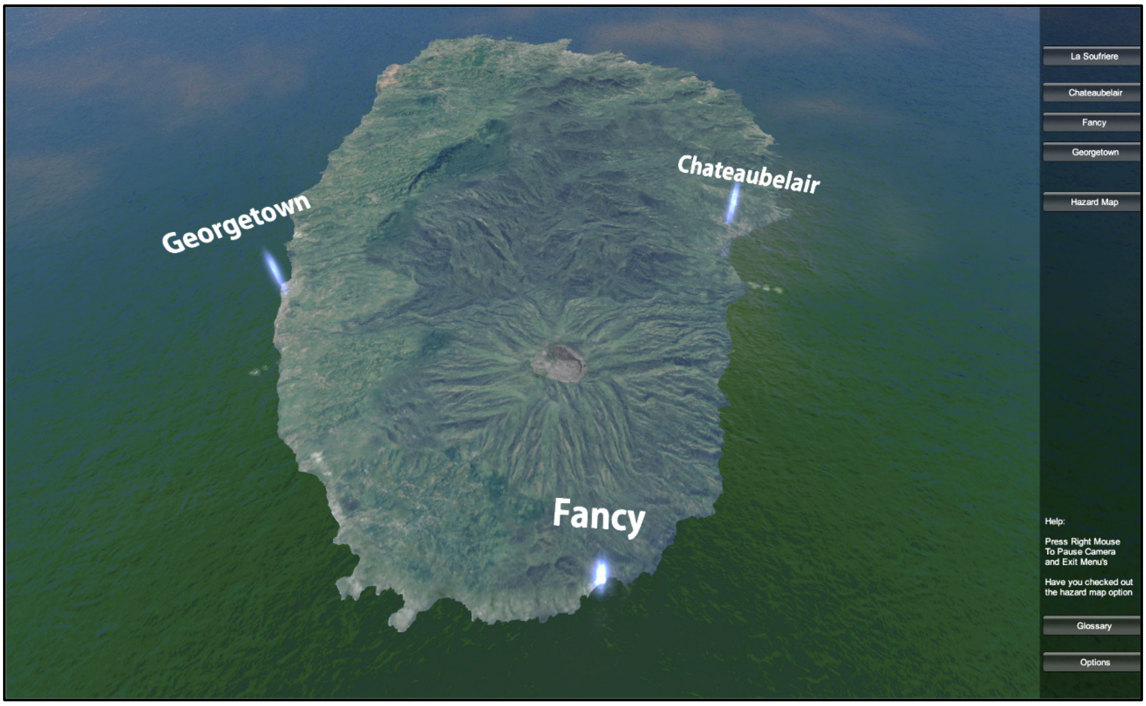



**Figure 5.2. The *island hub* scene which comprises a DEM model overlain with satellite imagery of the island for realism.**

To the right of the scene is the main navigational menu which consistently features throughout the game. It comprises four buttons: *La Soufriere, Chateaubelair, Fancy and Georgetown*, which allow the user to zoom into any of the locations. Control throughout the game is through the computer mouse, which allows the player to zoom in and out and navigate around the scene. This scene was designed to demonstrate what St. Vincent looks likes to the island residents from a birds-eye-view and in an interactive and different way than they may have experienced previously. The addition of the town names not only adds familiarity to the model for the player but also allows them to easily see their town of residence and understand its proximity to La Soufriere. Uniquely, the satellite imagery also enables the player to see how river valleys radiate from the summit crater of the volcano and reach their towns of residence, something that is not often easy to visualise or understand when in the towns.

Within the side menu, there is also a *Hazard Map* button which, when clicked, overlays the model with the established volcanic hazards map produced by Robertson (2005) (Figure 5.3). A key is also provided for the map in the top left of the scene, providing detail on the meanings of each of the hazard zones. The map was considered to be a key existing communication tool to be integrated into the game's design by the questionnaire respondent (Section 4.1). When represented in this way, the player can very clearly see which hazard zone their town of residence is within whilst manipulating the model.

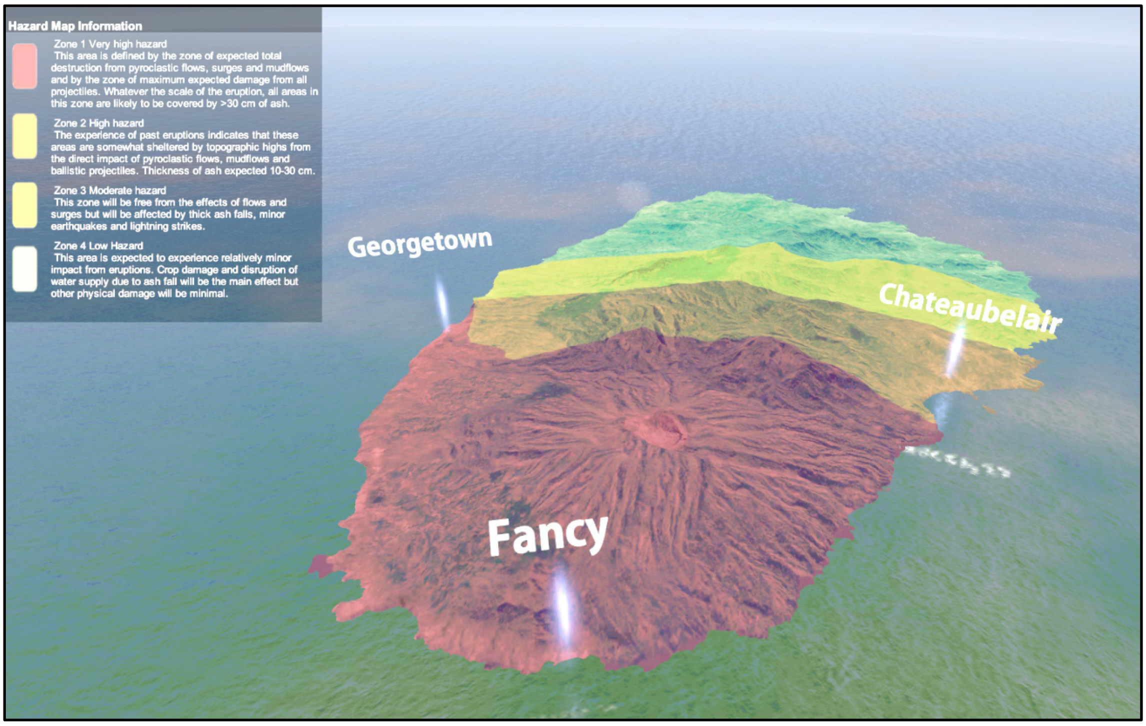



**Figure 5.3. When the 'Hazard Map' button is clicked, the established Volcanic Hazard Map for St. Vincent (Robertson, 2005) is overlain onto the island model.**

Once the player has explored the island, they are encouraged to click on one of the towns highlighted in blue on the model to continue. When the player hovers over the blue light highlighting the town or on the town name, the mouse cursor changes shape to a triangle to indicate that it can be clicked. Once clicked, a menu pops-up asking the player to select whether they would like to go to the *historical eruption visualisation* scene or the *hazard training* scene. The next scene to follow in the learning cycle incorporated into the game is the *historical eruption visualisation* scene. This menu was added to allow players to shortcut through the game should the game crash (identified during the functionality testing) or should they need to exit for any reason, avoiding having to re-do each scene of the game. When the *historical eruption visualisation* scene is selected in the menu, the player is asked to choose either the 1902 or 1979 eruption to view which, when either option is clicked, guides the player to the visualisation for that specific eruption.

## 5.2 Historical Eruption Visualisations

Initially, when the player clicks to go through to the *historical eruption visualisations* they must select either the 1902 or the 1979 eruption to view. Each visualisation was developed using historical data and accounts extracted from the literature (as specified in Table 4.2), to create near-accurate visualisations of the events of each of the eruptions.

The aim of this scene is to demonstrate the sequence of events and severity of the historical eruptions of La Soufriere whilst demonstrating the importance of learning about volcanic hazards and how dangerous they can be, from the outset of the game. The volcanic hazards included within this scene are: explosions, ash plumes, ash fall, ballistic projectiles (blocks and bombs), lahars (volcanic mudflows) and pyroclastic flows as well as the inclusion of precursory activity in the form of minor earthquakes and gas venting. Where possible, the behaviour and movement of each of the hazards is as accurate as possible to ensure they are realistic to what may be experienced by islanders during a future eruption. This includes the direction of movement for the ash plumes (Brazier *et al.*, 1982; Krueger, 1982), their height and the inundation areas of the island by lahars and pyroclastic flows (e.g. particular valleys) (Anderson & Flett, 1903; McClelland & Fiske, 1979; Shepherd *et al.*, 1979). Additionally, volcanic lightning within the ash plume and glowing from the summit crater have also been added to ensure the visualisations accurately reflect the events of both 1979 and 1902 (Anderson & Flett, 1903).

The scene provides numerous features (Figure 5.4) that ensure the player feels involved in the learning experience and establishes familiarity with the game. These include the addition of textural descriptions provided throughout to describe the events as they unfolded and radio voiceovers that also pop-up at regular intervals throughout the eruptions. The voiceovers were added to provide information to the player about what was happening during the eruption on other parts of the island. They were recorded with Dr Richard Robertson Director of SRC and a St. Vincent native; further, adding fidelity and familiarity to the game with authentic accents. During the eruption scenarios the player can also move the camera to look around the scene, by holding down the right-hand mouse button.

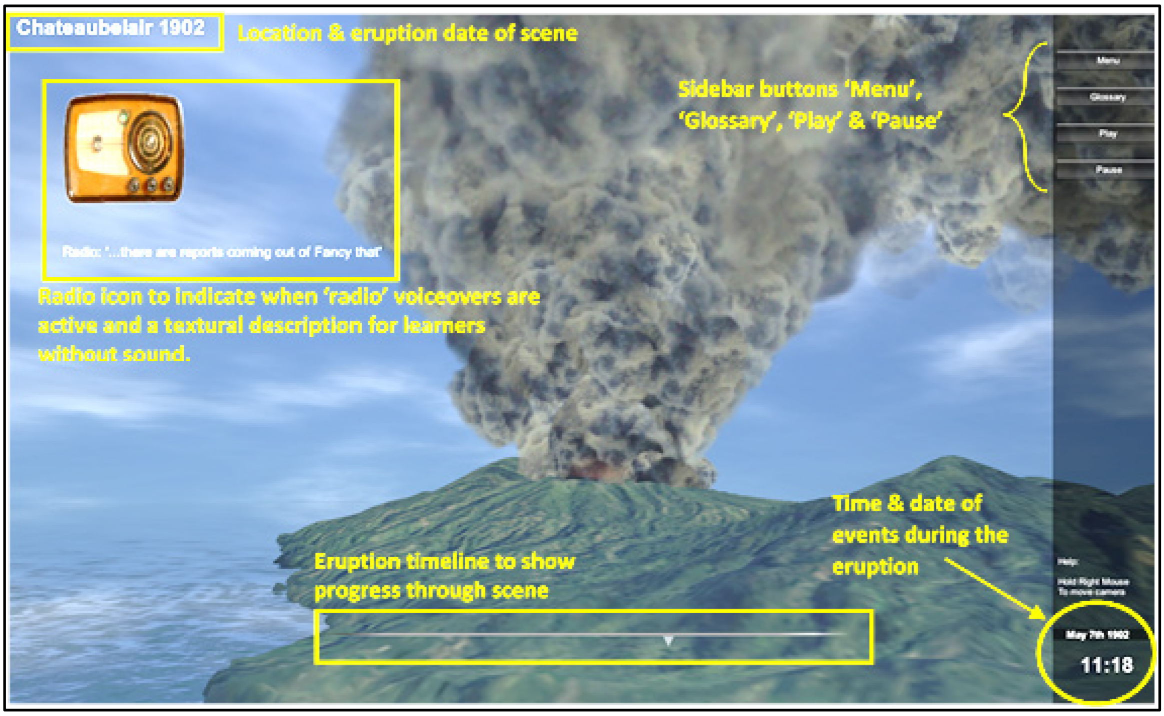



**Figure 5.4. The Chateaubelair viewpoint of the 1902 eruption detailing a number of aspects highlighted in yellow, that allow the player to accurately visualise the eruption events and to navigate the scene.**

Approximate times and dates of the eruption sequence activity is included in the bottom-right of the scene within the side menu bar, providing a scale to the eruptions and highlighting how long an eruption can last. A timeline is also included at the bottom of the scene to indicate how far into the visualisation the player is. The side menu bar includes buttons that enable the player to *Pause* the scene, return to the *Main Menu* or view the game *Glossary* of terminology (Figure 5.5).

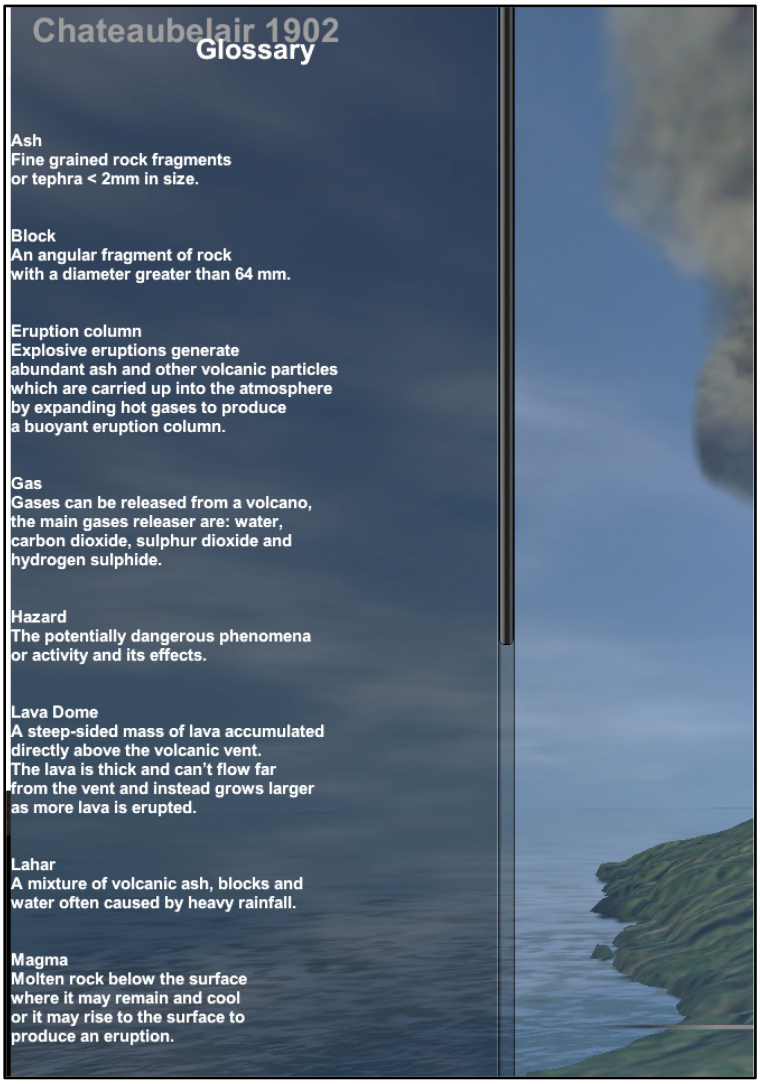



**Figure 5.5. The game glossary which contains definitions for the terminology used throughout the game. The glossary is viewable in all scenes of the game except the *volcano quiz*.**

Once the player has finished watching the visualisation of their chosen eruption, they are presented with a menu comprising four options: return to the *island hub*, view the other eruption visualisation (i.e. if they have viewed the 1902 then the option to view 1979 appears), start *hazard training* or quit the game. The option to view the alternative historical eruption visualisation was added to enable players to contrast and compare the sequence of events, magnitude and duration of the eruptions (1902 was significantly larger than 1979). Where players are not limited on gameplay time, they are encouraged to watch both visualisations to enhance the learning experience as much as possible.

Once the player has completed the *Historical Eruption Visualisation* scenes they are encouraged to continue to the *Hazard training* scene, to learn more specific information about the volcanic hazards visualised.

### 5.3 Hazard Training

The *hazard training* scenes of the game are designed to be the main knowledge transfer stage. Results from the community focus groups and online questionnaire indicated that the most significant outcome of the game should be educating about volcanic hazards. This scene is designed to expose the player to specific information about the volcanic hazards whilst maintaining the familiarity and engagement with the game.

When the scene is initially loaded, an instruction window is displayed explaining what the player is about to experience and guidance for how to navigate the scene. Similar to the initial instructions provided before the *island hub* scene, this information was added to the game after the functionality testing as a method to overcome some of the issues encountered during navigation through the game (Section 4.5.1). The instructions also remind the player to use the game glossary if they encounter any terminology they are unfamiliar with.

Once the player has read the scene instructions, they can click *Start* to begin the scene. The *hazard training* section of the game comprises three scenes – one for each potential future volcanic hazard: explosions and ash fall, pyroclastic flows and surges and lahars.

In each of the scenes, the volcanic hazard is displayed in action, demonstrating its formation and behaviour during an eruption. The visualisations are the same as previously seen in the *historical eruption visualisation* scenes to maintain familiarity and to build upon what the player has already seen within the game. While the visualisations are running, large white numbers from 1-5 appear throughout the scene in sequential order (Figure 5.6). When the first number is clicked a piece of information is displayed, describing an aspect of the formation or behaviour of the hazard. When clicked, this then triggers the next number in the sequence to be displayed for the player to find. The information that has been included for each of the volcanic hazards for each of the 5 numbers are included as Appendix F. Each number has been placed in a significant point of the scene to the information provided; for example, where the pyroclastic flow continues to travel over the sea at the coast, the information provided describes this behaviour.


**Figure 5.6. White numbers appear throughout the *Hazard training* scenes which, when clicked, reveal a snippet of information about the formation and behaviour of the volcanic hazard depicted.**

When a number has been clicked, it is added to the side menu bar which allows the player to review any of the pieces of information at any time throughout that hazard scene. Once all five numbers have been read within the scene, a *'Next Hazard'* button appears on the side menu. To enable players to find the numbers, they can move the camera around the scene by clicking and holding down the right-hand mouse button. They are also able to pause the visualisations by clicking the *'Pause'* button on the side menu. Once the player has completed all three scenes a *'Play Quiz'* button appears on the side menu (Figure 5.7). When clicked this leads the player to the multiple-choice *volcano quiz*.

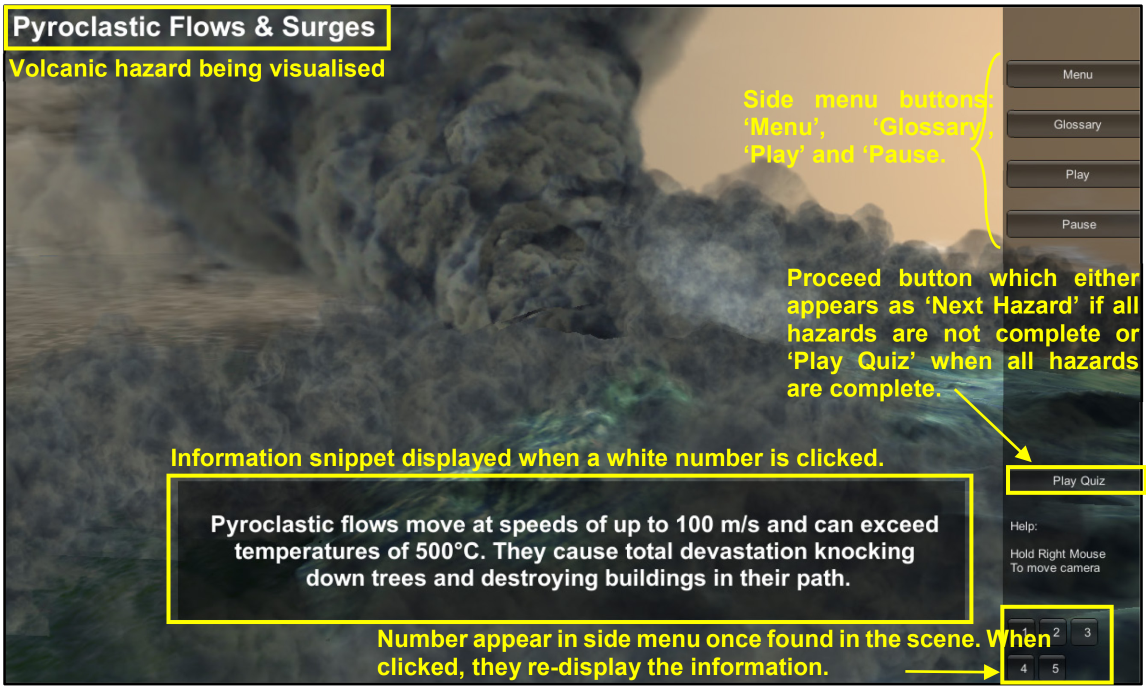



**Figure 5.7. *Hazard training* scene with all features described.**

The information about each of the volcanic hazards provided in this scene has been extracted from the historical record and literature as detailed in Table 4.2. The scene has been made with simple interactions (e.g. clickable icons) to ensure it is suitable for use by all computer literacies as mentioned by community members during the user requirement focus group sessions.

### 5.4 Volcano quiz

When the player clicks the *'Play Quiz'* button in the final *hazard training* scene, they are led to the *volcano quiz*. The *volcano quiz* is a multiple-choice quiz designed to allow the player to apply their knowledge and to correct any misunderstandings they may have, incorporating the 'active experimentation' stage of Kolb's experiential learning cycle (Kolb, 1984; Vince, 1998; Konak *et al.*, 2014).

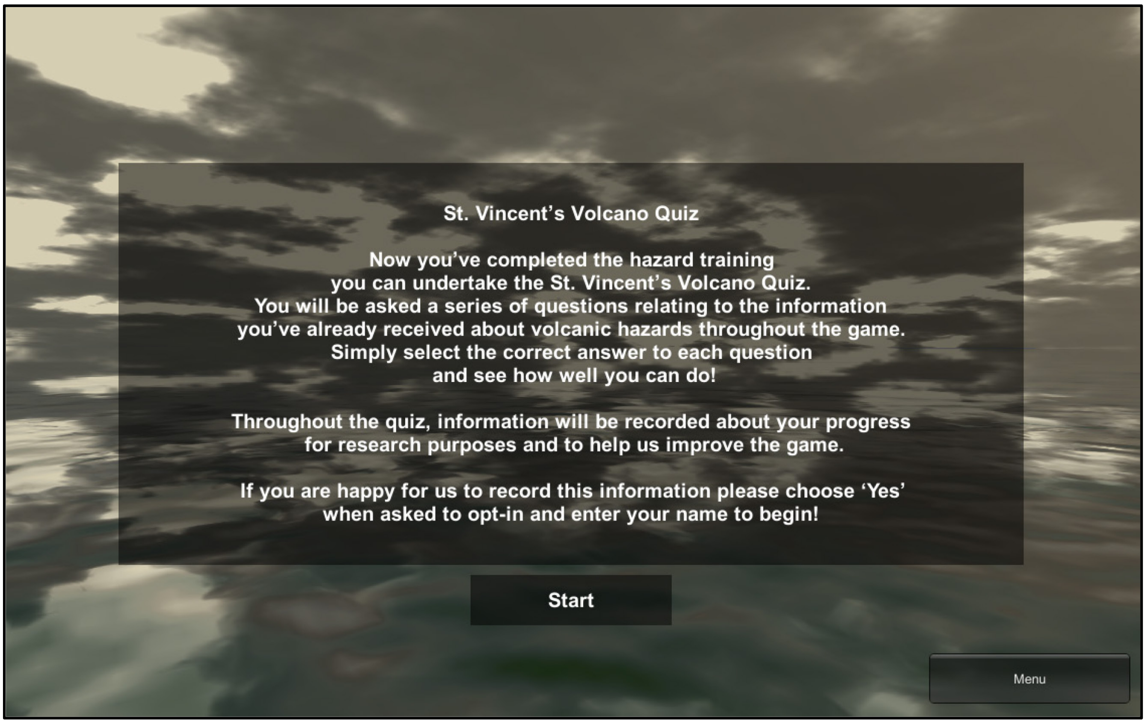



**Figure 5.8. Introductory information is provided at the beginning of the v*olcano quiz* scene which provides information on what the scene involves and navigational information for the player.**

When the quiz is first launched the player is confronted with a window describing the activity and providing guidance for the quiz to aid navigation (Figure 5.8), similar to the one presented before the *island hub* and *hazard training* scenes. Additionally, the player is asked if their data from the quiz can be recorded for research purposes (informed consent in line with ethical approval). This describes the in-built game analytics which, if the player choses to 'opt-in', records how long the player takes to complete the quiz, what questions they are asked and how they answer them. Once the player clicks *'Start'* a window appears, the next window asks they player if they are happy to record their quiz data, if 'Yes' is clicked then the player is asked to enter their name before proceeding. The integration of in-built game analytics is described in more detail in Section 5.4.1.

The *volcano quiz* comprises multiple-choice questions all based on the information provided about the volcanic hazards featured throughout the game (Figure 5.9). The player must answer six questions in total and is awarded points per question answered correctly (5 points per question). The questions are drawn from a bank of 15 questions at random, meaning that each player is likely to be asked different questions. This means the player is able to replay the game and not be asked the same questions to avoid repetition and redundancy for the player (CLT). The list of questions included within the game are included as Appendix F.

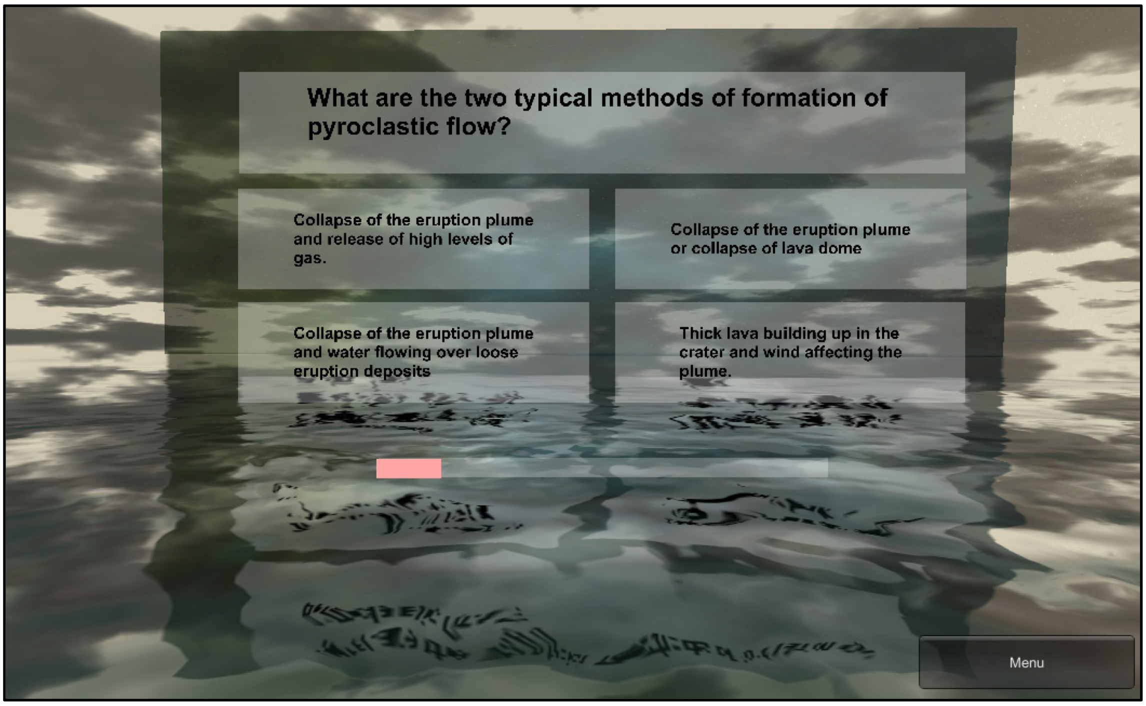



**Figure 5.9.** ***Volcano quiz*** **scene where a player is confronted with 6 questions chosen at random from a data bank of 20 questions which all relate to the formation and behaviour of volcanic hazards.**

Each question in the quiz has four potential answers, with three incorrect answers (distractors). The questions were carefully worded to match the terminology and phrasing used throughout the game and to include the most significant pieces of information. If the player answers the question correctly the question turns green and leads to the next question. Where the player answers a question incorrectly the question turns red and they are provided with instantaneous feedback to provide information on why their answer was incorrect (Figure 5.10). This instantaneous feedback is a significant advantage of using video games that allows any misunderstanding or misappropriation of knowledge to be corrected immediately (Whitton, 2009).

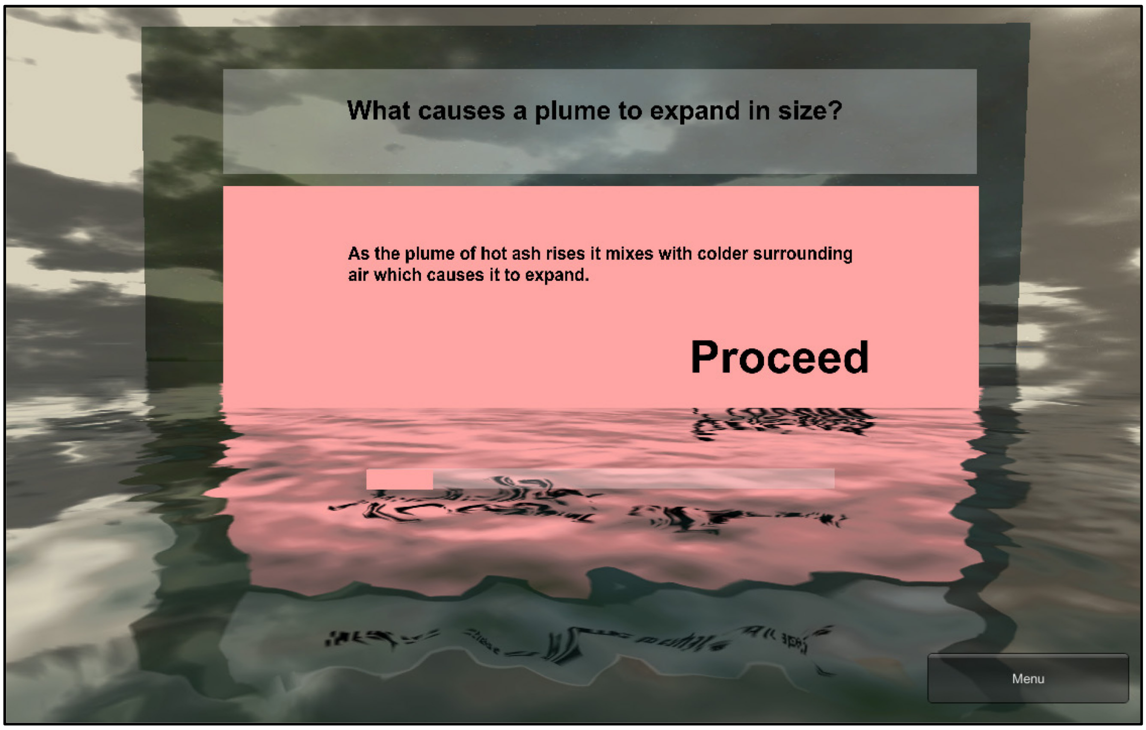



**Figure 5.10. Example of instantaneous feedback provided to the player where a question is answered incorrectly.**

A red bar is included at the bottom of the scene to show the player their progress throughout the *volcano quiz*. Additionally, a *'Menu'* button is also included to the bottom-right of the scene which allows the player to return to the *main menu* or to quit the game.

### 5.4.1 In-built game analytics

In-built game analytics were included within the game to retrieve data from participants about how they play the game. The analytics within *St. Vincent's Volcano* record the player's name, how long they have played the game, what questions they are asked during the *volcano quiz*, how they answered each question and their final score.

The primary function of recording these analytics is to understand the strengths and weaknesses within the games design. Recording the questions each participant is asked and how they answered can reveal patterns in areas of strength and weakness (lack of knowledge or knowledge gaps) across participants. This enables analysis of the effectiveness of the knowledge transfer from the game and identifies areas for improvement in game design. It can also enable session instructors to identify weak topics in the player's knowledge, allowing them to tailor their outreach session to correct the weak points.

In-line with ethics for working with minors (<16 years), all students were asked to 'opt-in' to having their data recorded and this was also extended to the adult participants (Section 5.4). This data is then recorded in an *.XML* file within the games data files as the player moves through the game. An example of the *.XML* file with recorded data is included within Figure 5.11.


```
<?xml version="1.0" encoding="utf-8"?>
<Data>
  <PlayerName>John Doe<Score>5/30</Score><date>1/15/2016 1:54:05 PM</date><duration>39.90444</duration>
<Question>Give the correct definition for a lahar.<Answer>Incorrect</Answer></Question>
<Question>Give the correct definition for a pyroclastic flow.<Answer>Correct</Answer></Question>
<Question>What causes a plume to expand in size?<Answer>Incorrect</Answer></Question>
<Question>What is volcanic ash?<Answer>Incorrect</Answer></Question>
<Question>Why are pyroclastic flows dangerous?<Answer>Incorrect</Answer></Question>
<Question>Where do lahars deposit their material?<Answer>Incorrect</Answer></Question>
</PlayerName>
</Data>
```


**Figure 5.11. An example of the data recorded by the in-built game analytics as a player completed the *volcano quiz* section of the game.**

### 5.5 Final Score and Reward scene

One of the comments raised during the functionality testing was that the game needed a stronger reward system (Section 4.5.1). As a direct result, a new scene was added to the game – the *reward* scene. Throughout the *volcano quiz* players are awarded points for questions they answer correctly. At the end of the quiz, the total score is then provided to the player out of 30 (Figure 5.12). They are then prompted to click the *'Proceed'* button which leads the player to their final *wrap-up* scene which converts the players score into either a Gold, Silver or Bronze medal (Figure 5.13). The medal is presented along with a cartoon-like volcano erupting, fireworks and clapping noises to congratulate the player. Once the player has finished reviewing their scores and medals clicking the *'Proceed'* button leads them back to the *Main Menu* of the game (Figure 5.1).

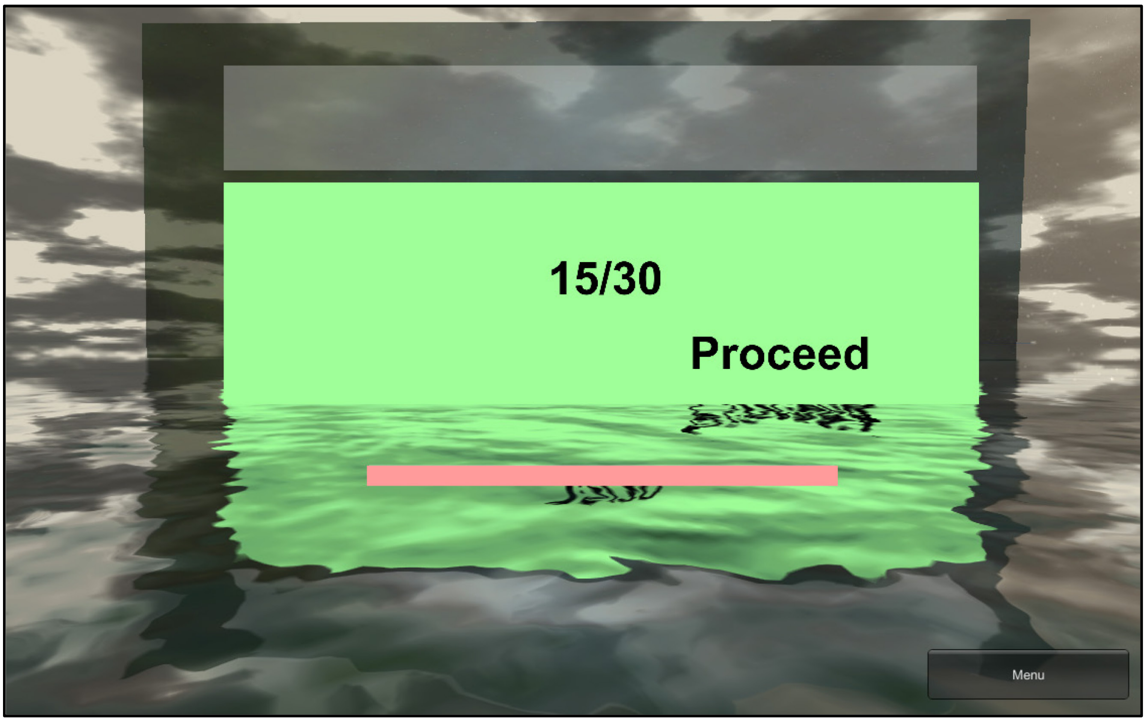



**Figure 5.12. Throughout the *Volcano Quiz* the player is awarded 5 points for every question answered correctly. On completion of the quiz the player is presented with their final score out of 30.**


**Figure 5.13. The player's final score is converted into either a gold, silver or bronze medal and is presented in the final scene of the game.**

### 5.6 Game design affordances

Game affordances are efforts made to guide players through the game without direct instruction. Affordances are considerations made for how a person interacts with an object in order for the object to be designed to perform the action required (You & Chen, 2007). For example, a door knob affords a twisting action and a light cord affords a pulling action. Similar considerations have been encompassed throughout the game to aid navigation and flow.

The side menu has been integrated into the *island hub, historical eruption visualisations* and *hazard training* scenes and is a key tool added to the design to aid navigation through the game. In every scene, the side menu layout and button systems remain the same to allow for familiarity and simplistic usability. This was considered important based on the feedback from participants from the Owia focus groups, who reinforced the idea that the game should be able to be used by members of the community with varying levels of computer literacy. Further, the results from the functionality testing indicated that the navigation through the game was not straight forward. To alleviate this issue, it was decided to include the side menu throughout the game to aid navigation (where possible) and to keep the layout consistent for ease of use.

Another key affordance through the game is the simplification of the games controls, which are all done through the computer mouse. The right-click mouse button allows players to move the camera around the *historical eruption visualisations* and *hazard training* scenes so the full view can be explored. All buttons within the game are clicked with the left-mouse button. The use of the mouse was considered to be a more affordable option for the potential end-users who may have low computer literacy, due to the ease of control that enable the players to manipulate the game as desired.

After the functionality testing was completed, instruction was noted to be a significant difficulty throughout the game with many participants not understanding what was expected of them. To overcome this, affordances were made to include introductory instructional descriptions before each scene (Figure 5.8). This allowed the player to understand what the scene was about and provided detail on what they are expected to do during that scene.

During the *island hub* scene, further affordances were made to allow smooth flow and direction for players through the game. When a player hovers over one of the three town localities (Chateaubelair, Georgetown or Fancy), the mouse cursor changes shape to a white triangle and the highlight colour over the town changes from blue to red, indicating that the player can click in this location (Figure 5.14).

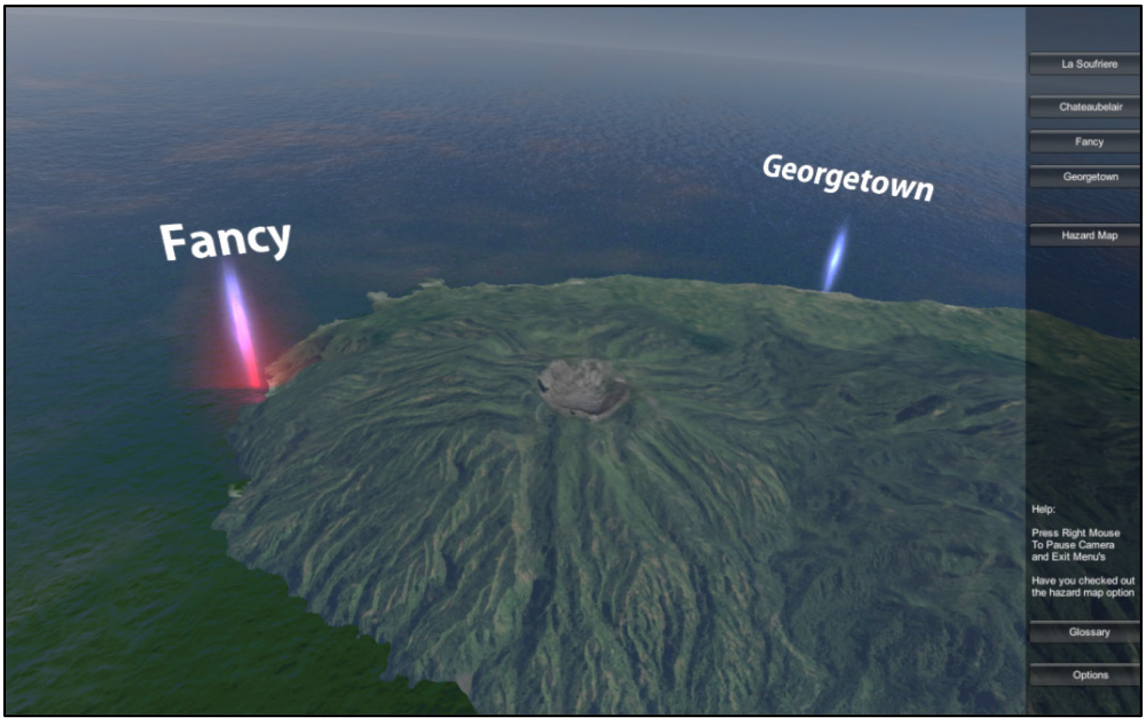



**Figure 5.14. During the *Island hub* scene, affordances have been made to guide the player to the next stage of the game.**

Affordances have also been considered throughout the *volcano quiz* section of the game. The layout has been designed to be simple to use for all computer abilities with large boxes to click and easy to read information (Figure 5.9). When the player answers a question correctly the question lights to green to indicate it is correct and emits a 'ping' sound. Where a player answers a question incorrectly the question highlights red to indicate it is incorrect and instantly displays feedback as to why the answer given was incorrect (Figure 5.10). These simple affordances quickly indicate to the player whether they have answered the question correctly.

## 5.7 Summary

The finalised version of the *St. Vincent's Volcano* game encompasses all aspects of the game design outlined throughout Chapter 4. The final game design altered slightly from the storyboarded designs dependent on the limitations of the software, budget and development time restrictions.

The *St. Vincent's Volcano* game comprises five main scenes: *island hub, historical eruption visualisations, hazard training, volcano quiz* and *reward* scenes. Each scene has been carefully crafted to incorporate learning theory and account for affordances to enable simple flow and navigation through the game. Visualisations of each of the hazardous phenomena have been created to look realistic and behave in a way that reflects reality to ensure a high realism for the player. Information throughout the game has been streamlined to be accurate and precise but avoiding repetitions and confusion where possible.

To ensure the learning outcomes are met, the *volcano quiz* has been included to allow players to test their newly gained knowledge. Where a question is answered incorrectly, the player is promptly provided with feedback to ensure they understand why they got the question wrong and deliver the correct information.

The game is also designed to record data from players on their progress through in-built analytics, helping to determine strengths and weaknesses in their learning. These data can be used to inform the game design on where improvements can be made for future iterations. It can also provide information to instructors about potential weaknesses in a player's knowledge; thus, allowing them to tailor outreach sessions to target the identified weaknesses.

The finalised version of the *St. Vincent's Volcano* game as described in this chapter was used in education and outreach sessions on St. Vincent during March to May 2015. Details of how the game was used in outreach sessions is described in Chapter 6.

# CHAPTER 6: *St. Vincent's* Volcano game implementation strategy

The finalised *St. Vincent's Volcano* game was trialled on St. Vincent over a six-week period between March and May 2015. This implementation testing comprised outreach sessions on volcanic hazards utilising the game with both adults and students to determine the effectiveness of the game as an education tool. It was then also trialled with students in the UK during January 2016. The strategy used for the game implementation testing is described within this chapter, including details on the participant population and justification for the chosen strategy for data collection.

On St. Vincent, the game was used within existing education and outreach programmes forming part of Volcano Awareness Week (VAW), however it was also used with adult participants during outreach sessions outside of VAW. The UK student sessions were held as stand-alone sessions. The first part of this chapter provides detail about the participant populations, including how they were recruited and demographic information relating to the adult participants (e.g. age, gender, educational background and vocation). For the St. Vincent participants, this section of the chapter also includes location of residency data and details the level of background knowledge concerning volcanic hazards held by participants.

The second part of this chapter focuses on how the game testing sessions were conducted, including details on the session structure. For St. Vincent students, 3 session styles were used due to the dynamic nature of the school environment: 1) SRC presentation only, 2) *St Vincent's Volcano* game only or 3) an idealised session comprising both the presentation and the game. Adult participants were asked to play the game as a stand-alone, i.e. unsupported by other educational actions (e.g. presentations or explanations). UK student sessions were conducted similarly to St. Vincent student sessions comprising both the SRC presentation and game.

A mixed method data collection approach was adopted comprising: 1) pre- and post-session knowledge quizzes to measure knowledge gain, 2) video recordings and session observations to measure engagement levels, and 3) in-built game analytics to identify strengths and weaknesses in knowledge obtained from the game (adults only). A justification for the selection of each of these types of data collection is also provided within this chapter along with details on how the data were cleaned (removal of cheating participants and incomplete data) ready for analysis.

### 6.1. Participant population

The first stage in the implementation testing for the game was to recruit participants in St. Vincent to help test the finalised game. As the primary target audience was secondary school children (Chapter 4), the most effective way to test the game was to combine the testing with the existing VAW volcano education programme on St. Vincent. VAW is a week-long programme of outreach sessions across St. Vincent, held each April to commemorate the 1979 eruption (previously described in Section 3.7.1). Throughout the week outreach sessions are held at primary and secondary schools across the island, comprising presentations and table-top activities (quizzes and drawing posters). As these sessions are the type of pre-existing outreach sessions that the game is designed to be integrated into, the game testing was undertaken during these sessions during VAW 2015. It was also important to test the game with groups of adults, who may also use the game in a stand-alone format in the future, so adult sessions were conducted in four communities across the island during the same period.

Students in the UK were also involved in the game testing. The primary justification for the running of this cohort comparison group was to provide further insight into the games effectiveness as a learning tool, to assess the different in knowledge gain between at-risk and non-at-risk participants and to balance for familiarity within the collected data which may bias the overall result. An introduction to each of the groups of participants is included within this section.

### *6.1.1. St Vincent student participants*

As student participants were already involved in the VAW activities, recruitment of schools to participate was undertaken by the Ministry of Education (MoE) through an online schools' circular. For VAW 2015, SRC wanted to focus on conducting outreach for schools in the green hazard zone (Robertson, 2005), primarily around the Kingstown area, as although not likely to be directly affected by volcanic hazards, these parts of the island will receive many of the evacuated residents from the north of the island during a future eruption.

The testing of the game during VAW had potential for introducing bias to the study as there may have been a naturally heightened awareness of volcanic hazards during this period, due to exposure to press and media coverage. However, typically this coverage included information relating to the proposed activities rather than providing information on volcanic hazards themselves and typically, coverage and following of VAW activities increased as the week progressed. Further, the primary focus of VAW activities is the school education sessions, with many of the activities undertaken by disaster management agencies across the island. Due to these factors, the effect of undertaking the game trials during VAW is considered to have had minimal bias on the study results.

In total, 13 secondary schools were visited as part of this research to conduct VAW activities, with data collected from 126 students from 6 of these schools generating 73 usable data sets (Section 6.3.5). Where data were not collected, this was either due to a lack of time available to run the sessions as desired, lack of facilities available (e.g. computers or electricity) or the size of the groups involved in the outreach session (where in excess of 35). If group sizes were too large, then this made it too difficult to communicate navigation and direction to the students and to provide assistance and support for them when required.

As many students in St. Vincent travel between towns to attend school, all students were asked to provide their location of residency. Plotting these locations on a map of the island (Figure 6.1) revealed that the study participants' live within various different communities and volcanic hazard zones across St. Vincent. For this reason, location of residency is not considered to be an influence on the data.

Student participants involved in the study were all Form 4 Geography students aged between 14 and 15 years old and in full-time education. School attendance is compulsory for all children until 16 years old on St. Vincent and enrolment of both male and female students is comparable, with 943 male and 979 female students enrolled in Form 4 in 2015. In some developing countries, particularly within Asia, there can be a disparity between the number of male and female students enrolled in secondary education, with more female students opting to leave school early due to societal pressures and expectations (Anjad, n.d.). However, this is not the case on St. Vincent, were student drop-out rates are extremely low – just 3.1% for Form 4 students in 2016 (Ministry of Education St. Vincent and the Grenadines, 2016). For this reason, gender is not considered to be an influencing factor on the data and therefore was not recorded from student participants.

Prior to all sessions being conducted, teachers were asked whether their students had already completed the topic of volcanoes as part of their CSEC curricular studies. All student participants at the time of the study had completed their study of volcanoes as part of the Geography syllabus.

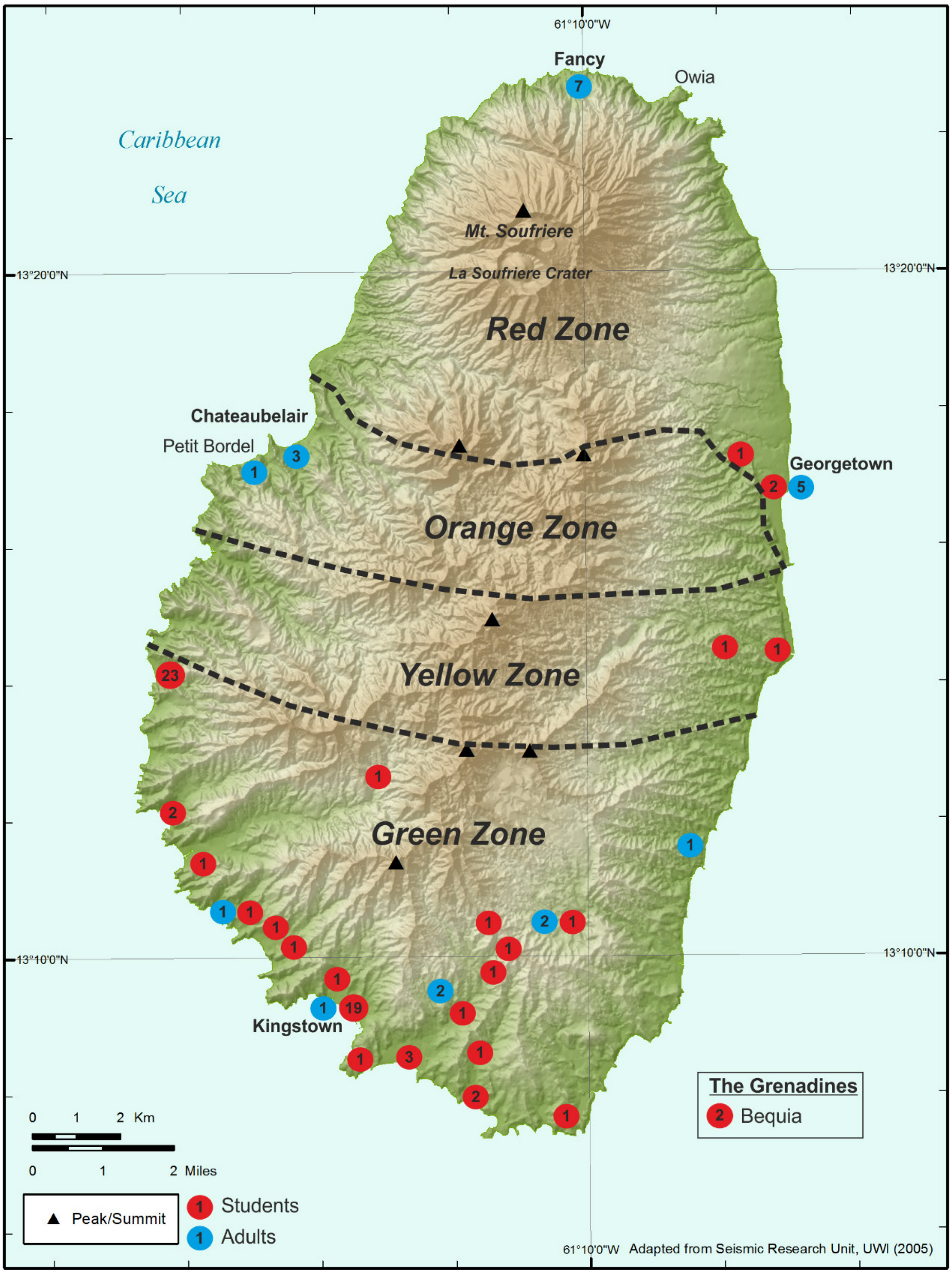



**Figure 6.1. Location of residency for St. Vincent participants used in this study. The number of participants stated is the number of completed and usable data sets of which provided location of residency information (Students *N* = 70 and Adults *N* = 23). The black dashed lines indicate the boundaries of the volcanic hazard zones as defined by Robertson (2005). Permission to reproduce this map has been granted by R. Robertson.**

*6.1.2. Adult participants*

As the game is likely to be used as a stand-alone tool for adults on St. Vincent, adult participants were recruited to help establish whether it was effective for this type of use. Four adult sessions were run in the towns of Chateaubelair, Fancy, Georgetown and Kingstown, comprising a total of 25 participants, of which 23 usable data sets were obtained. These towns were chosen due to their location close to La Soufriere and within the red volcanic hazard zone but also, with the exception of Kingstown, their inclusion as named locations within the game. Kingstown, located in the green zone, was selected as a comparative location for the study.

Participants were recruited through community leaders in the 4 towns, who invited community members to attend the sessions directly, whilst others attended due to word-of-mouth. Sessions were held on week days within the communities at local schools, pre-schools, community centres and civil offices. All participants were asked to provide demographic information including their location of residency, their age and educational and vocational backgrounds (Figure 6.2). This sampling method and the timing of the outreach sessions led to a bias in the data. As the sessions were held during a normal-working day, this excluded many working-age (18-60 years) men. This also meant that many of the available participants involved in the study were either younger and unemployed or older and retired. Additionally, one session was held within the ministry department of the St. Vincent government, with many of the young female office and administration staff invited to attend which has resulted in an over-representation of females in the study. This is identified as a limitation of the study within Section 9.3.

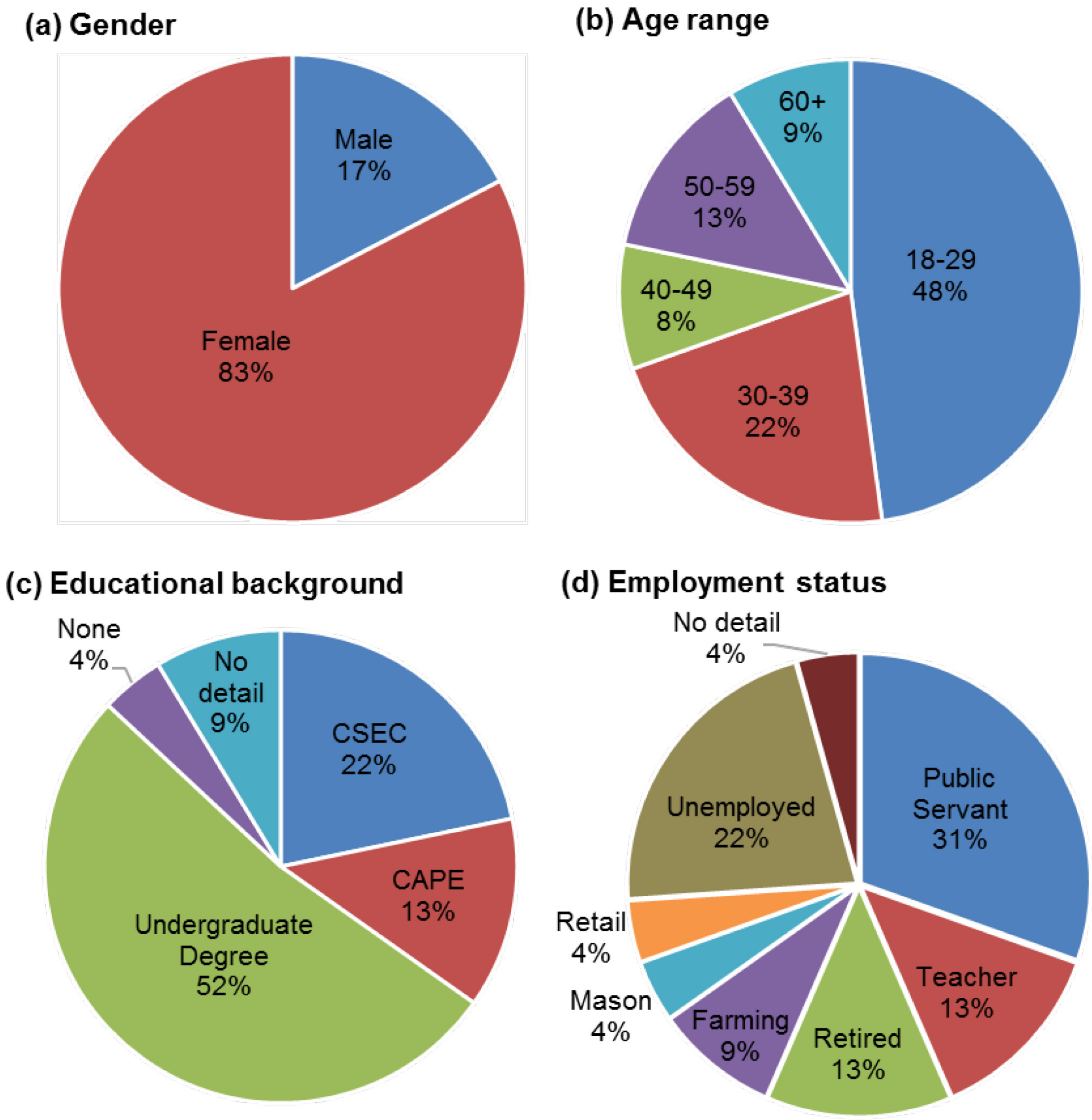



**Figure 6.2. Demographics data for all adult participants (*N* = 23) including (a) gender ratio, (b) age range, (c) educational background and, (d) occupational status.**

Of the 23 participants from which usable data were obtained, 83% (*N* = 19) were female. Gender for the adult participants, unlike the for the student participants, is considered likely to be an influencing factor on the data. For some of the adult participants, school attendance may not have been compulsory, particularly for female students who may have been actively discouraged to attend due to societal pressures. To account for this potential disparity, participants were also asked to indicate their highest educational certification. In total, 35% of participants had either a CSEC (GCSE equivalent) or CAPE

(A-level equivalent) school certification with a further 52% of participants having achieved an undergraduate degree qualification. Only one participant (4%) identified as having no formal education qualification and two participants' (9%) provided no detail when asked. Unfortunately, no higher education progression rates were available for St. Vincent to be able to establish if this was a representative sample. However, this is in line with higher education progression rates for the UK which were at 48% for the academic year 2014/15 (Department for Education, 2016), suggesting that the proportion is higher than expected.

Age data was also gathered for the participants with 48% aged between 18-29 years, 22% between 30-39 years, 8% between 40-49 years, 13% between 50-59 years and 9% aged 60+ years. St. Vincent has a bottom-heavy population with 42% of the population ages under 25 years (Census, 2012). Therefore, the age demographic sampled as part of the implementation testing is considered to be representative of the general St. Vincent population. The age range of the participants is significant as this can contribute to levels of computer literacy, overall educational levels and exposure to volcanic hazards (e.g. experiencing the 1979 eruption).

The participants were also asked to provide detail on their employment status with 31% participants identifying as public servants, 22% as unemployed, 13% teachers and 13% unemployed (where percentages were rounded up). Employment background is not considered to an influencing factor on the data obtained from the game sessions but was gathered to exclude it as an influencing factor during the data analysis phase of the study.

### *6.1.3. UK student participants*

To help ascertain the true extent of the effectiveness of the *St. Vincent's Volcano* game at improving knowledge of volcanic hazards, a cohort comparison study was designed.

The cohort comparison involved the use of students from UK secondary schools of a similar age range and educational background as the students encountered in St. Vincent. The aim of the cohort comparison was to understand if the game was able to improve knowledge of volcanic hazards both with a community at-risk and one not at-risk of a potential volcanic eruption. Additionally, the study was undertaken to help establish if the integration of familiarity (e.g. town names and authentic accents) had an influence on the outcome of the game trials, causing a potential bias in the data.

Letters were sent to 6 secondary schools within Plymouth to invite them to participate in the comparison study for this research. Two schools responded to the letter – Hele's School a mixed-secondary school and Notre Dame an all-girls secondary school. Unfortunately only year 9 students from Notre Dame were able to participate in the study, meaning a cohort comparison would not be possible, therefore data was not obtained from this session. However, year 10 students from Hele's School were able to participate in January 2016, providing 59 students for the comparison study. The students involved in the study were all year 10 geography students who had all studied volcanoes and volcanic hazards through the national curriculum at the time of the game trials. These students were considered to provide an ideal comparison to students in St. Vincent who also had a similar background knowledge and were of the same age group. Parental consent and participant consent was received for all students that took part in the study in-line with ethical clearance for this research.

### 6.2. Details of game testing sessions

Once all participants were recruited, sessions were conducted for both students and adults. Student sessions were designed to understand the game's effectiveness at educating about volcanic hazards when integrated into existing outreach sessions and adult sessions for a stand-alone application. This section provides details of the outreach sessions and describes variations from idealised sessions (an introductory presentation followed by participants playing the game), if and where they occurred.

### *6.2.1 St. Vincent student sessions*

Student game testing sessions were integrated into the existing education sessions as part of VAW activities (Section 6.1). The idealised sessions comprised an introductory presentation by the SRC outreach team on volcanoes and volcanic hazards in the Eastern Caribbean and St. Vincent, followed by students playing the game. The maximum number of students for each session was 35 to ensure an appropriate level of assistance could be provided by the outreach team when required. For some school sessions, this idealised outreach session was not possible due to time constraints, the facilities available (including computers and electricity), and the number of students involved in each session. Due to these factors, this led to three styles of sessions being conducted:

A. *Presentation only* – participants received only the SRC presentation to allow for a comparison of outreach techniques. This was only used where time was not able to support the idealised session.

B. *Game only* – participants played only the *St. Vincent's Volcano* game, where sessions were time restricted and a full idealised outreach session could not be conducted.

*C/D.* *Idealised session* – participants receive both the SRC presentation and also play the St. Vincent's Volcano game. This was completed over either during one session (C) or across two sessions (D), dependent on the availability of the students for outreach sessions.

The SRC presentation delivered to sessions A, C and D participants and comprised a simplistic introduction to volcanoes in the Eastern Caribbean including their location, formation and detailed descriptions of the associated volcanic hazards. The presentation also presented detail of the historic eruptions of La Soufriere, introduced the Volcanic Hazard Map and described the role of key agencies, including NEMO, SRC and SMU.

Where possible session type C was conducted, comprising the SRC presentation and the game in one session – an idealised integration of the existing materials and the game. However, for two groups of students, the idealised session was conducted over two visits, with the first session dedicated to the presentation and the second for playing the game, with a one-week gap between visits (session type D). Session A comprised 8 students and was run as a control session to allow a comparison of education techniques between a traditional outreach presentation (as previously described), and the *St. Vincent's Volcano* game. Details of the number of schools and participants per session style (A-D) are displayed in Table 6.1. In total, 126 students were involved in the study with useable data sets obtained from 73 participants.

| Type of Session | No. of schools per session type | No. of students per session (*N* = 126) | No. of usable data sets obtained (*N* = 73) |
|---|---|---|---|
| **A. Presentation only** | 1 | 8 | 8 |
| **B. Game only** | 1 | 28 | 19 |
| **C. Idealised session – presentation & game in one session** | 2 | 59 | 20 |
| **D. Idealised session - presentation & game in two sessions (one-week gap).** | 2 | 31 | 26 |

**Table 6.1. Summary of the session types and number of schools and participants per session, including the number of usable data sets obtained.**

### *6.2.2 Adult sessions*

Adult sessions were conducted outside of VAW activities, during March and May 2015. As the adult sessions were designed to provide understanding of how effective the *St. Vincent's Volcano* game could be as a stand-alone application, the sessions comprised only the gameplay similar to session style B for the student participants. In total 25 adults participated in the study with usable data recorded from 23 participants.

Each participant was asked to play the *St. Vincent's* game individually without any presentation given or introduction to volcanic hazards. In some sessions where there was a lack of computers available, participants played the game in pairs. Participants were able to ask questions throughout the session relating to either the functionality of the game or its content.

### *6.2.3 UK Student sessions*

The UK student sessions comprised the same introductory presentation created and delivered by SRC in St. Vincent. Slightly more basic detail was included in the presentation (e.g. highlighting of towns and communities and population figures) to provide as much context to the session as possible, without compromising the information provided to students. After the presentation, students were asked to play the *St. Vincent's Volcano* game with the same guidance provided as during the sessions in St. Vincent. Each student played the game individually with three sessions run consecutively. The sessions were all held within computer rooms within the school, with the game already loaded onto each machine prior to the sessions. In total, 64 data sets were obtained yielding 59 usable data sets.

### *6.2.4 Session challenges and issues*

Numerous challenges were encountered during the running of both the student and adult testing sessions. Some of these challenges were overcome through adaptation of the session structure and alteration of the methods for data collection.

One of the biggest challenges faced during the student sessions was developing a method to enable data collection from large numbers of participants. The initial method of data collection was through the manual completion of the pre- and post-session knowledge quizzes. However, due to the number of participants involved in the study being higher than expected, a digital version of the pre- and post-session quizzes was produced using Google Forms to enable as much student data to be recorded as possible. This was effective for several of the sessions and where internet access was not reliable or there were not enough computers available students were able to complete an offline version of the knowledge quizzes.

During adult sessions, the major challenge to overcome was the lack of computing facilities available to conduct the testing. To resolve this issue, where only limited facilities were available, participants' attendance was staggered to enable enough time for them to complete the game. For sessions where all participants attended at the same time (Fancy and Georgetown) and not enough computers were available, some participants were required to play the game in pairs. However, adult participants were asked to complete the *volcano quiz* individually. This was also the case during student sessions, where not enough computers were available per participant. This typically occurred when students failed to charge their laptops, or when a student's computer was undergoing maintenance.

### 6.3. Data collection techniques

Before any data could be recorded from the sessions, informed consent was required from all participants in-line with ethical approvals granted for the study by the Faculty of Science and Engineering Ethics board (Appendix G). Data were collected from both student and adult sessions through the completion of pre- and post-session knowledge quizzes (pre- and post-tests), video recordings and session observations, and in-built game analytics.

The data collection strategy used for this study is a mixed-methods approach designed to gather both quantitative and qualitative data. As the study aimed to understand if the video game led to an improved knowledge, but also if it motivated and engaged players, different data collection methods were required for triangulation purposes. A mixed-methods approach combining both qualitative and quantitative data collection techniques aimed to strengthen findings by obtaining compatible 'view points' on the subject, allowing for enhanced accuracy in the interpretation (Jick, 1979; Bryman, 2004; Donovan, 2010). This approach also enables strengths of one data collection type to be used to overcome weaknesses in another data collection method, providing a robust approach to data collection (Johnson & Onwuegbuzie, 2004). Additionally, each data collection technique used in the study had a specific aim: pre-and post-session knowledge quizzes are used to establish potential knowledge gain and video observations are used to identify levels of motivation and engagement. However, ultimately, the results from the various data collection methods are analysed in combination and these mixed method results were used to inform the greater picture; to help establish if the *St. Vincent's Volcano* game is effective as an education tool.

### *6.3.1 Pre- and post-session knowledge quizzes*

To obtain quantitative data to establish how effective the *St. Vincent's Volcano* was at improving participants knowledge of volcanic hazards, pre- and post-testing was adopted in the form of knowledge quizzes (pre- and post-session knowledge quizzes). Pre- and post-testing was used to establish the change in levels of knowledge and understanding of volcanic hazards before and after interacting with the outreach sessions. Pre- and post-testing is one of the most well-established methods for assessment of new teaching methods and approaches by measuring changes in educational outcomes of participants (Bellotti *et al.*, 2013b).

Pre- and post-session testing was selected as the primary data collection due its common use within analysis of learning from serious games (Papastergiou, 2009; Habgood & Ainsworth, 2011; Bai *et al.*, 2012; Iten & Petko, 2014; Green & Bavelier, 2015) and its successful use to obtain quantitative data for knowledge gain within similar studies. One such example is Dohaney *et al.* (2012) who used visualisations and virtual reality to teach undergraduate level students about field geology techniques. To establish how effective the visualisations were for training of the students when compared to a more practical in the field-based approach, Dohaney *et al.* (2012) used pre- and post-testing to gather quantitative data to assess student's learning gain. The results obtained were clearly showed that field-based practical activities achieved higher overall learning gains compared to the visualisations.

In the case of this study, the purpose of the pre- and post-testing was to assess levels of knowledge gain achieved through playing the game and to allow robust comparison with more traditional techniques of education and this data collection technique was deemed to be the most suitable. Additionally, the pre and post-testing method allowed for the collection of large amounts of data from the outreach sessions and was a simple, but flexible method that allows for customisation of questions to target particular desired outcomes.

However, pre- and post-testing does also come with some drawbacks which were encountered during the implementation testing phase of this research and which are further discussed in Section 8.6. The most significant problem associated with this data collection technique is the possibility that administering the pre-test assessment could influence the post-test results (Bellotti *et al.*, 2013b). To try and reduce the effect the pre-test assessment had on the data, the questions on the post-test were re-worded and re-organised to avoid students from repeating an idealised answer.

All pre- and post-session knowledge quiz questions were designed and written with a specific outcome aim in mind. Once completed, the quizzes were approved as suitable for use by Dr Stephanie Lavau.

The pre-session knowledge quiz was completed prior to any outreach activities for students within session types A, B and C. However, students within session type D completed the pre-session knowledge quiz after their first session comprising the presentation but before their second session in which they played the game. This was due to large numbers of students present within the first session (in one case >120 students in one session) meaning data collection was difficult. All post-session knowledge quizzes were completed immediately after conclusion of the outreach sessions.

The knowledge quizzes comprised 12 open-ended questions relating to general terminology and definitions of volcanic phenomena, and to the historical eruptive history of St. Vincent. The pre- and post-session knowledge quizzes comprised the same questions but with the wording slightly changed and the order altered to avoid participants from memorizing the idealized answer. Two questions varied between the adult and the student quizzes – one question relating to precursory activity (seismic activity and gas release) and one which asks participants which volcanic hazards can be experienced on St. Vincent by providing a list of hazards with tick boxes. The question relating to precursory activity was added to the adult quiz as some participants may have had direct experience of this from the 1979 eruption, whereas it is not taught to geography students as part of their curricular studies. Tick boxes were used to ask adults about the types of volcanic hazards that may occur on St. Vincent. This provided more detail on participants' background knowledge on the subject, without being hindered by lack of known terminology. The same question was left open-ended for the student participants as they should have encountered the correct terminology as part of their school studies.

Other questions within the knowledge quizzes covered one of three topics. Firstly, general knowledge about the volcanic history of La Soufriere (e.g. *'what is the name of the volcano'* and *'can you name previous eruption dates of this volcano?'*). Secondly, detailed information about volcanic hazards (e.g. *'what is meant by a pyroclastic flow?'* and *'when can a lahar occur?'*) to establish depth of knowledge and participants' use of colloquial language. Thirdly, questions relating to the existing volcanic hazard map (e.g. *'what hazard zone is 'Fancy' within?'*) to assess the student's existing exposure to education resources (e.g. through curricular studies) and to test if the game enhances how this information is received. A copy of the pre- and post-session knowledge quizzes are included in Appendix H.

Depending on the participants' preference, the knowledge quizzes were completed either manually or digitally, were undertaken individually and took approximately 20 minutes to complete. All pre-session knowledge quizzes were completed prior to any interventions taking place and all post-session knowledge quizzes were completed immediately after completion of the outreach session.

Once all outreach sessions were completed, the knowledge quizzes were marked using a rubric of model answers. The developed rubric allowed for points to be awarded for correct answers and additional points to be awarded where deeper knowledge was demonstrated, such as where a student can add specific detail relating to a hazardous phenomenon (e.g. the speed at which a pyroclastic flow can travel or the size of ash particles in millimetres). To avoid unconscious bias during marking, all quizzes were allocated a unique reference number and marked anonymously.

### *6.3.2 Video recordings*

All sessions were video recorded to allow for assessments to be made of students levels of engagement and motivation (Shapiro, 2004). Video recording is a frequently used method for collecting qualitative data on student engagement during a learning session and as a tool for monitoring student behaviour (Abikoff & Gittelman, 1985; Achenbach, 1986; Walker & Severson, 1990; Saudargas, 1997; Shapiro, 2004). The advantage of using video recordings is that they can be analysed in detail after the session has ended to asses overall class engagement but can also be used to analyse individual students' engagement (Shapiro, 2004).

For this study, video recordings were chosen primarily due to the practicality of recording information from large groups of students where live direct observations proved difficult. By using video recordings this allowed for more than one student to be monitored from the same outreach session and for the videos to be replayed to ensure a robust approach to the analysis. The video recordings also allow for a general perception of motivation for the entire group of students to be drawn based on their interactions with outreach instructors and each other, as well as their engagement with the game.

A video camera was used to record all sessions with the overall aim of establishing participant engagement with the *St. Vincent's Volcano* game. During the student sessions the camera was placed in the corner of the room recording the students playing the game. All student participants were made aware of the camera's presence within the room but were told to approach the session as they normally would (i.e. to be natural their behaviour and approach). Despite this, the camera proved a distraction for some student participants who were often observed gesturing towards the camera.

Each video recording from the student sessions was analysed by selecting participants who were in full camera-view throughout the recording. The Behavioural Observation of Students in Schools (BOSS) measurement tool was adopted to analyse the student videos. The BOSS tool was developed by Shapiro (2004) to observe individual students for on- and off-task behaviour within an instructional setting and was developed to measure levels of engagement of students in their sessions based on their behavioural engagement characteristics. Studies have shown the results from using the BOSS tool to have a high reliability with between 90 -100% agreement across multiple observers (Volpe *et al.*, 2005).

Although no examples of the use of the BOSS model were available applied to serious games or video games in general, the BOSS model has been successfully adopted in classroom-based settings to establish levels of student engagement with their learning sessions. One such example was by Vile Junod *et al.* (2006) who successfully adopted the BOSS model to measure academic engagement of students with attention-deficit hyperactivity disorder (ADHD) during Maths and English instruction. Through use of the BOSS model the authors were able to determine a link between academic achievement and levels of engagement of the students. For this reason, the use of the BOSS model was considered to be an effective method of identifying student engagement levels with their outreach sessions as part of this research.

The observer is required to record positive and negative behavioural characteristics and reports them as a percentage of the overall behaviours. The tool measures student engagement by 5 coding categories; 2 of engagement and 3 of non-engagement (Fredricks *et al.*, 2011). The 2 positive engagements comprise: 1) active engagement (incorporates any signs the participant is exhibiting relating to the task at-hand, e.g. talking-out-loud or asking questions), and 2) passive engagement (relates to the participant passively moving through the session, e.g. asking no questions but continuing with the work). The 3 negative engagements comprise: 1) off-task motor (participant leaving their seat), 2) off-task verbal (participant talking to other participants about unrelated subjects) and 3) off-task passive (participant staring out of the window).

To analyse the video recordings, behavioural characteristics (Table 6.2) for each participant were noted every 15-seconds throughout the session with a mark awarded for each noted behavioural characteristic (positive or negative). The difference between the positive and negative scores was then calculated to provide an overall engagement score for each participant. This process was repeated twice for each participant to provide a robust score of engagement. Additionally, each participant was then timed throughout the session for the amount of time spent engaging in on-screen activities. This time interval was then calculated as a percentage of the overall session time to further provide an idea of student engagement levels.

| Positive behavioural characteristics | Negative behavioural characteristics |
|---|---|
| • Eye-contact with instructor when instructions given<br>• Positive gesture (nodding, leaning forwards, smiling).<br>• Asking questions of outreach team about subject-activity.<br>• Responds to questions from Instructor when asked.<br>• Using computer for on-task activities.<br>• Taking notes during the session.<br>• Discussing subject/activity with a neighbour or instructor.<br>• Acting enthusiastically about the subject/session.<br>• Student completes all session tasks.<br>• Other positive engagement (detail provided). | • No focus on instructor when instructions given.<br>• Engaged in activities not related to the session/topic (using mobile phone etc.).<br>• Resting head on table or displaying other signs of boredom.<br>• No response to questions when asked to the group.<br>• Chatting with neighbours about unrelated topics/subjects.<br>• Participant interferes with other members of the class.<br>• Uses computer for off-task activities.<br>• Participant moves away from the computer area entirely.<br>• Participant is spoken to about their behaviour/conduct during the session.<br>• Other negative behaviour (detail provided). |

**Table 6.2. An overview of the rubric used to assess positive and negative behavioural characteristics for engagement when watching all participant session videos from student sessions.**

### *6.3.3 Session observations*

For adult participants, rather than video recordings, real-time session observations were made of how participants engaged with the game. As adult outreach sessions comprised no more than 7 participants at any one-time, live observations were considered an appropriate technique to capture data for engagement. The observations comprised looking for characteristics of active engagement such as writing notes, asking questions or talking with other participants about the game. The observations made provided an overview of the engagement characteristics and recording of participants’ thoughts and comments whilst playing the game.

### 6.3.4 In-built game analytics

As described in Section 5.4.1, game analytics that automatically recorded learners' data were integrated into the v*olcano quiz* section of the game. These analytics recorded information relating to how long the learner played the game, which questions they were asked during the *volcano quiz*, how they answered each question, and recorded their final quiz scores. Data were only collected where a learner chose to have their data recorded ('opt-in') and was not a requirement of the session participation.

Game analytics are in the early stages of adoption within serious games. However, their initial use within some serious games provided evidence of their effectiveness is understanding the learner's interactions with the game. Westera *et al.* (2014) used game analytics to monitor behaviour and performance patterns of students as they played an environmental policies game. The game analytics were used to record information included duration of play, length of time in certain game scenes and how the students moved through the game. Based on the collected data, Westera *et al* (2014) were able to identify that there was a link between how students moved through the game, switching between activities and problems and the expected levels of learning achieved. Further, the data from the game analytics also identified that students who adopt a switching approach to the game required longer to complete the game, thus informing the game design and deliverance. Although the use of game analytics are in the early stages of use within serious games, the approach was adopted due to its simplicity and a growing evidence base for their use in successfully obtaining large quantities of data with minimal input (Serrano-Laguna & Fernández-Manjón, 2014).

The primary aim of collecting game analytics data from the *St. Vincent's Volcano* game was to obtain information relating to how participants engaged with the game. By obtaining details about the questions learners were asked and how they responded, this could identify potential areas of strength and weakness in the game (i.e. areas that were not effective for knowledge transfer). For example, if most learners answered a particular question incorrectly, this could indicate that the knowledge provided within the *hazard training* scenes may not be clear enough to encourage knowledge transfer and may require alteration in future iterations of the game (Serrano-Laguna *et al.*, 2014; Westera *et al.*, 2014). Further, this information can also be fed back to instructors enabling them to tailor their outreach sessions to account for student weaknesses. For example, where students show patterns of lack of knowledge around a specific topic, this can be covered by an instructor in a supporting outreach session.

During the session trials in St. Vincent, a malfunction occurred in the games essential coding which caused the game to stop recording the analytics data. Further, the game analytics were designed to be extracted from a file stored locally on the student's computers at the end of the sessions; due to large numbers of students in some sessions this method of data retrieval was not possible. Therefore, no analytics data was collected from student participants. However, the adult sessions were better-able to accommodate the extraction process for the analytics data and a total of 22 data sets were obtained from across the adult sessions.

### *6.3.5 Unusable data*

Despite data being collected from a total of 126 St. Vincent students and 25 adult participants through pre- and post-session knowledge quizzes, 53 student data sets (42.1%) and two adult datasets (8%) were removed from the study. Data were removed where removed for three primary reasons: cheating; incomplete data sets; or lack of formal consent (either digitally or manually). Where no formal consent was provided by participants their data was immediately removed and destroyed, in-line with the approved ethical guidelines (Appendix G).

From the original recorded data pool, 22 (17.5%) St. Vincent student data sets and one (4%) adult data set were removed due to cheating. In the case of the adult data set, the participant was observed using their mobile phone to search for the answers to the knowledge quizzes. For many of the student data sets removed, copying answers between participants was evident when the knowledge quizzes were marked with some answers identically matching neighbouring students. Many of the participants also used the internet to answer questions with answers written verbatim from Wikipedia pages. To ensure a robust data set for analysis, data sets where a participant was suspected to have cheated or copied their answers, even for one question, were removed.

Incomplete data sets, where a participant did not complete both the pre- and post-session knowledge quizzes, were also removed as this does not enable analysis of knowledge gained as a result of the interventions received. In total, 31 St. Vincent student data sets (24.6%) and one adult data set (4%) were removed from the original data pools due to incompleteness. Additionally, incomplete data was also the reason for removal of five data sets (from 64 original data sets) obtained from the UK students. The number is particularly high for student participants in St. Vincent as during one session, half the students who began the intervention sessions and completed the pre-session knowledge quiz were removed by teachers to attend a different class and therefore, were not present to complete the post-session knowledge quiz.

Despite the number of pre- and post-session knowledge quizzes that were removed from the study, the remaining data (73 student data sets) was still significant to enable statistical analysis using paired-sample t-tests and analysis of variance. The methods used for statistical analysis are introduced throughout Chapter 7 in the context of the data provided.

## 6.4. Summary

This chapter has detailed the implementation strategy for the St. Vincent game testing during March and May 2015.

St. Vincent student participants trialled the *St. Vincent's Volcano* game during pre-arranged education and outreach sessions as part of VAW activities. Data were recorded from 126 students producing 73 usable data sets (once cleaned to include only complete data and remove data where cheating was evident), through pre- and post-session knowledge quizzes, and video recording. Students had all previously studied volcanoes as part of their CSEC Geography studies. Due to the dynamic nature of the school environments, three sessions styles were adopted: game only, SRC presentation only and idealised session (SRC presentation and game).

Adult sessions were conducted in four locations across St. Vincent: Chateaubelair, Georgetown, Fancy and Kingstown. The towns were chosen for their proximity to the volcano, inclusion within the *St. Vincent's Volcano* game (Chateaubelair, Georgetown and Fancy) or as a control measure (Kingstown). In total 25 participants were recruited through community leaders for the study, yielding 23 useable data sets. Data were collected from adult participants through pre- and post-session knowledge questionnaires, session observations and, in-built game analytics.

Some data sets were removed from the study due to either incompleteness or as evidence of cheating was identified. Analytics data was not recorded for the student participants due to a malfunction within the game and logistical difficulties with obtaining the data from individual computers.

Three consecutive sessions were completed with UK students during January 2016, comprising session style C – presentation and game sessions. Data was collected through pre-and post-session knowledge quizzes providing 59 usable data sets from 64 originally obtained (four data sets removed due to incompleteness).

The results from the sessions and data collection activities outlined in this chapter are presented in Chapter 7.

# CHAPTER 7: Results of implementation testing

The *St. Vincent's Volcano* game underwent implementation testing with students and adults in St. Vincent and students in the UK between March 2015 and January 2016 as outlined in Chapter 6. This chapter presents the results obtained through the employed mixed methods data collection techniques (pre- and post-session knowledge quizzes, video recordings and session observations and in-built game analytics). The aim of this chapter is to present the data collected from implementation testing which can be used to establish how effective the *St. Vincent's Volcano* game was at improving participants' knowledge of volcanic hazards.

## 7.1 Learning Gain

As previously described in Section 6.3.1, responses to the pre- and post-session knowledge quizzes collected from both adult and student participants were compared with a model answer rubric, marked out of 54 points and then converted into a percentage scores. For each group of participants, the pre-session knowledge quiz scores (%) were then plotted against the post-session knowledge quiz scores (%) to identify the apparent learning gain from each outreach session. Comparing the basic pre- and post-session knowledge quiz scores provides a rudimental overview of the shift in knowledge of participants before and after the interventions have taken place.

### *7.1.1. St Vincent Students*

The St Vincent students pre- and post-session knowledge quiz scores (%) are plotted on Figure 7.1 for sessions styles B, C and D, where participants played the *St. Vincent's Volcano* game ($N$ = 65). A trendline (a line of best fit identified by a black solid line) for the data shows a general positive trend identifying general improvement in score between the pre- and post-session knowledge quiz, where the regression coefficient is $R^2$ = 0.47 ($p$ = 0.5). The trendline also lies above the line of no change (dashed line), which identifies the point at which students above the line show positive improvement, below the line negative change and on the line, no change between the pre- and post-session knowledge quiz. The graph shows three students (4.6%) plotting on the line of no change and two students (3.1%) below the line, resulting in an overall 92% ($N$ = 60) improvement of apparent learning gain for participants involved in the study.

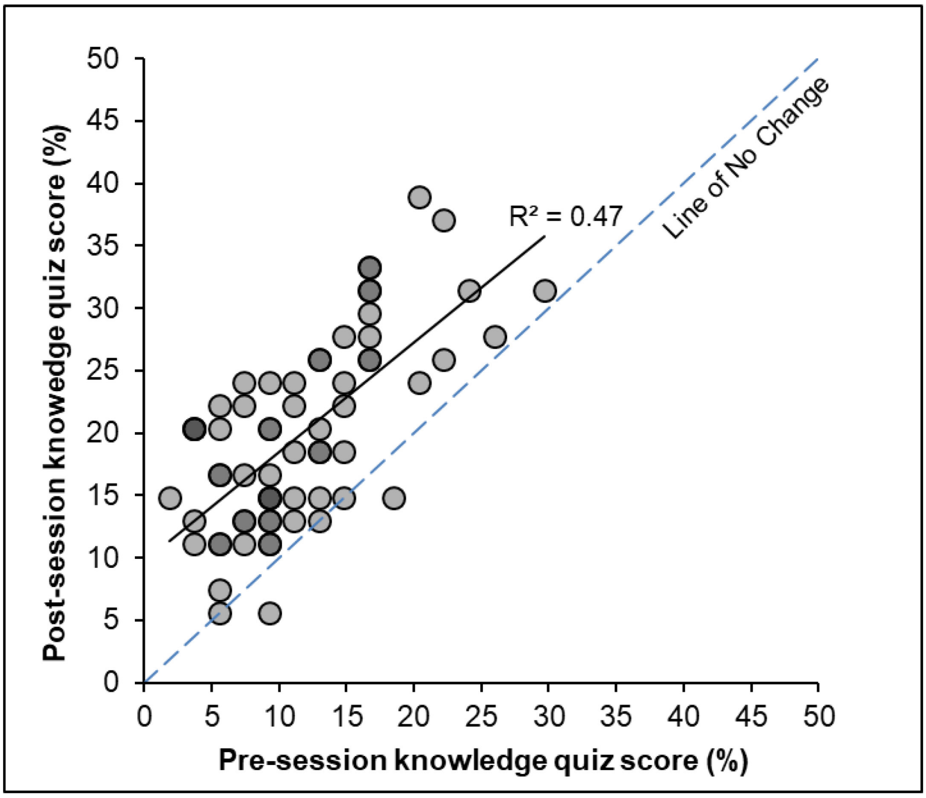



**Figure 7.1. Student knowledge quiz data plotted with pre-session knowledge quiz scores (%) against post-session knowledge quiz scores (%) (*N* = 65). Where a point appears darker, this represents more than one data point plotting at the same location.**

A paired-sample t-test was conducted to evaluate the difference between the pre- and post-session knowledge quiz scores for student participants. There was a statistically significant improvement in quiz score from the pre-session knowledge quiz (Mean [M] = 11.67, Standard Deviation [SD] = 5.93) to the post-session quiz score (M = 19.98, SD = 7.65), $t_{64}$ = 11.87, $p$ = <0.05 (two-tailed). The mean increase in quiz score from the pre- to the post-session knowledge quiz was 8.3% with a 95% confidence interval (from 6.9% to 9.7%).

The same data was then replotted, categorised by outreach session style (B, C and D) (Section 6.2.1) but also including the data from presentation only participants (session A) (Figure 7.2). The graph shows a general positive trend, with the majority of students plotting above the line of no change, including the additional 8 participants from session A.

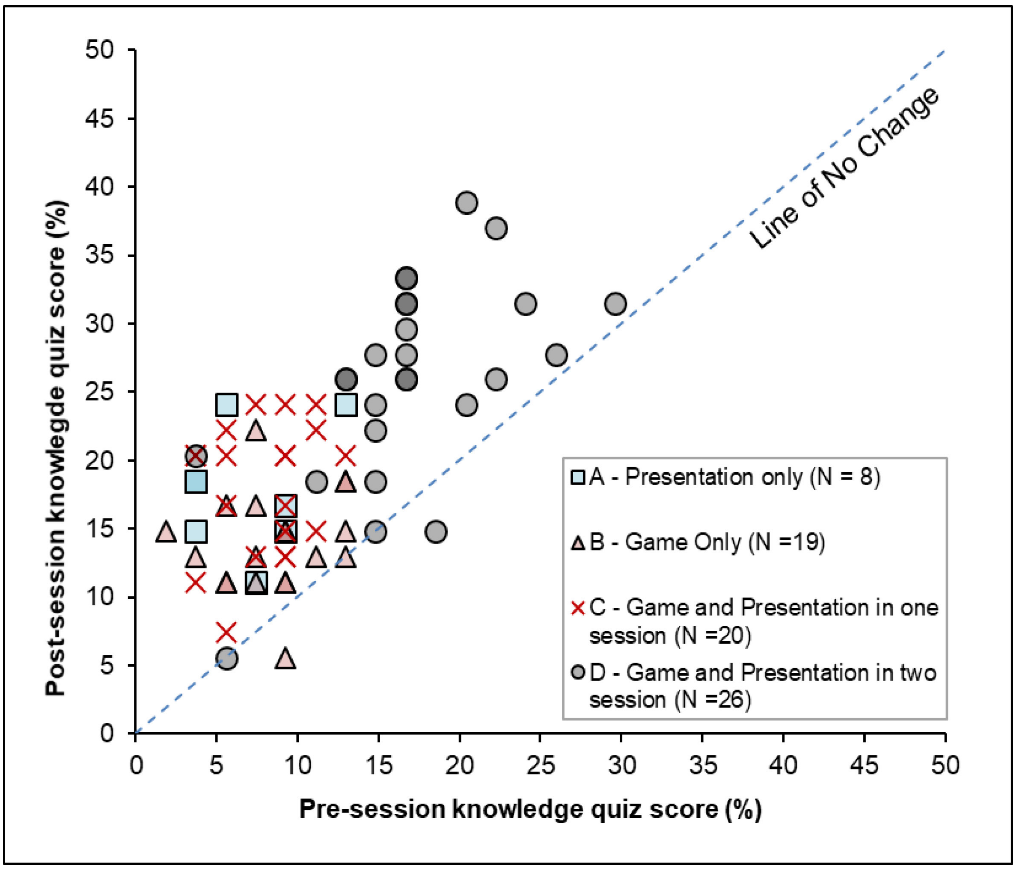



**Figure 7.2. Student pre- and post-knowledge quiz scores (%) categorised by outreach session type, where *N* = 73.**

The graph shows that the majority of session D participants (*N* = 16, 61% of the original pool), plot to the uppermost part of the data cluster when compared to students from the other session types. This observed pattern can be explained when the average pre-session knowledge quiz scores are considered (Table 7.1). In general, participants within session type D achieved a much higher average pre-session knowledge quiz score (16.8%) than any other session (A = 6.9%, B = 8.5% and C = 7.8%). This elevated pre-session knowledge quiz score may be due to the method of session type D intervention, and the intervals at which the pre- and post-session knowledge quizzes were administered. The session D participants undertook two outreach sessions, with a presentation in the first session and the game session one week later in the second session, with the pre-session knowledge quiz completed by students after session one but before session two. This process may have led to bias in the data as the students will have undertaken the pre-session knowledge quiz having undertaken an intervention, opposed to students from sessions B and C who had not.

| | Type of Session | Average pre-session knowledge quiz score (%) | Average post-session knowledge quiz score (%) | Average apparent learning gain (%) |
|---|---|---|---|---|
| A | Presentation only | 6.9 | 17.8 | 10.9 |
| B | Game only | 8.5 | 13.9 | 5.5 |
| C | Presentation and game continuously | 7.8 | 18.0 | 10.2 |
| D | Presentation and game in two sessions | 16.8 | 25.9 | 9.1 |

**Table 7.1. The average scores (%) for the pre- and post-session knowledge quizzes categorised by outreach session style.**

An average apparent learning gain (%) was calculated for the participants within each session style using the following equation taken from (Dimitrov & Rumrill, 2003; Serrano-Laguna *et al.*, 2014), where:

*Apparent learning gain = post-test quiz score (%) – pre-test quiz score (%)*

The results for the average apparent learning gain per session type are presented in Table 7.1. Session A participants had the highest average apparent learning gain (10.9%) and session C participants had the lowest (5.5%). Notably, session C participants were close in average apparent learning gain to session A participants (10.2%), with a marginal difference of 0.7%. A one-way analysis of variance (ANOVA) test was conducted to compare the impact of outreach session style on a student's apparent learning gain. The analysis showed that the effect of different session styles on a student's apparent learning gain was significant, $F (3, 69) = 3.15$, $p = 0.03$.

### 7.1.2. St Vincent Adults

The St. Vincent adults pre- and post-session knowledge quiz scores (%) were plotted against each other in the same way as the student data and displayed in Figure 7.3, where *N* = 23. Similar to the St. Vincent student data, the graph shows a general positive trend with the trendline lying above the line of no change, where the regression coefficient is $R^2 = 0.39$ ($p = 0.5$). One participant plots on the line of no change and one plots below the line of no change. Overall 91% of participants demonstrated knowledge improvement after undertaking the outreach session, which comprised the game only (*N* = 21).

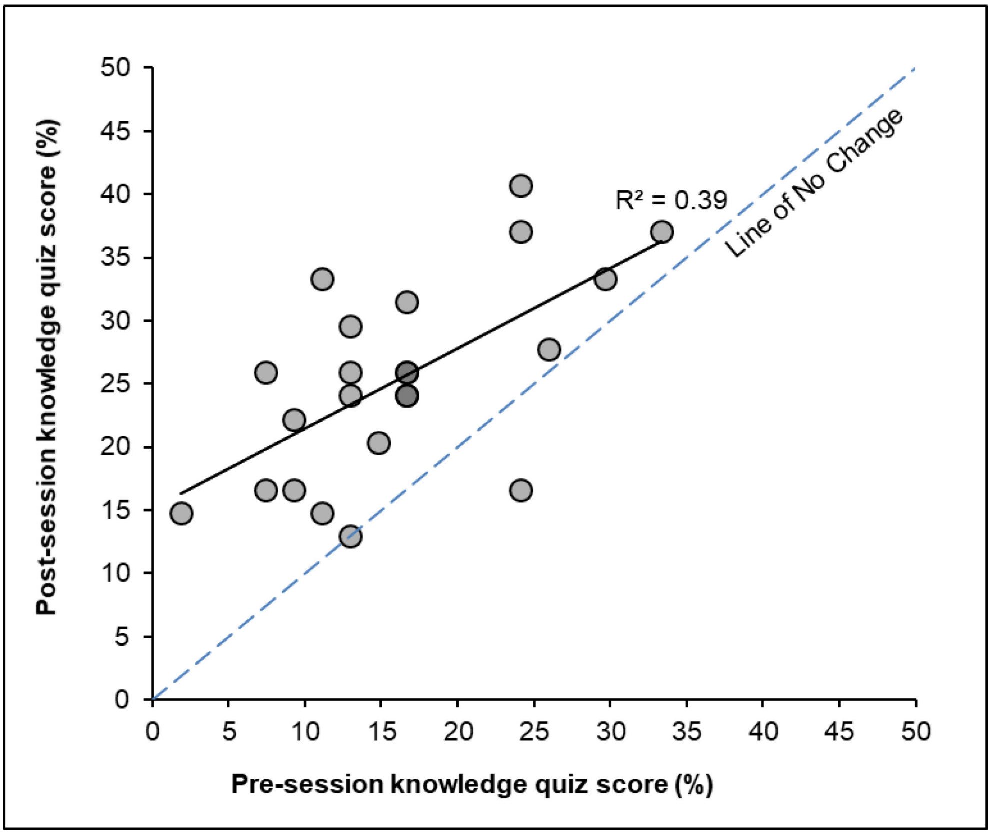



**Figure 7.3. Adult pre- and post-session knowledge quiz scores (%) against each other (*N* = 23). Where a point appears darker, this represents more than one data point plotting at the same location.**

The average apparent learning gains for the St. Vincent adult participants was 9.3%, which is comparable to the apparent learning gains observed for St. Vincent students who undertook session D (9.1%). A paired sample t-test was conducted to compare the pre- and post-session knowledge quiz scores for adult participants. There was a significant increase in quiz scores from the pre- ($M = 16.0$, $SD = 7.7$) to the post-session knowledge quiz ($M = 25.3$, $SD = 7.8$), $t_{22} = 6.6$, $p = <0.01$ (two tailed). The mean increase in quiz scores was 9.3% with a 95% confidence interval (ranging from 6.4% to 12.2%).

From Figure 7.3, a pattern was observed within the adult data set comprising a cluster of five data points to the top-right (upper-most percentages) of the graph, with a gap of nearly 10% between the next points of the lower cluster of participant scores. This represents a group of participants who have higher pre-session knowledge quiz score (between 24% and 33%) when compared to the lower cluster of points (between 2% and 17%). To understand why such a gap exists between these two data clusters and to explore the potential influencing factors, the adult data set was categorising by varying demographic information (age, gender, location of residence and volcanic experience) as shown in Figure 6.2.

The same adult pre- and post-session knowledge quiz scores (%) were replotted and characterised by: age, gender, location of residency and experience of volcanic hazards (Figure 7.4). The participants of interest are circled in each of the four graphs.

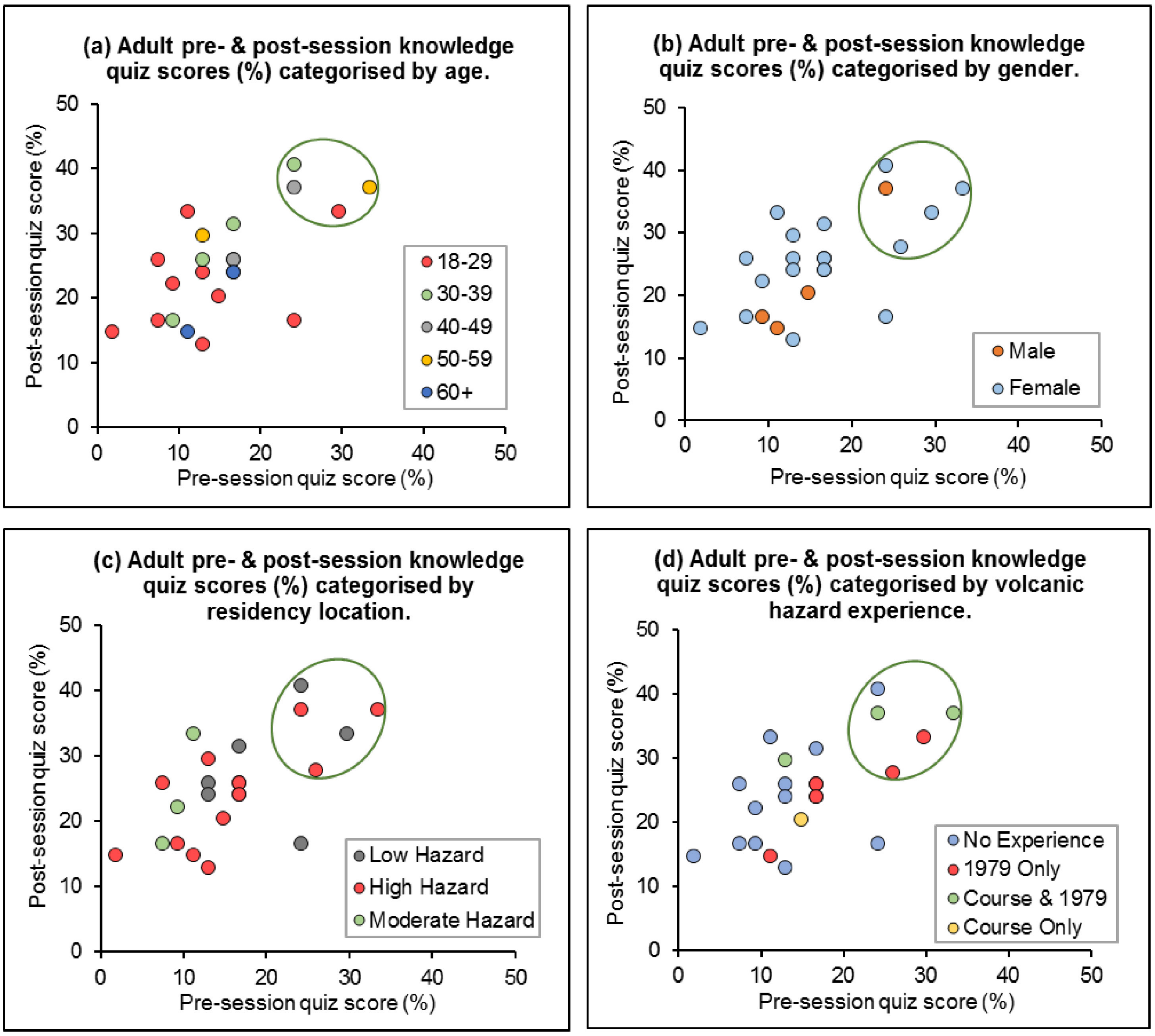



**Figure 7.4. Adult pre-session knowledge quiz scores (%) plotted against post-session knowledge quiz scores (%) and characterised by (a) age, (b) gender, (c) participant location of residency based on the volcanic hazard map (Robertson, 2005) and, (d) volcanic hazard experience.**

Figure 7.4 (a) shows that the participants from the upper cluster (identified as within the circle) are from a range of different age categories ranging from 18-59 years old, indicating that age is not likely to be a contributing factor to the data. Graph (b) categorises the participants by gender and again demonstrates no correlation between the participants within the circle, as four of the five participants are female and one is male. However, it should be noted that a significant conclusion cannot be drawn based on gender as there is an over representation of female participants involved in the study (Section 6.1.2). Graph (c) categorises the data by location of residency, based on the volcanic hazard map produced by Robertson (2005) (Figure 3.5). Green points indicate residents who live within the green zone towards the south of the island and red points indicate residents living within the red zone. Location of residency on the island was therefore not a contributing factor to the data cluster pattern observed, which shows the participants within the circle from both the red and the green hazard zones.

Graph (d) of Figure 7.4 categorises the data based on experience of volcanic hazards (undertaken an outreach course and/or experienced the 1979 eruption) and covers a complete and balanced cross-section of potential experience. The participants within the circle have mostly (80%) either experienced the 1979 eruption and/or have undertaken an outreach course. This could demonstrate a correlation between the data cluster and volcanic hazard experience. Additionally, the one participant who had no experience of either 1979 or an outreach course within the circle, when probed more deeply, is a secondary school geography teacher. This means they would likely have a good base knowledge of volcanic hazards as they teach it to students as part of the national curriculum. It was considered likely that participants either experiencing the 1979 eruption and/or undertaking an outreach session contributed to the increased pre-session knowledge quiz scores for the participants within the circle and within the wider data set. However, as gender could not be discounted as a potential influencing factor due to an under representation of male participants, it is not possible to establish whether previous experience is the only contributing factor influencing the data.

#### *7.1.3. UK Students*

In total, 59 UK secondary school students were involved in the implementation testing which took place in January 2016. The UK students acted as a cohort comparison group of the same age-group and having previously received a similar level of education on volcanoes as part of their curricular studies as students in St. Vincent. Through first-hand discussions with students both in the UK and St. Vincent, it was also established that there was a comparable level of experience with computer games and technology (e.g. using computer consoles and playing online games). If any bias in the exposure to technology exists, it is likely present on the side of St. Vincent students who are provided with personal laptops as part of their school studies, opposed to UK students who may not have access to personal computer equipment. Therefore, it is considered that both cohorts of students from St. Vincent and the UK likely had comparable levels of experience with computer games and the technology adopted for this study. The implementation testing with the UK cohort was undertakes for two main reasons: 1) to establish if the game also improved knowledge of volcanic hazards with students who do not live close to a volcanic centre, and 2) to identify the extent to which familiarity integrated into the games design influences knowledge gain (Section 6.1.3).

Similar to the St. Vincent sessions C and D, UK students received an outreach session comprising both the SRC presentation (slightly enhanced to provide more background and context such as identifying key locations on the island) and the game. Data was collected through pre- and post-session knowledge quizzes, identical to those used on St. Vincent. For best practice, on completion of the testing, all student quizzes were coded to remove unconscious bias during marking, which may result from the same person undertaking the outreach session as marking the quizzes to achieve a desirable result. The quizzes were marked out of 54 points, using the same rubric as previously used for the St. Vincent testing. These numerical scores were then converted to percentage scores and the pre-session quiz scores plotted against the post-session quiz scores (Figure 7.5).

The UK school student data shows an overall positive trend, however the trendline crosses the line of no change towards the right of the graph, indicating that the apparent learning gains, although positive, are unlikely to be significant. The $R^2$ value for the data is 0.25 ($p$ = 0.5). Twelve students plot below the line of no change (indicating a negative effect) and three students plot on the line of no change.

A paired-sample t-test was conducted to evaluate the difference between the pre-session and post-session knowledge quiz scores for the UK student participants. There was a statistically significant difference in score (%) from the pre-session knowledge quiz (M = 18.2%, SD = 6.4) to the post-session knowledge quiz (M = 23.0%, SD = 6.9), $t_{58}$ = 5.6, p = <0.01 (two-tailed). The mean increase in score (%) between the pre- and post-session knowledge quizzes was 4.9% with a 95% confidence interval ranging from 3.1% to 6.5%. The average apparent learning gain was calculated at 4.9% for the UK students, lower than that of any of the outreach sessions undertaken in St. Vincent.

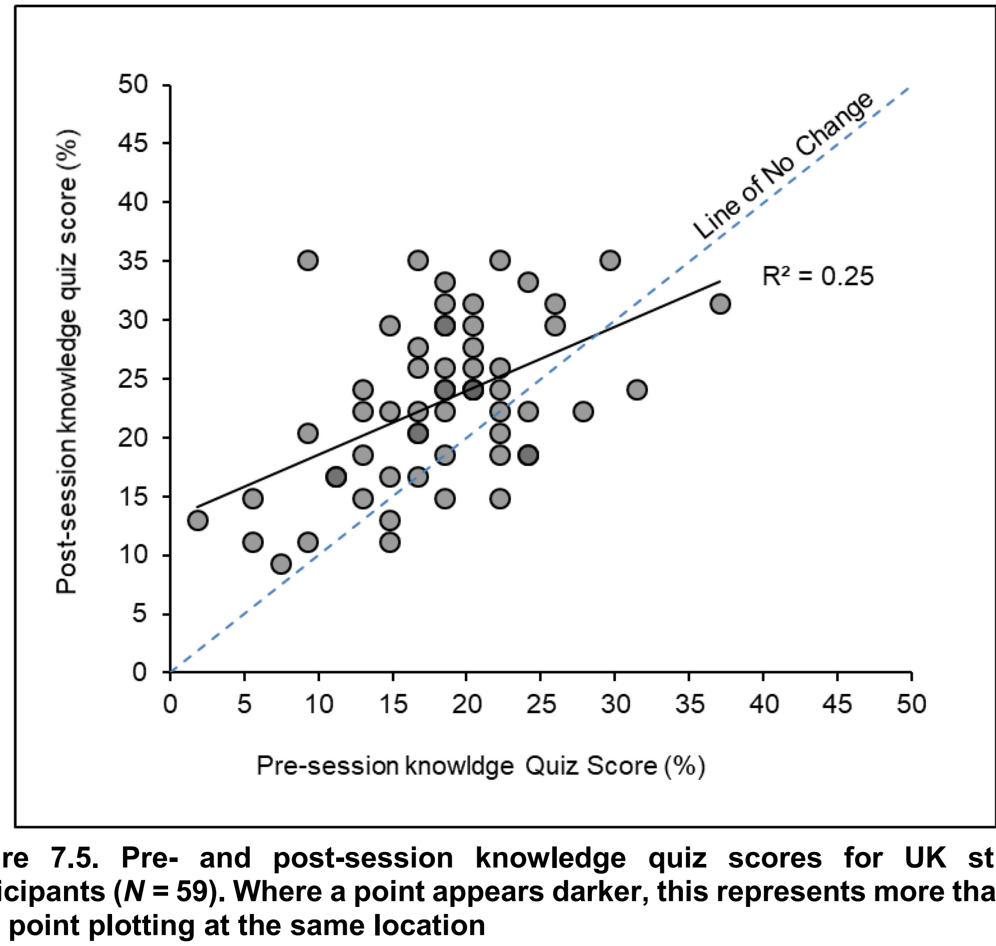



**Figure 7.5. Pre- and post-session knowledge quiz scores for UK student participants (*N* = 59). Where a point appears darker, this represents more than one data point plotting at the same location**

### 7.2 Normalised Learning Gain

In order to correctly establish if the improvement between pre- and post-session knowledge quiz scores as identified in Figure 7.1 and Figure 7.3 translates to learning, the data were normalised using the Hake (1998) equation for learning gains. This means that irrespective of a participant's pre-session knowledge quiz score, their improvement can be meaningfully compared to another participant.

$$\text{Learning Gain} = \frac{(\text{Post-test quiz score } (\%) - \text{pre-test quiz Score } (\%))}{(100\% - \text{Pre-test quiz score } (\%))}$$

Learning gains can be expressed as the difference between pre-session and post-session quiz score %, divided by the difference between the maximum possible score (100%) and the pre-session quiz score (%). This method determines potential 'gains' each participant can make, irrespective of their initial starting level (normalised). The learning gains for each participant (both adults and students) was calculated and plotted on Figure 7.6.

Normalised learning gains is often adopted in studies as it can allow a comparison of varied intervention methods whilst accounting for a varied population with varying initial knowledge states (Pentecost & Barbera, 2013). This method of analysis was adopted after its successful use within similar studies such as Dohaney *et al.* (2012), to measure learning from outreach intervention sessions (Section 6.3.1).

#### *7.2.1. St. Vincent Students and Adults*

Figure 7.6 plots the calculated normalised learning gains for all St. Vincent participants (adults and students) who played the game (student sessions B, C & D only). The graph shows a general trend of positive normalised learning gains for both adult and student participants (majority of participants plot above 0.0 learning gains), with two students and one adult plotting negative learning gains. The averages for both participant groups were calculated, with the students' average normalised learning gains of 0.09 ± 0.06, marginally lower than the adult average learning gains of 0.11 ± 0.07.

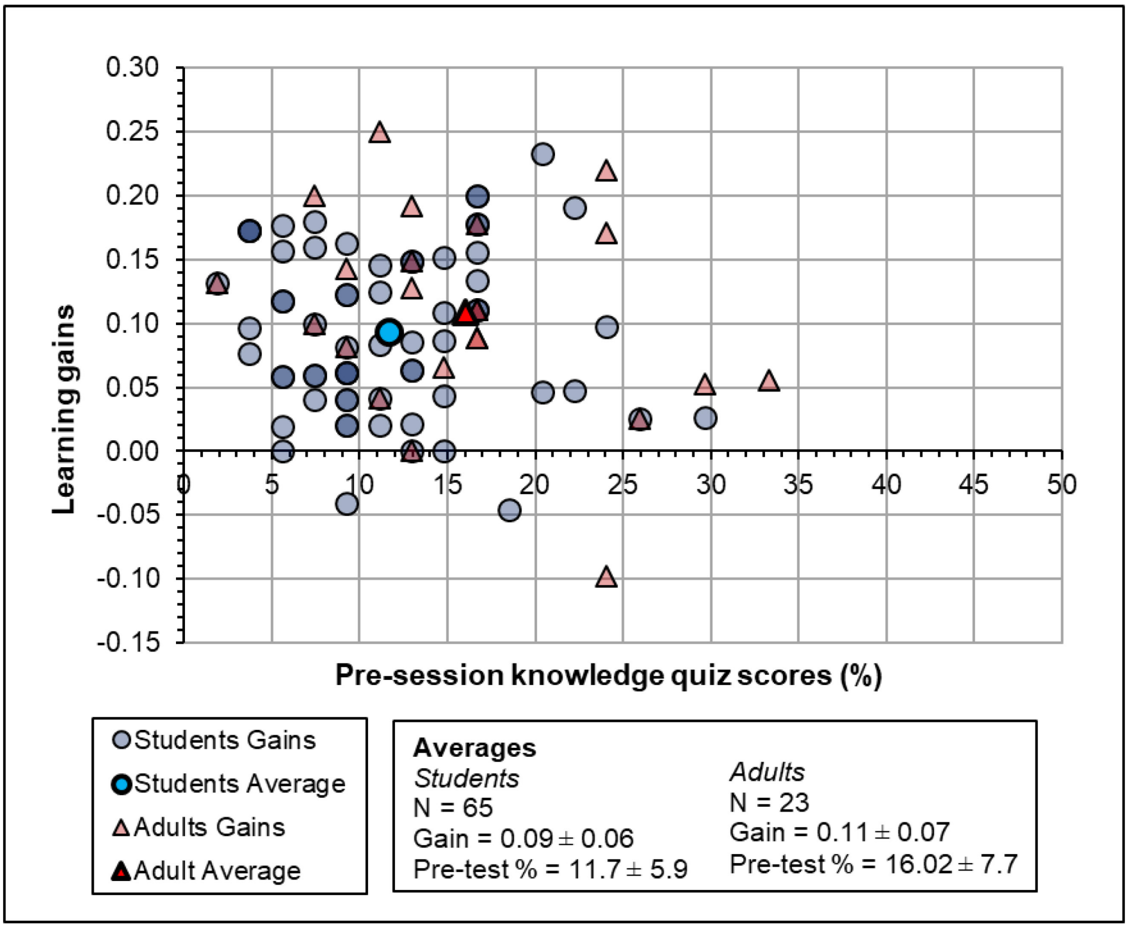



**Figure 7.6. St. Vincent student and adult pre-session knowledge quiz scores (%) plotted against learning gains (Hake, 1998). Where a point appears darker, this represents more than one data point plotting at the same location.**

### *7.2.2. St Vincent Students: Sessions style*

To further analyse which method of outreach session is the most effective for learning, a learning gains analysis was conducted on the student participants and categorised by session type (A-D) (Figure 7.7). In general, the calculated average learning gains for each session type demonstrated a positive average learning gain (plotting above 0.0 learning gains). However, sessions type A participants achieved the highest average learning gains (0.12 ± 0.05) compared to the other session styles, with session style B achieving the lowest average learning gains (0.06 ± 0.05). Participants from session types C and D were comparable both achieving average learning gains of 0.11, marginally less than the learning gains achieved by session A participants (0.12).

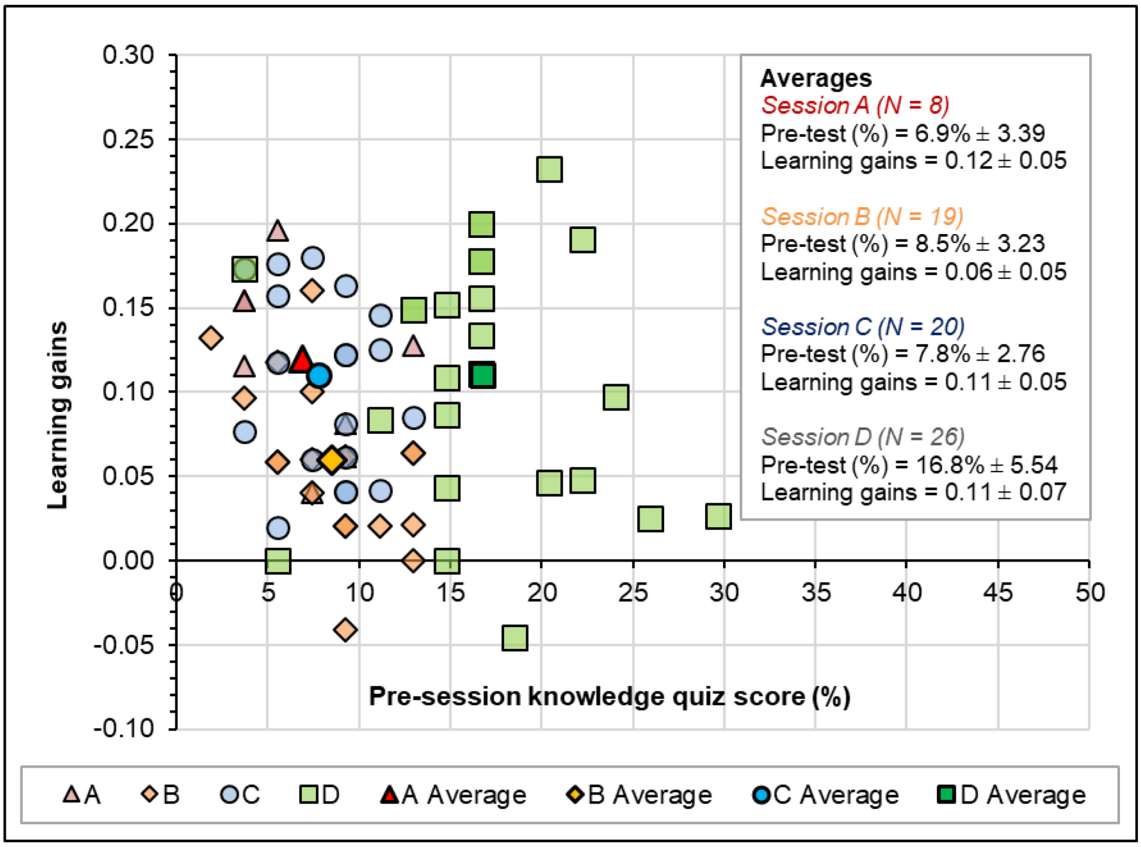



**Figure 7.7. Student pre-session knowledge quiz scores (%) plotted against learning gains (Hake, 1998) and categorised by session style. Where a point appears darker, this represents more than one data point plotting at the same location.**

A one-way analysis of variance (ANOVA) test was conducted to compare between the learning gains. This indicated that the impact of session style on a student's apparent learning gain was significant, F (3, 69) = 3.47, p = 0.021. A post-hoc Tukey range test, which compares multiple data sets for statistically significant relationships (Tukey, 1949), revealed that the learning gains achieved by students undertaking session style D (idealised – presentation and game over two sessions) (M = 0.11, SD = 0.73) was statistically significantly higher compared to the learning gains achieved by session B participants (game only) (M = 0.58, SD = 0.48) after the outreach session (p = 0.03). No significant differences were found between the other outreach sessions styles.

From this data, the learning gains achieved by participants who received a presentation only (session A: 0.12) and those who undertook an idealised session (sessions C or D: 0.11 respectively) are comparable. The graph also shows the highest learning gain achieved was 0.23 by a session D participant. Further, amongst the participants achieving a learning gain of >0.15, there were only three participants in session A compared to six and nine for sessions C and D respectively. Students from the game only (Session B) were not able to achieve as high learning gains as students from the other session types.

This result suggests that students who are exposed to sessions which comprise an instructor led presentation are more likely to achieve learning than students who did not receive this type of intervention (Session B). This could support the suggested method of delivery for the game which is for it to be integrated within an existing outreach session, supported by an instructor-led type of intervention.

### 7.3 Knowledge retention: one-year on

Although the results of the initial pre- and post-session knowledge quizzes proved positive in demonstrating a short-term knowledge gain from the intervention sessions, it was uncertain as to whether this newly acquired knowledge would remain for participants over a longer period of time. This was considered particularly important as one of the justifications for the selection of video games for this study was that engaging nature and the novelty of their use in education sessions may lead to a longer-term knowledge retention (Section 2.3.2). Therefore, to provide insight into potential long-term learning impact of the *St. Vincent Volcano* game on knowledge gain, post-session knowledge quiz data were gathered from two schools on St. Vincent in April 2016, one year after the original data collection to assess knowledge retention in the longer-term. All participants re-sampled were initially involved in the 2015 implementation testing. Geography teachers from the two schools involved in the 2016 study confirmed the students had not received any further education about volcanoes since the initial implementation testing in 2015. Due to the timing of this repeat testing being close to the end of term (April 2016), many of the students from other schools involved in the initial testing had left for exam preparation and were not available for the repeat study.

The two schools involved in the data collection comprised one group from session type C (*N* = 7*)* and one group from session type D (*N* = 2). Data was initially collected from 37 students across the two schools; however, due to evidence of cheating (as previously described in the initial 2015 study (Section 6.3.5)), data from 28 student were removed. The quiz administered to participants was identical to the post-session knowledge quiz completed in 2015. The quizzes were marked in the same way as previously (using a rubric out of 54 points) and the marks then converted into quiz score percentages. The 2015 pre- and post-session knowledge quiz scores and the 2016 post-session knowledge quiz score were then plotted (Figure 7.8).

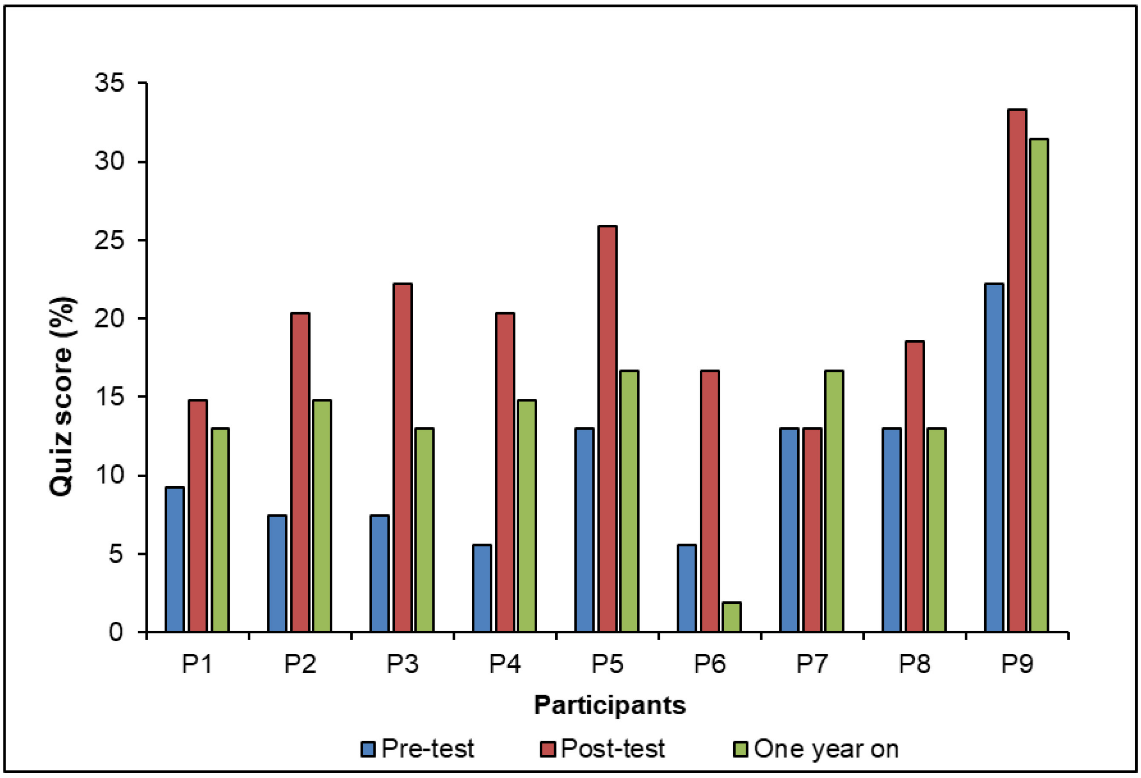



**Figure 7.8. Long-term learning effect of the *St. Vincent's Volcano* game. The graph shows the results for participants (*N* = 9*)* of their 2015 pre- and post-session knowledge quiz scores and their 2016 one-year on knowledge quiz score.**

When plotted, eight of the nine participants from who this additional data was collected, showed an initial improvement between their pre- and post-session knowledge quizzes in 2015. For the eight participants that did show initial improvement in 2015, seven of these participants demonstrated a loss of knowledge from their post-session quiz score in 2015 and one-year on data in 2016. However, the one-year on data representing knowledge retention remained above the initial pre-session knowledge quiz scores (2015) for these eight participants. Two participants (P6 and P8) showed either negative or no change in apparent knowledge gain between the pre- and the 2016 knowledge quiz score.

One participant (P7) showed no initial improvement in their quiz scores in 2015 and then showed an improvement in their quiz score in 2016. A further participant (P6), despite showing an initial score improvement between the pre- and post-session quizzes in 2015, recorded a significant reduction in knowledge one-year later, lower than their initial pre-session quiz score.

The results of the knowledge retention (one-year later) study show a distinguishable pattern in the longitudinal knowledge gain for seven of the nine participants. Although these seven students show degradation in knowledge from the post-session quiz in 2015 to the one-year on data collected in 2016, the one-year data still remains higher than that of their pre-session knowledge quiz in 2015. This data could suggest that the game is capable of producing a longer-term effect on knowledge retention of participants as similarly described in the literature (Benware & Deci, 1984; Ryan & Deci, 2000; Prince, 2004; Vile Junod *et al.*, 2006).

## 7.4 Engagement

Video recordings of all student sessions were made to allow for a qualitative analysis to be completed to assess levels of participants' engagement with the game. The aim of the video recordings was to establish whether the game was effective at engaging participants in their learning experience and to compare this with more traditional education techniques (presentations) (Section 6.3.2). By observing positive and negative behaviours in students, this can help identify active engagement with the interventions, with active engagement often linked with improved knowledge gain and ultimately learning. Session observations were also made during the adult outreach sessions to provide insight into attitudes and engagement with the game. Adult sessions were not video recorded but rather, key observations noted for methods of engagement and attitudes towards the game (Section 6.3).

The video recordings were assessed using the Behavioural Observations of Students in Schools (BOSS) model as previously introduced in Section 6.3.2. This model requires participants' behaviour to be coded every 15-seconds for either positive (active or passive) or negative (off task- motor, verbal or passive) engagement characteristics. The results of the video recording analysis are presented in this section.

### *7.4.1. Student video observations*

Two students selected from each outreach session were recorded and analysed to monitor for engagement characteristics, where the total number of students observed was 12. Two students from each sessions were observed as this was considered the minimal number of students required to provide information relating to student engagement levels and still enable statistical analysis, should it be required. The analysis for each student took a significant period of time to complete, with each student observation taking approximately four times the length of the recording (i.e. a one hour recording took four hours to analyse per student). Further, some students could not be used for observations as they did not remain in full-camera view throughout the session or did not complete the session in its entirety.

Each video recording was observed twice, with a week-long interval between observations, to ensure a robustness of the data. When calculated, agreement of the data sets (recording of either positive or negative engagement characteristics) varied between 86% and 96% agreement, with an average of 91%. It should be noted that, although analysis was focused on individual participants, some of these participants played the game as a pair during the session.

According to the BOSS method for classroom observation developed by Shapiro (2004), for each participant observed with engagement behavioural characteristics were noted every 15-seconds throughout the recordings. Behavioural characteristics were noted to be either positive or negative, as previously described in Table 6.2. A coding strategy was adopted for ease during the observation as developed by Shapiro (2004) and comprised:

- Positive - active engagement (AET) e.g. writing notes or on-topic discussions
- Positive – passive engagement (PET) e.g. listening to a presentation
- Negative – Off-task motor (OFT-M) e.g. moving out of seat around classroom
- Negative – Off-task verbal (OFT-V) e.g. off-topic discussions with a neighbour
- Negative – Off-task passive (OFT-P) e.g. gazing around the classroom

The total number of times each behavioural characteristic were observed during the course of the session were then totalled, separated into their positive and negative categories and then converted to percentage values of the total number of observations made. The positive and negative engagement percentage values for students who played the game (sessions B, C and D) and who did not (session A) are summarised on Figure 7.9. The values also include ‘Teacher Directed Instruction’ (TDI) percentages, correlating to the time a student spent engaged in discussion with an outreach instructor.

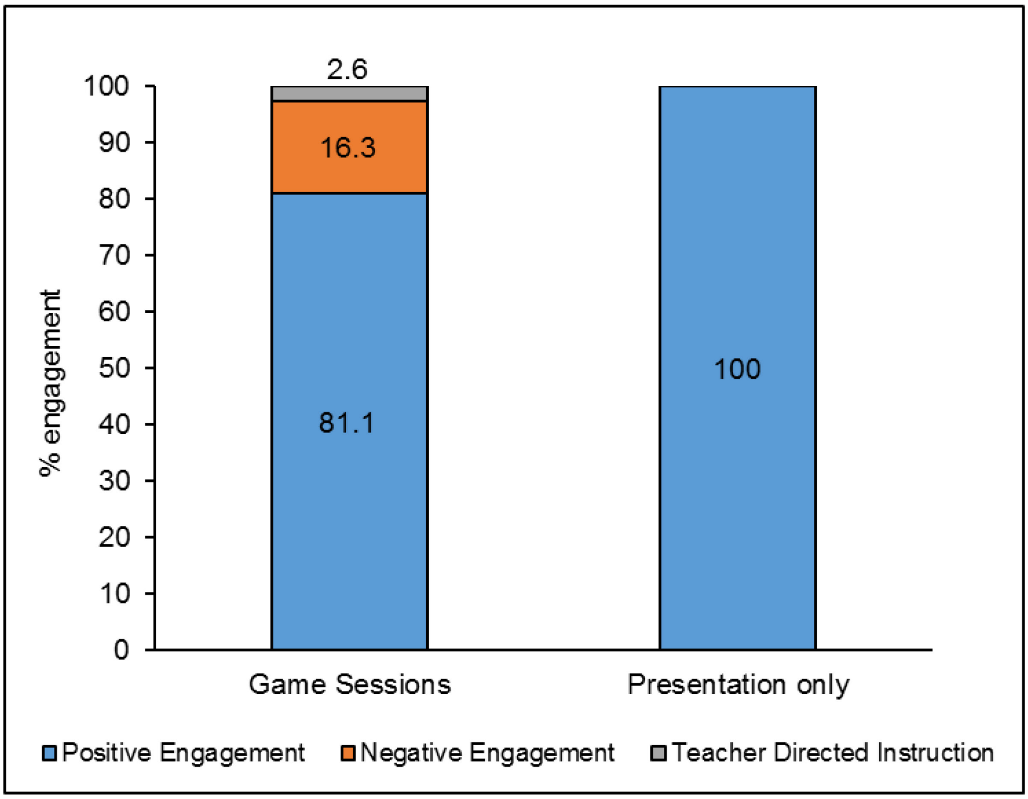



**Figure 7.9. Percentage of TDI, positive and negative behavioural characteristics observed for student who played the game (B, C & D) and students who received the presentation only.**

Figure 7.9 shows that the students who received the presentation only (A) session were 100% positively engaged throughout the observation period, compared to 81.1% for the game session students. However, the students who received the presentation were not observed to have any interaction with the session instructors, compared to 2.6% engagement recorded for the game session students. TDI includes time given by the instructors to provide assistance to the learner, answer questions they may have and to provide guidance as they played the game. In total, 6 of the 10 game-playing students observed (60%) recorded TDI during their session.

The same data was then categorised by separate session style (A, B, C & D) (Section 6.2.1) (Figure 7.10). Session D participants achieved a marginally higher percentage of positive engagement than the other two game sessions (B & C) although comparable at 80.9% (B), 78.9% (C) and 84.1% (D). For the each of the sessions that included the game, there were some negative engagement characteristics observed translating to

16.8% for session B, 17.9% for session C and 13.9% for session D. These negative behaviours typically comprised off-task conversation, moving around the classroom or in some cases passive behaviour such as staring around the room. All game sessions also recorded TDI of between 2.0-3.2%, which was often noted to be student initiated and either asking questions about their interactions or for assistance with the game.

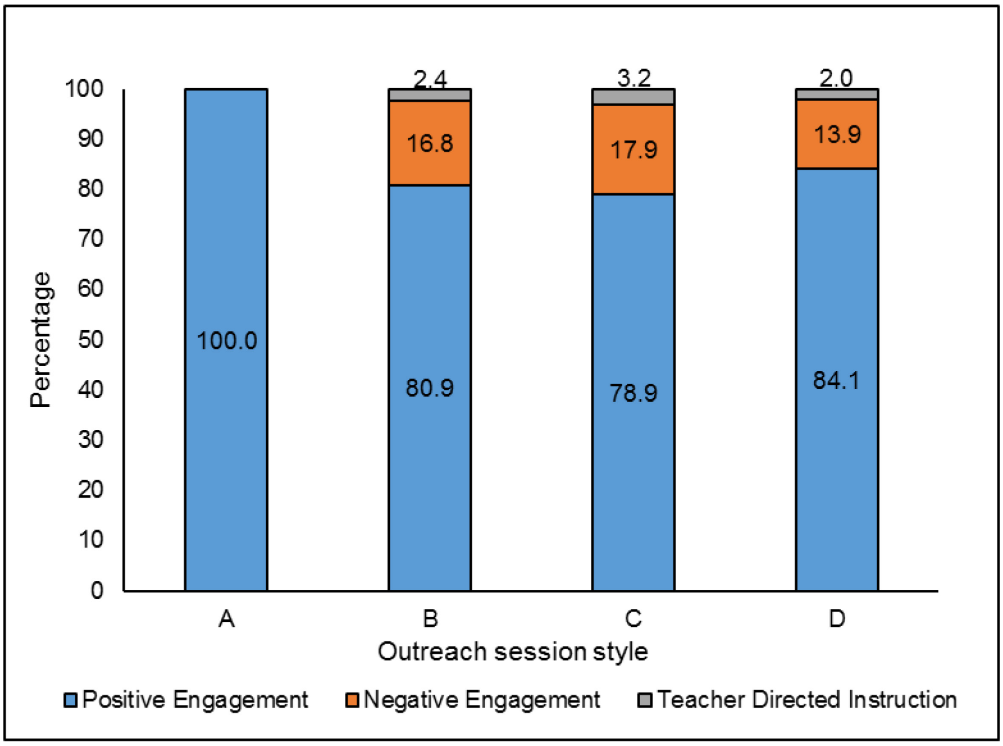



**Figure 7.10. Positive and negative engagement percentage scores for observed behavioural characteristics per session type; where, session A is presentation only session, B is game only, C is idealised session (game and presentation) in one session and D is idealised session over two sessions.**

To further assess participants' apparent levels of engagement whilst undertaking their outreach sessions, a deeper analysis on the positive engagement data was completed. The positive engagement percentage scores for each participant were replotted, categorised by either active engagement (e.g. a student writing notes or physically interacting with the game) or passive engagement (e.g. a student listening to instruction or reading information related to the session) as observed during the video analysis (Section 6.3.2) (Figure 7.11).

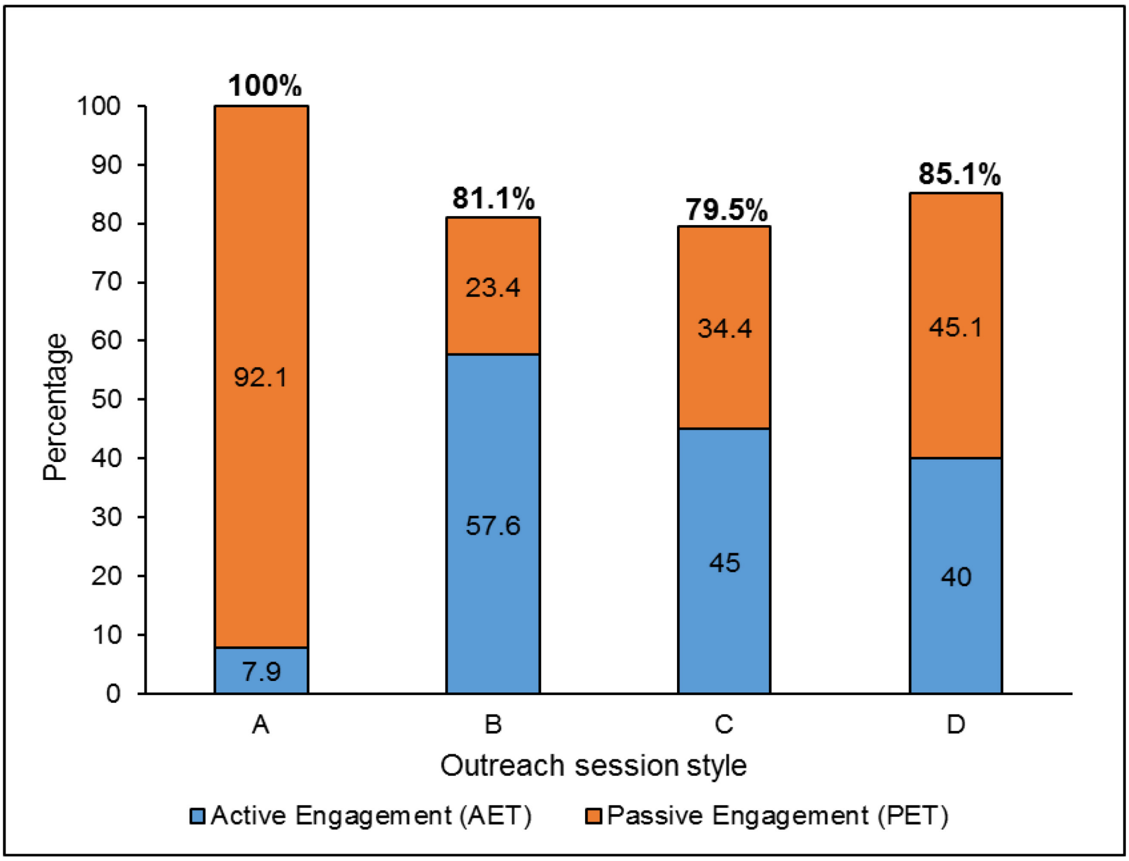



**Figure 7.11. Graph showing students positive engagement percentages categorised by either active (blue) or passive (red) engagement. Numbers in bold indicate the total percentage of positive engagement observed.**

The graph (Figure 7.11) shows that there is a variation in the percentage of active to passive engagement observed for each session type. Session A had the highest percentage of passive engagement (92.1%) compared to the game sessions (B, C & D), but only recorded 7.9% active engagement. Session B participants on the other hand, were the most actively engaged (57.6%) and sessions C and D had a more balanced ratio between active and passive engagement (session C – 45.0%:34.4%; session D – 40.0%:45.1%). The results demonstrate that a key difference in the session styles is on the type of positive engagement they generate with the game-playing students significantly (over three times) more actively engaged with their intervention session that students who undertook the presentation only session.

The results for the video analysis (summarised in Table 7.2) demonstrate that the session A participants (presentation only) displayed the highest percentage of overall positive engagement at 100% compared to a maximum of 85.1% (session D) for any of the game sessions. However, when the positive engagement is examined more closely, the positive engagement for the session A participants comprised mostly passive engagement (92.1%) (e.g. students listening to the presentation being given). On the other hand, game sessions demonstrated a marginally lower positive engagement score (between 79.5 and 85.1%), of which a significantly higher percentage comprised active engagement (40.0-57.6%), when compared to the session A participants (7.9%). Further, 60% of participants observed during the video analysis within the game sessions (B, C & D) engaged in TDI meaning they either asked a question or required assistance with the session, demonstrating further time spent actively engaging with the education session. No participants from session A were observed engaging with an outreach instructor at any time, further indicating a more passive engagement with their outreach session.

| | A | B | C | D |
|---|---|---|---|---|
| ***Positive Engagement (%)*** | **100.0 (42.5)** | **81.1 (20.1)** | **79.5 (11.4)** | **85.1 (17.6)** |
| Active (AET) (%) | 7.9 (1.2) | 57.6 (4.2) | 45.0 (10.5) | 40.0 (20.8) |
| Passive (PET) (%) | 92.1 (23.0) | 23.4 (4.7) | 34.4 (10.8) | 45.1 (16.4) |
| ***Negative Engagement (%)*** | **0.0 (0.0)** | **16.2 (4.3)** | **18.5 (4.1)** | **12.7 (8.0)** |
| Off-task Verbal (%) | 0.0 (0.0) | 6.1 (3.7) | 3.3 (3.9) | 0.3 (0.7) |
| Off-task Motor (%) | 0.0 (0.0) | 9.4 (1.6) | 6.5 (4.1) | 9.7 (12.5) |
| Off-task Passive (%) | 0.0 (0.0) | 0.8 (0.5) | 8.6 (3.0) | 2.6 (3.3) |
| ***Teacher Directed Instruction (%)*** | **0.0 (0.0)** | **2.7 (1.1)** | **2.0 (3.5)** | **2.2 (2.7)** |

**Table 7.2. Means scores (%) and standard deviation (in brackets) for observations categorised by each outreach session type.**

### *7.4.2. Adults session observations*

In general, the adult participants displayed high levels of engagement with the game, although many participants required assistance with navigation and interactivity throughout the session. During the adult sessions, participants were observed writing notes as they moved through the game, asking questions throughout and linking what they saw in the game to their personal experiences. In a few cases, some negative engagement of adult participants was observed – often as off-task discussions (OFT-V). However, in general participants mostly displayed positive engagement characteristics.

At the end of the sessions, many of the participants asked questions about things they had observed in the game or asked for clarification on the answers to questions posed during the pre- and post-session knowledge quizzes. This was something not observed during the student sessions, possibly due to the limited time available to run the sessions in schools compared to an unlimited time period to run the adult sessions.

During the adult session held in Fancy, many of the participants had experienced the 1979 eruption. One participant was noted to have an emotive memory re-call (LaBar & Cabeza, 2006a; LaBar & Cabeza, 2006b) whilst playing the game – suggesting that the game brought back strong memories about the events they had witnessed in 1979. The participant vividly described how they remembered the intense noise they heard and heat they felt as the ‘thunder cloud’ (pyroclastic flow) descended the flanks of the volcano and how it appeared to ‘tumble’ down towards the village. This emotive memory recall was something also noted during a viewing session for the game with key agencies on the island prior to any testing sessions. The stakeholder noted how the sounds they heard in the game reminded them of the explosion sounds they heard on the morning of the 1979 eruption. In both cases, the trigger for the memory recall was as they watched the historic eruption visualisations of the 1979 eruption.

Additionally, at the conclusion of playing the game, many of the participants (particularly within the Fancy session) who had experienced the 1979 eruption began to collective re-tell their stories of the events. This generally included descriptions of experiences both at the personal and community level. Many described in detail the processes they undertook in the immediate aftermath of realising the volcano was in eruption, such as raising the alarm to neighbours, how they prepared for the evacuations and the events of the evacuations themselves.

From the adult game sessions, observations made provide a good overview of the engagement levels of adults whilst playing the game. Many participants were noted to be exhibiting active engagement characteristics (e.g. writing notes and on-task discussions). Further, the observations demonstrated that the game was also able to act as a trigger for some adults to begin to recall their vivid personal memories from the 1979 eruption.

### 7.5 In-built game analytics (St. Vincent adults)

As detailed in Section 6.3.4, in-built game analytics were recorded for adult participants only ($N$ = 18) with one participant choosing not to record data through analytics, and a malfunction leading to no analytics being recorded for two participants. No student analytic data was recorded from either the St. Vincent or UK sessions due to either a malfunction with the game (due to human error and accidental deleting of essential coding) or due to logistical difficulties (data needed to be downloaded from individual computers and this was not possible during large sessions with restricted time slots).

Information collected through the game analytics included a list of the questions participants were asked during the *volcano quiz* and how they answered them. Questions within the *volcano quiz* covered aspects relating to the formation and behaviour of each volcanic hazard included within the game (ash falls and explosions, lahars and pyroclastic flows) or asked for the correct definition of the hazard. The questions were designed to establish if any of the knowledge of volcanic hazards presented within the game were read and understood by the participants enough for them to then apply this knowledge. This included questions relating to simple definitions and the more detailed conceptual questions to try and understand what information the participants had picked up during their game session. A list of the questions included within the *volcano quiz* are included in Appendix G and a discussion of the selection of questions and phrasing is included in Section 5.4.

The game analytics data were analysed to identify how many time each question was asked and how it was answered. There were 15 questions within the *volcano quiz* question bank, covering three different volcanic hazards (pyroclastic flows, lahars and ash fall and explosions). In total, the game analytics recorded the responses to 108 questions, equating to 36 questions posed per volcanic hazard category. The number of times each individual question was asked was counted with a breakdown how it was answered (either correctly or incorrectly) also noted. These totals were then converted to percentages and categorised by the volcanic hazard type the question referred to. The results are displayed in Figure 7.12.

For all three volcanic hazards categories, participants were able to answer more questions correctly than incorrectly. Questions relating to lahars achieved the most correct answers of any of the hazards with 67% of questions answered correctly, compared to 61.1% and 52.8% for pyroclastic flows and ash falls and explosions, respectively.

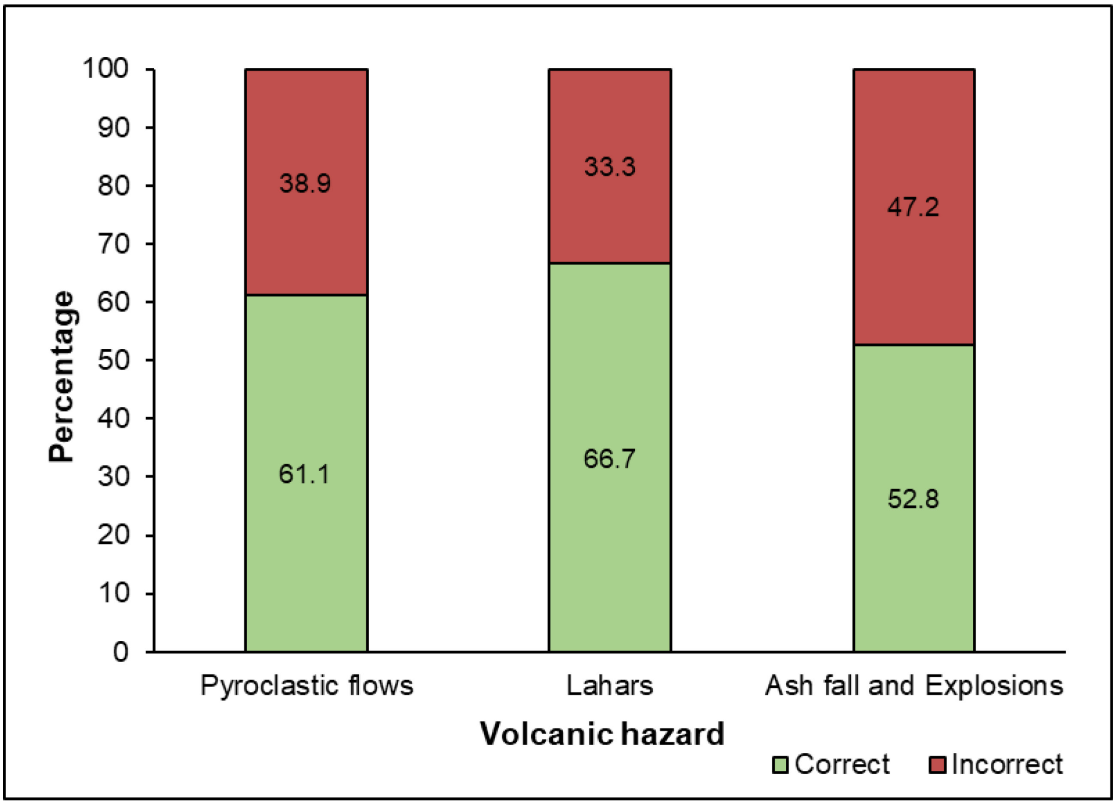



**Figure 7.12. Percentage of questions answered correctly (green) or incorrectly (red) during the *Volcano Quiz* for adult participants from game analytics data.**

Question specific analysis was also completed on the data (looking at individual question responses in turn), to establish if patterns of strength or weaknesses could be identified. With minimal examples of the use of game analytics and the analysis of acquired data with educational games in the literature, this was considered a simple method to see if any patterns emerge from the collated data. This was considered important as any patterns identified within the data may correlate to how well information is being communicated through the game. Any patterns identified can inform later iterations of the game to become more efficient for knowledge transfer and overcoming misappropriations of knowledge. To identify patterns in the participants' data, the total number of correct and incorrect answers were considered for each question presented within the *Volcano Quiz* (Table 7.3).

For each question provided on Table 7.3, scores have been highlighted in red where a large difference exists in the ratio of correct and incorrect answers. The questions posed to each participant were selected by random from the data bank of 15 questions held within the game. Three questions (one for each volcanic hazard) were not asked to any participant and this is thought to be due to a malfunction in the game, relating to the way questions are chosen at random.

For questions relating to pyroclastic flows (Table 7.3 [a]) only one question had a significant difference in the number of correct to incorrect answers (significant is considered an arbitrary value of > 4 answers): *"why are pyroclastic flows dangerous?"* (eight correct and three incorrect). In general, for the questions relating to pyroclastic flows, more people answered the questions correctly than incorrectly (22 out of 34 questions; 65%).

For questions relating to lahars (Table 7.3 [b]), just one question showed a significant difference between the number of questions answered correctly and incorrectly. The question *"give the correct definition for a lahar"* was answered correctly seven out of eight times (88%). All questions within this volcanic hazards category had a higher number of questions answered correctly than incorrectly (24 out of 36; 67%).

| (a) Pyroclastic flows | Total | CORRECT | INCORRECT |
|---|---|---|---|
| Give the correct definition for a pyroclastic flow. | 5 | 3 | 2 |
| What are the two typical methods of formation of pyroclastic flow? | 10 | 5 | 5 |
| Why are pyroclastic flows dangerous? | 11 | 8 | 3 |
| Where are pyroclastic flows most likely to travel? | 10 | 6 | 4 |
| What happens when pyroclastic flows reach the sea? | 0 | 0 | 0 |
| Total | **36** | **22** | **14** |

| (b) Lahars | Total | CORRECT | INCORRECT |
|---|---|---|---|
| Give the correct definition for a lahar. | 8 | 7 | 1 |
| What is the key trigger for a lahar to form? | 8 | 5 | 3 |
| How is more material added to a lahar as it flows down through river valleys? | 9 | 6 | 3 |
| Where do lahars deposit their material? | 11 | 6 | 5 |
| When does a lahar event occur? | 0 | 0 | 0 |
| Total | **36** | **24** | **12** |

| (c) Ash fall and explosions | Total | CORRECT | INCORRECT |
|---|---|---|---|
| Where on the volcano does a plume originate? | 8 | 7 | 1 |
| What causes a plume to expand in size? | 8 | 2 | 6 |
| What key factor can affect which direction a plume spreads? | 9 | 7 | 2 |
| What is volcanic ash? | 11 | 3 | 8 |
| What happens when volcanic ash mixes with rain water? | 0 | 0 | 0 |
| Total | **36** | **19** | **17** |

**Table 7.3. Data retrieved from game analytics for adult participants. The tables show the number of times each question was asked and how many times it was answered correctly or incorrectly, grouped by volcanic hazard type.**

For questions relating to ash fall and explosions (Table 7.3 [c]), there was higher variability in the number of questions answered correctly and incorrectly with four out of five questions demonstrating a significant difference in this ratio. Two of the questions had more correct answers than incorrect answers and they comprised the questions *"where on a volcano does a plume originate?"* (asked eight times) and *"what key factor can affect which direction a plume spreads?"* (asked nine times) with both questions being answered correctly seven times respectively. However, two questions also received higher incorrect than correct answers. These questions *comprised "what causes a plume to expand in size?"* (answered incorrectly six out of eight times) and *"what is volcanic ash?"* (answered incorrectly eight out of 11 times). Despite the variability in the number of questions answered correctly for ash falls and explosions, in general participants answered more questions correctly (19 out of 36; 53%) than incorrectly (17 out of 36; 47%).

The game analytics data for the adult participants provides insight into some of the strengths and weaknesses of the *St. Vincent's Volcano* game as an education tool. Participants generally answered more questions correctly than incorrectly for each category of volcanic hazards (65 out of 108 questions answered correctly; 60.2%). The category of questions where fewest were answered correctly related to ash falls and explosions, potentially identifying an area for improvement within the game. It is unknown why this may be the case for these questions but the questions relating to ash fall and explosions are slightly more technical in nature (e.g. referring to buoyancy of ash plumes and asking about how and why ash plumes expand). These questions have some anticipation of prior basic knowledge of physics concepts (e.g. hot air rises due to convection), unlike for the questions from the other volcanic hazard categories. Further, bias associated with language and phrasing of the questions cannot be ruled as an influencing factor on the data.

Exploring why some questions within the game receive more incorrect than correct answers is important to understand appropriate techniques for providing information in video games and understanding how the game can evolve for future iterations. Patterns that can be identified through game analytics data, such as those identified in this section, can also provide insight to outreach instructors to enable them to tailor their education sessions to target weaknesses in knowledge.

### 7.6 Communication of existing outreach material

One of the key aims of this research is to understand if the use of video games, such as *St. Vincent's Volcano*, can be effective in communicating existing education and outreach materials, such as maps and diagrams (Section 2.2.1). Studies by Haynes *et al.* (2007) and Preppernau *et al.* (2015) have shown that presenting hazard information in a more interactive manner such as through 3D photographs or digital elevation models (DEM) may lead to an improved understanding of the information, heightened spatial awareness of exposed areas, comprehension of personal risk and knowledge retention. Integration of existing communication materials within the St. Vincent game provided an ideal platform to build upon this existing research to establish if utilising video games could also have similar outcomes.

As described in Section 5.1, the Robertson (2005) volcanic hazard map for St. Vincent (Figure 3.5) was integrated within the game design. The map was presented as an overlay to a DEM of the island within the opening *island hub* scene which comprised a satellite image of the island. The inclusion of the volcanic hazard map within the game was considered important by the respondent of the online agencies questionnaire as it is the most popular method of educating about exposure to volcanic hazards on St. Vincent (Section 3.7).

To test the effectiveness of presenting the map in a more interactive way, questions were incorporated into the pre- and post-session knowledge quizzes for student and adult participants from all St. Vincent sessions. The questions asked participants to name which volcanic hazard zones the towns of Fancy, Chateaubelair and Georgetown were in, by either naming the colour of the zone (e.g. red zone) or its level of hazard (e.g. very high hazard). One mark was awarded for each of the towns named in the correct hazard zone, where the maximum possible marks per quiz was three (one mark per correctly identified town). The scores were then averaged for the pre- and post-session knowledge quizzes and plotted by student outreach session type and for the adult participants (Figure 7.13).

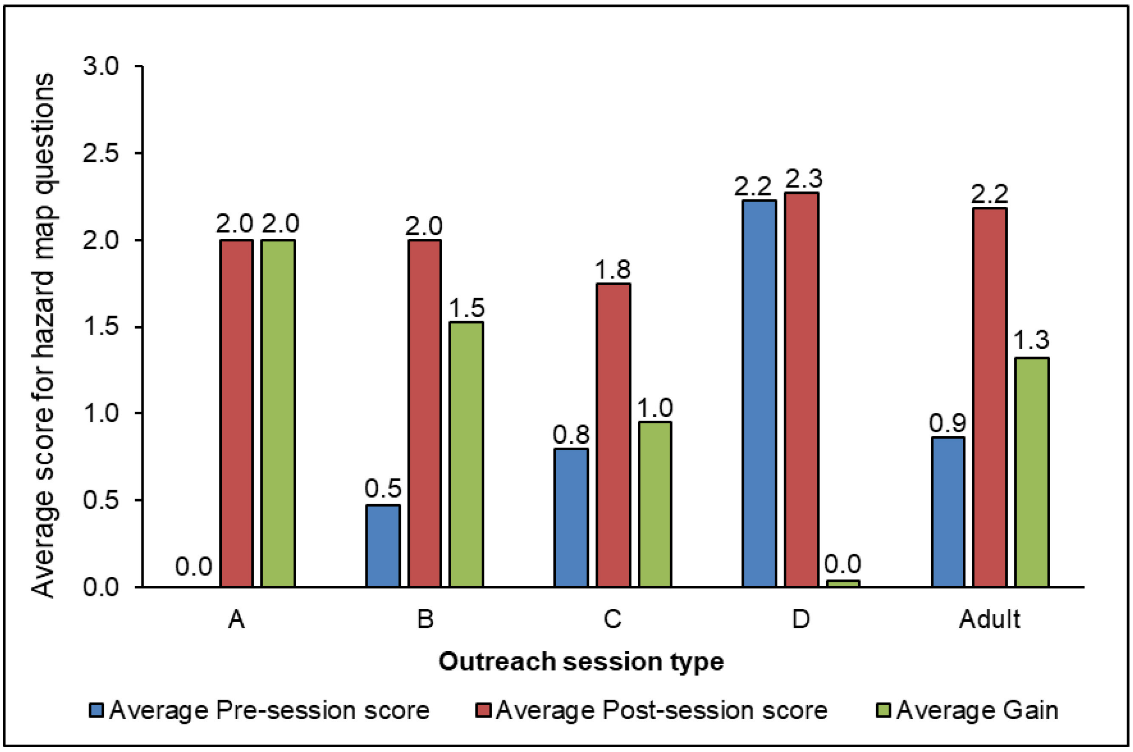



**Figure 7.13. The average scores of the questions included within the pre- and post-session knowledge quizzes relating to the volcanic hazard map.**

The results from this analysis (plotted on Figure 7.13) all show an increase in scores for the hazard map questions between the pre- and post-session knowledge quizzes (where the maximum achievable score is 3.0), indicating that, in general, most participants improved their scores between the two quizzes. The average gain score (difference between pre- and post-session question marks) was then calculated for each participant group and shows that the participants within student session A improved the most (by 2.0 marks) between their pre- and post-session quiz scores and student session D participants showed no average improvement. Despite showing no gain between the pre- and post-session knowledge quiz, the students from session D do have the highest average scores for both the pre- and post-session knowledge quiz questions (2.2 and 2.3 correct answers respectively). These high pre- and post-session scores for the questions would justify the low average gains scores as there was less room for improvement for these participants when compared to other session participants (e.g. session A participants achieved 0 average score on the pre-session quiz, allowing for a three mark possible improvement). When asked if any of the students in this session had previously seen the hazard map, no student indicated that they had – potentially resulting in the average pre-session question score of 0. A summary of the mean pre- and post-session marks for the volcanic hazard map questions and the mean gains scores for each participant group are included in Table 7.4.

| Session type | Mean pre-session | Mean post-session | Mean Gains |
|---|---|---|---|
| **A** | 0.0 (0.0) | 2.0 (0.8) | 2.0 (0.8) |
| **B** | 0.5 (0.6) | 2.0 (1.0) | 1.5 (1.3) |
| **C** | 0.8 (1.0) | 1.8 (0.9) | 1.0 (1.4) |
| **D** | 2.2 (0.9) | 2.3 (0.8) | 0.0 (0.9) |
| **Adults** | 0.9 (0.8) | 2.2 (0.9) | 1.3 (1.1) |

**Table 7.4. Mean values for pre- and post-session knowledge quiz questions scores based on the hazard map (marked out of 3) and the mean gains achieved.**

Due to the difference in starting point of for each of the groups of participants (i.e. session A participants achieving 0.0 and session D participants achieving 2.2 marks), it is not possible to make a valid comparison as to the effect of outreach styles on the scores achieved. Rather, the scores achieved may be reliant on the student's exposure to the volcanic hazard map prior to the sessions. It should be noted that the students from session D received the outreach presentation one-week prior to completion of their pre-session knowledge quiz (completed at the beginning of their second session) and subsequent playing the game and completion of the post-session knowledge quiz. Therefore, it is considered possible that the results for session D participants may be influenced by their pre-exposure to the hazard map prior to completing the pre-session knowledge quiz.

In general, these data recorded from the pre- and post-session quizzes demonstrate that there is an improvement for all groups of participants (students and adults) after the outreach session, irrespective of the type of outreach session they received. These findings add further weight to current research finding in this field that presenting hazard information to exposed communities in a more engaging and representative way, this can lead to improved comprehension of the information.

### 7.7 Balancing for familiarity

Familiarity was considered a potentially influencing factor on the data obtained from St. Vincent students. The *St. Vincent's Volcano* game was designed to have high levels of fidelity and realism to try to establish a connection with the player, making them feel part of the game to potential improve knowledge gain (de Freitas & Oliver, 2006; de Freitas *et al.*, 2010). This was achieved through the inclusion of town names, landmarks (rivers and mountains) and inclusion of authentic accents for voiceovers (Section 4.3.4). Due to the levels of familiarity embedded into the game, the UK student testing also provided a platform to explore how well the game performs as a general learning tool, outside of the target audience it was designed for (St. Vincent secondary school students).

Familiarity was also embedded into the pre- and post-session knowledge quizzes potentially creating a bias in the data. For example, questions included asking students to name the volcano and the date of the last eruption – this information is commonly known amongst the Vincentian population as it is regularly revisited during volcano awareness week annually and talked about in popular culture. However, students from the UK would only know this information through exposure during the intervention.

In order to further assess the impact of familiarity of the *St. Vincent's Volcano* game on the data obtained from the St. Vincent implementation testing, the quiz data was balanced for familiarity. This was done by reassessing the pre- and post-session knowledge quizzes for students in St. Vincent who played the game (sessions B, C and D) and subtracting marks for questions that related specifically to St. Vincent (e.g. *"what is the name of the volcano on St. Vincent?" "When did this volcano last erupt?"* and *"Which volcanic hazard zone is the town of Fancy within?"*). The questions that remained related to the specifics of volcanic hazards, including terminology definitions and specifics on the formation and behaviour of the hazards (e.g. *"why are pyroclastic flows dangerous?"* and *"how long can a volcanic eruption last?"*).

Once the quiz scores were recalculated, removing aspects of familiarity, the pre- and post-session knowledge quiz scores were plotted for the he UK students (Figure 7.14) and the St. Vincent students who played the game (Figure 7.15).

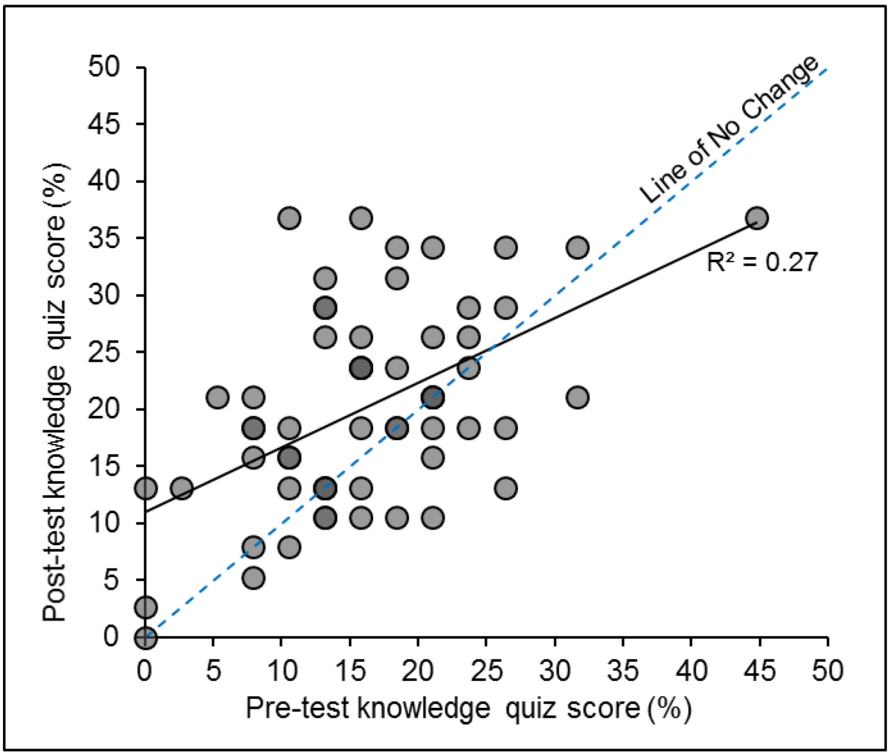



**Figure 7.14. Graph showing the pre- and post-session knowledge quiz scores for UK students (*N* = 59), balanced for familiarity factor. Where a point appears darker, this represents more than one data point plotting at the same location.**

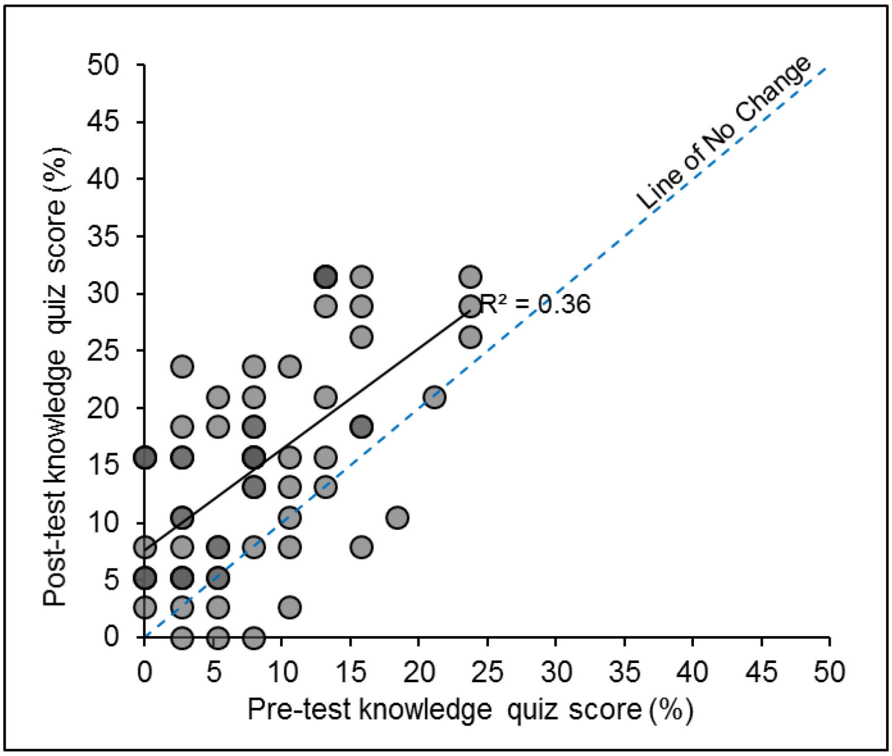



**Figure 7.15. Pre- and post-session knowledge quiz scores (%) for St. Vincent students who undertook game sessions (*N* = 65), balanced for familiarity factor. Where a point appears darker, this represents more than one data point plotting at the same location.**

When the St. Vincent student data was replotted balancing for familiarity factor (for game sessions only, *N* = 65) (Figure 7.15) the data showed a distinctive shift to the lower end of the scores (%) with a broader scatter of the data ($R^2$ = 0.36, p = 0.5) than in Figure 7.1 when not balanced for familiarity. However, a general positive trend was still observed, with the trendline plotting above the line of no change. The number of students plotting below the line of no change has increased from two to eight students with, seven students now plotting on the line compared to three from the original data set. When calculated the average apparent learning gain is 6.6%, compared to 8.3% for the original data set.

A paired-sample t-test was conducted to evaluate the difference between the pre-session and post-session knowledge quiz scores when balanced for familiarity factor for the St. Vincent game session students. There was a statistically significant difference in scores (%) from the pre- (M = 8.3%, SD = 6.3) to the post-session knowledge quiz (M = 15.0%, SD = 9.2), $t_{64}$ = 7.2, p = <0.01 (two-tailed). The mean increase in score (%) between the pre- to the post-session knowledge quizzes was 6.6% with a 95% confidence interval ranging from 4.8% to 8.4%.

The same graph was produced for the UK students' data (*N* = 59) after being balanced for familiarity (Figure 7.14). The graph shows a general positive trend, however the trendline, similarly to Figure 7.5, crosses the line of no change, indicating a positive but low apparent learning gain. The data also shows a broader scatter with a marginally lower correlation ($R^2$ = 0.27, where p = 0.5) and a marginal shift towards the origin of the graph. Compared to the unbalanced data (Figure 7.5), 15 students plot below the line of no change (previously 12) and 10 students plot on the line (previously three). However, the average apparent learning gain only marginally reduces after the data has been balanced to 4.0% from 4.9%.

A paired-sample t-test was conducted to evaluate the difference between the pre-session and post-session knowledge quiz scores, balanced for familiarity factor, for the UK students. There was a statistically significant difference in score (%) from the pre- (M = 16.1%, SD = 8.2) to the post-session knowledge quiz (M = 20.1%, SD = 8.9), $t_{58}$ = 3.7, p = 0.01 (two-tailed). The mean increase in score (%) was 4.0% between the pre- and post-session knowledge quizzes, with a 95% confidence interval ranging from 1.8% to 6.2%.

| ***Balanced for familiarity*** | **St. Vincent Students (*N* = 65)** | **UK Students (*N* = 59)** |
|---|---|---|
| **Average pre-session knowledge quiz score (%)** | 8.3 ± 6.3 | 16.1 ± 8.2 |
| **Average post-session knowledge quiz score (%)** | 20.1 ± 8.9 | 14.9 ± 9.2 |
| **Average apparent learning gain (%)** | 6.6 ± 7.4 | 4.0 ± 8.4 |

**Table 7.5. The average pre- and post-session knowledge quiz scores and apparent learning gain for both St. Vincent and UK students once balanced for familiarity.**

The results (summarised in Table 7.5) show that both groups of participants recorded positive apparent learning gains between the pre- and post-session quizzes, even when balanced for familiarity. The apparent learning gains for St. Vincent student's (6.6%) were marginally higher than the UK students (4.0%), but comparable.

The St. Vincent (game session) and UK student data were then normalised using Hake (1998) learning gains (Section 7.2) and plotted on Figure 7.16, along with the average values for the pre-session knowledge quiz scores and learning gains. The results show that both participant groups recorded overall positive learning gains. The majority (*N* = 61; 95%) of St. Vincent students plot above the 0.0 learning gains however, a large number of UK students (*N* = 14; 24%) plot below the 0.0 learning gains (indicating a reduction in learning). The average learning gains for the St. Vincent students was calculated at 0.12 ± 0.08 higher than that of the U students at 0.04 ± 0.10. The average pre-session knowledge quiz scores were also calculated for each group with 8.3% ± 6.30 for St. Vincent students and 16.1% ± 8.22 for UK students. The results suggest that although UK students had a higher background knowledge about volcanic hazards, the St. Vincent students benefitted more from the game sessions, even after being balanced for familiarity.

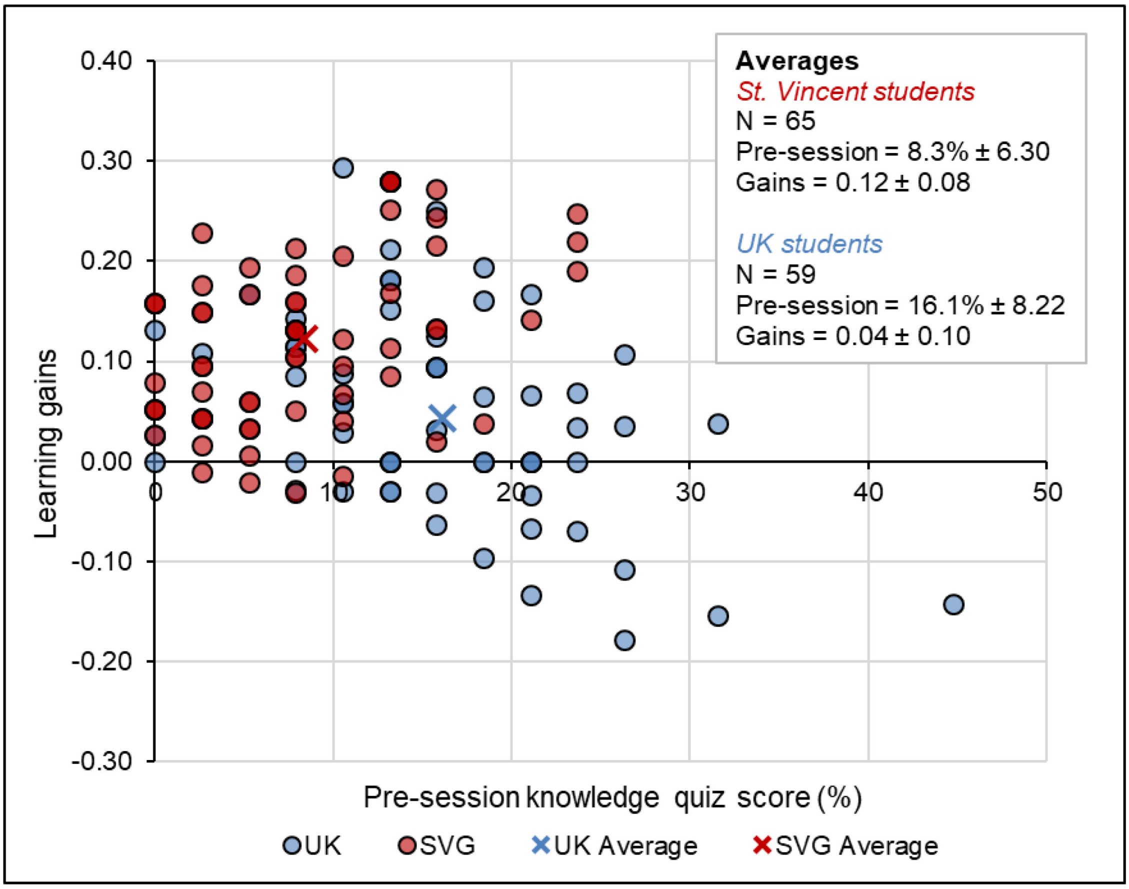



**Figure 7.16. Normalised learning gains (Hake, 1998) for students who undertook game session in St. Vincent (session styles B, C and D) (red) and UK students (blue). Where a point appears darker, this represents more than one data point plotting at the same location.**

An independent samples t-test was conducted to compare the learning gains results of St. Vincent and UK participant groups. There was a statistical significant difference between the learning gain scores for St. Vincent students (M = 0.12, SD = 0.08) and UK students (M = 0.04, SD = 0.10); t(122) = 4.75, p = <0.01. These results demonstrate that, even once balanced for familiarity, the *St. Vincent's Volcano* game has been effective as a learning tool for both St. Vincent and UK students; however, the game proved most successful at improving knowledge of volcanic hazards for St. Vincent students.

The results of the cohort comparison between UK and St. Vincent students has provided insight into how successful serious games as a whole can be as education tools, proving learning gain for the majority of participants. More significantly from this data, it shows that despite balancing for familiarity, St. Vincent students who are exposed to future volcanic hazards achieved greater learning from the intervention sessions, potentially providing evidence that education and outreach intervention sessions with exposed communities is effective at improving knowledge and achieving learning.

### 7.8 Summary

This chapter presents results from the mixed-methods approached adopted to assess the effectiveness of the *St. Vincent's Volcano* game as an education tool. Implementation testing of the game in St. Vincent took place in April to May 2015 for St. Vincent participants with data was collected through pre- and post-session knowledge quizzes, video recordings (students), session observations (adults) and game analytics. Additional implementation testing with students in the UK was completed in January 2016 with data collected through pre- and post-session knowledge quizzes.

Pre- and post-session knowledge quizzes were assessed for apparent learning gains and identified that the game was effective at improving knowledge for 92% of students and 91% of adult participants. The average improvement in knowledge score after the outreach sessions was 8.3% for St. Vincent students, 9.3% for St. Vincent adults and 4.9% for UK student participants.

These data were then normalised to allow for a robust comparison, revealing that the learning gains for both St. Vincent students and adults were comparable (0.09 and 0.11

respectively). This identified the game as being capable of improving knowledge for both students and adults, despite the game having been designed specifically for secondary school students. The St. Vincent student data was then plotted categorically by session type and revealed that students who undertook the ‘presentation only’ session had a higher normalised learning gain (0.12) than the other session types, although just marginally higher than sessions C and D (0.11 respectively). This outcome suggests that engagement by an instructor through a presentation as included within Sessions A, C and D can lead to a higher learning gain for students from those sessions.

To understand the potential longer-term outcomes from integrating the *St. Vincent’s Volcano* game into outreach sessions, one-year on data was recorded for nine participants involved in the initial implementation testing in St. Vincent in 2015. These data suggest that although some initially acquired knowledge is lost over a one-year period, the game can lead to knowledge retention in the longer-term potentially resulting in an improved knowledge of volcanic hazards when compared to participants’ pre-intervention state

Engagement data obtained through session observations from video recordings and coded for individual student behavioural characteristics (BOSS model) (Shapiro, 2004) identified that students who received the presentation only session were much more positively engaged that their counterparts in sessions comprising the game. However, when examined further, presentation only sessions exhibited much more passive engagement than game-session students who displayed predominantly active engagement. Although passive engagement is still positive, the levels of active engagement of student during intervention sessions can be linked to the adoption of knowledge and ultimately improved learning.

In-built analytics data were recorded for adult participants to identify questions posed during the *volcano quiz* and how they answered them. This data provides insight into the participants' knowledge about different aspects of volcanic hazards (e.g. the reasoning for formation and behaviour of hazards). A closer look at question specific data identified that in comparison to questions relating to pyroclastic flows and lahars, participants showed a marginal weakness for questions relating to volcanic ash and explosions, potential linked to the more technical use of language in the wording of questions. This data could suggest that the way the information about volcanic ash and explosion are presented and communicated through the game could be improved to be more user friendly.

To test the overall ability of the *St. Vincent's Volcano* game at improving knowledge of volcanic hazards, a control group of UK students were also asked to undertake an outreach session comprising a presentation and game to enable a comparison to St. Vincent students. This testing also enabled a comparison of at-risk and non-at-risk groups of participants to establish the influence of familiarity embedded into both the game design (e.g. place names, locations etc.), and the data collection instruments (e.g. questions relating directly to St. Vincent rather than volcanic hazards). To balance for this familiarity factor the pre- and post-session knowledge quizzes for all student participants who played the game were re-marked, removing St. Vincent specific questions. When compared, the students from St. Vincent (game sessions) and UK students both showed general positive improvement in apparent learning for both groups of participants. However, when the data was plotted as normalised learning gains (Hake, 1998), the students from St. Vincent showed a more significant improvement in learning gains than the students from the UK students. This data shows the game is capable of improving knowledge when used in outreach sessions both with the targeted audience (secondary school students on St. Vincent) and with students from the UK. However, the data also revealed that participants living at-risk from volcanic hazards (St. Vincent), were able to achieve higher knowledge gain than students from the UK considered not at-risk. These results and their implications are discussed in detail in the following chapter, Chapter 8.

# CHAPTER 8: Discussion: Using video games for volcanic hazard

A gap was identified within the literature relating to a lack of empirical evidence for the effectiveness of serious games used for public education and outreach, despite games already being designed and used for this purpose. To bridge this gap, this study was designed to appraise how effective serious games could be when used in outreach programmes for volcanic hazards through the development and testing of a bespoke video game – *St. Vincent's Volcano*. The research was driven by a series of research themes outlined in Chapter 1, which are to provide insight on the design and development process for serious games, how games could be used in outreach, and how effective these games are at improving knowledge and motivation to learn.

The first part of this chapter discusses the results obtained through mixed-methods from implementation testing on St. Vincent and the UK in the context of the academic literature. The aim is to provide insight as to how effective serious games can be as education and outreach tools and how they can best be used to support learning and improve motivation. Therefore the results are discussed in terms of their influence on players' knowledge and learning gain, how the game can encourage learning through shared experiences and finally, the game's ability to communicate existing volcanic hazard information.

The second part of this chapter reflects on the processes adopted for the design and development of the *St. Vincent's Volcano* game, with the aim of informing future studies of both the benefits and the challenges encountered by using the methods described in Section 6.3. The chapter provides a critical appraisal of the implementation strategy employed in St. Vincent and the UK and of the mixed-methods data collection methods used to evaluate the effectiveness of the game. Finally, this section provides reflection on successes from these stages of the research, identifies areas for improvement and provides recommendations for future studies.

## 8.1. Improving knowledge of volcanic hazards

One of the key aims of this research was to understand if the use of the *St. Vincent's Volcano* game could improve participant's knowledge of volcanic hazards. Results obtained through pre-and post-session knowledge quizzes identified that the game was successful at improving knowledge of volcanic hazards by 9.3% for St. Vincent adults, 8.3% for St. Vincent students and 4.9% for UK students. When converted to normalised learning gain after Hake (1998), the results showed that adult participants achieved the highest average learning gains of 0.11 compared to St. Vincent students 0.9 and UK students 0.04. In total, 89.6% of all participants involved in the study showed improved learning gains. These results reflect the common acceptance within risk communication literature that suggests that participants who undertake any form of intervention, commonly display an initial improvement in knowledge (Johnston *et al.*, 1999; Ronan & Johnston, 2003; Shaw *et al.*, 2004; Paton *et al.*, 2008).

For St. Vincent students (the primary target audience) 92% of participants demonstrated an improved knowledge between the pre- and the post-session knowledge quizzes, with 93.2% showing positive learning gains from the St. Vincent student sessions. When compared between game playing and non-game playing students, 100% of students from the non-game playing session (A - presentation only) showed positive learning gain compared to 92.3% of game-playing students (game only and combined sessions C and D). It was expected that students that played the game would achieved the greatest knowledge and learning gain due to the interactive nature of serious games and was a key justification for the adoption of serious games for this study (Section 2.3.2). However, the result directly contrasts with the expected outcome, with the greatest learning gains achieved by students who undertook the presentation only session (0.12), although marginally higher than students from sessions C and D (0.11 respectively) comprising both the presentation and the game.

Despite the marginal difference in learning gain between the presentation only and the idealised sessions C and D, all sessions including the presentation achieved a significantly higher learning gain for participants than the stand-alone game only session (B) at just 0.06. The results suggest that students who received the outreach presentation as part of their interventions (Sessions B, C and D) were able to achieve higher learning gains than the game-only students. To consider why there may be a variability in the level of learning achieved by the different groups of students, the learning gain results must be considered with the results of the video analysis engagement study (Section 7.4).

From the video analysis results, students who undertook the presentation only sessions were recorded as 100% positively engaged compared to 81.1% for students from sessions including the game (B, C and D) (Section 7.4). The high positive engagement percentage recorded for the presentation only students may be attributed to the varying teaching styles adopted during these sessions.

The presentation only sessions was entirely instructor-led compared to the game sessions which were predominantly one-way student-led, with minimal guidance or instruction provided. This student-led approach used during the game sessions is often referred to in the literature as *student centred learning* (SCL) (Brandes & Ginnis, 1996; Hannafin *et al.*, 1997; Jones, 2007; Baeten *et al.*, 2010; Hannafin, 2012). SCL, a type of problem based learning, refers to education practices where students are encouraged to think more independently and are actively engaged in their learning experience, working at their own pace rather than being teacher or instructor-led (O'Neill & McMahon, 2005; Baeten *et al.*, 2010). One advantage of SCL is that it is often linked to students fostering a deeper approach to learning which can result in a stronger knowledge retention (Hannafin *et al.*, 1997), similar to the effects of problem based learning in adults.

However, despite the high levels of positive engagement and the SCL approach adopted by the game-playing participants, they achieved lower learning gains than their counterparts who received the presentation only instructor led session.

When the positive engagement scores were categorised to reflect either passive or active engagement, the students that played the game showed a significantly higher level of active engagement (40-58%) compared to the presentation only sessions (7.9%). Throughout education literature, there are numerous references to the significance of active vs. passive engagement, in particular, discussions relating to the role of active engagement in encouraging learning and overall motivation to learn (Prince, 2004). It is often argued that the more active the education experience (e.g. through hands-on engagement or student-led activities), the stronger the motivation to learn and encourage learning (Benware & Deci, 1984; Ryan & Deci, 2000; Prince, 2004; Vile Junod *et al.*, 2006). Therefore, it would be expected that the students who played the game and recorded significantly higher levels of active engagement would have achieved a higher learning gain than those students who did not. However, the opposite trend was observed, with presentation only students recording more passive engagement but higher learning gains. This unexpected result directly contrasts with academic literature.

As previously discussed, game sessions adopted a SCL approach, with students in control of how they engaged with the game and their pace through the session. This was completely contrasted to the presentation sessions which were instructor led with the pace and flow of the session very much dictated by the outreach instructors. Although SCL has some advantaged in education sessions, the style of intervention also resulted in some negative impacts during the study. For example, students from the game sessions were noted to have a lower overall positive engagement of 81.1% compared to the presentation students who had 100% positive engagement. Typically, this negative engagement was observed as students chatting with friends or moving around the classroom. The less structured approach to the game sessions meant that student behaviour was much less disciplined compared to the presentation only session where students were motivated to stay on-task by the instructors. Therefore, on reflection, the role of the outreach instructors on encouraging learning and engagement is considered to be relevant to the analysis of these data.

The presentation sessions were presented by Omari Graham and Clevon Ash, members of the SRC education team, who have delivered sessions on a regular basis to at-risk communities throughout the English-speaking Caribbean. The sessions run by Omari and Clevon during the implementation testing were approached light-heartedly and in a fun and dynamic manner. Both Clevon and Omari are extremely animated and entertaining during their session, constantly seeking audience participation through questions or using students to assist with aspects of the session. One such example of this engaging approach to the outreach session is when they ask students to watch their finger nails grow and then link this to the rate of growth to the rate at which tectonic plates move in the Caribbean region. They were also observed using their personal experiences to enhance the outreach session, including descriptions of watching the Soufriere Hills volcano erupt on Montserrat.

The sessions delivered by SRC on St. Vincent are a result of continued development and discussions by the team to ensure the materials they deliver are relevant and engaging year after year (Pers. Coms. Clevon Ash, June 2018). Although students may not have encountered the SRC team before, they are well respected on St. Vincent for providing good outreach sessions, often revisiting the same schools during VAW. Additionally, SRC are well known across the island through outreach campaigns and through media coverage for natural hazards. Members of SRC often provide interviews when natural hazard events occur in the region, such as earthquakes or, most recently, heightened activity at the Kick ‘em Jenny submarine volcano (BBC, 2018).

Currently, there is a lack of academic literature that discusses the links between engaging outreach instructors and their influence on knowledge and learning gain, therefore this argument can only be presented anecdotally and from personal experience. However, the strong personalities and animated approach to the outreach session combined with tried and tested materials and a good reputation cannot be ruled out as an influencing factor on the student results.

Overall, the results from the pre- and post-session knowledge quizzes demonstrate that the game can encourage positive learning gain. However, the most successful use of the game was through its integration within an instructor-led session, resulting in a higher level of positive engagement and a mix of both active and passive engagement styles.

#### 8.1.1. Use with at-risk communities

The results from the St. Vincent student and adult testing sessions are promising at demonstrating how effective the *St. Vincent's Volcano* game can be at improving knowledge and learning gain. However, it was considered possible that the results obtained through the pre- and post-session knowledge quizzes may be influenced by the fact quiz questions related to specific aspects of St. Vincent that may form common knowledge. For example, questions within the quizzes asked students to name the active volcanic centre on St. Vincent, and to identify when it last erupted; information that is well known across St. Vincent. Participants on St. Vincent were considered aware of their proximity to an active volcano, with 100% of St. Vincent students able to correctly name the volcano and the last eruption date in 1979 on their knowledge quizzes; although this may not translate to comprehension of the risks posed to them from a future volcanic eruption. However, this perception of living close to volcano may also influence the attitudes adopted by students during the intervention sessions, potentially causing a bias in the data.

To counter this potential bias within the St. Vincent student pre- and post-session knowledge quiz data, a cohort comparison study was undertaken with a group of students from the UK. The UK students used for the comparison comprised Year 10 Geography students from Heles School, Plymouth. The UK students were considered comparable in terms of demographic information but also in their level and extent of volcanic hazard education, with the Geography curriculum in St. Vincent based on the UK curriculum. The UK students represented a cohort with no prior knowledge of St. Vincent or the eruptive history of La Soufriere and whom were considered not at-risk from any similar natural hazards.

As previously detailed in Section 7.1.3, the UK students received a combined outreach session comprising the SRC presentation and the game, equivalent to St. Vincent session style C. Data were collected through identical pre- and post-session knowledge quizzes to those administered to students on St. Vincent. Initial marking of the quizzes demonstrated an overall 4.9% score improvement for UK students (Figure 7.5), lower than that achieved by any student groups on St. Vincent (between 5.5-10.2%). To balance for familiarity and to remove the bias previously discussed within the knowledge quizzes, questions relating specifically to St. Vincent were omitted, leaving only questions relating to definitions and descriptions of volcanic hazards.

The results of the quizzes with familiarity questions removed demonstrated minimal effect on the UK students average knowledge quiz score which marginally decreased from 4.9% to 4.0%; however, for the St. Vincent students their average knowledge quiz score dropped from 8.3% to 6.6% (Figure 7.14 and Figure 7.15). When normalised, the results showed that the St. Vincent students achieved a greater learning gain at 0.12

compared to the UK students at 0.04, despite the UK students having initially achieved a high average pre-session knowledge quiz score (16.1% for UK students compared to 8.3% for St. Vincent students). The results suggest that despite having been balanced for familiarity, St. Vincent students were still able to achieve higher learning gains and knowledge improvement after playing the *St. Vincent's Volcano* game.

It should be noted that during significant overall behavioural differences were noted between the students in St. Vincent and the UK, with St. Vincent students displaying higher levels of discipline and maturity. Behaviour of UK students was challenging and often required the intervention of school teachers to regain discipline. This is potentially considered to be associated with the novelty of the sessions for the UK students with an external speaker but also using computers and games within their sessions. St. Vincent students have personal laptops to support their studies and they are used more widely in their education that UK students. This novely could provide a limitation of the data obtained, meaning that St. Vincent students were less distracred and excited during the session, therefore more focused on the session that the UK students.

These results could have significance to outreach sessions conducted with at-risk participants, as they demonstrate that at-risk communities are more likely to achieve knowledge and learning gains from a targeted intervention session (Allen & Philliber, 2001). This finding supports the present body of volcanic risk communication literature arguing the benefits of outreach and education interventions at improving knowledge of at-risk communities (McKay, 1984; Johnston *et al.*, 1999; Paton *et al.*, 2000; Ronan & Johnston, 2001; Paton *et al.*, 2008). However, as the game only focuses on improving knowledge of volanic hazards, this research is only able to provide support for improved kowledge gain and is not able to establish if this improved knowledge gain resulted in an increased adoption of preparative measures or behaviour change, highlighting an area of focus for future studies. Despite this, the findings of the cohort comparison demonstrates that serious games can be effectively used with at-risk communities to promote knowledge and learning gain of volcanic hazards.

### 8.1.2. Encouraging longer-term knowledge retention

It is commonly acknowledged that an issue associated with the pre- and post-testing method adopted for this study has the potential for bias due to participants memorising answers rather than demonstrating applied knowledge (Bellotti *et al.*, 2013b). Further, as described in Section 8.6, the pre- and post-session knowledge quiz results also represent a snapshot of student ability at the time of testing, influenced by student attitude on the day. Therefore, the results obtained may not be fully representative of the learning achieved by participants during the initial study.

To examine this potential bias, longer-term knowledge gain data was obtained from St. Vincent students, one-year after the initial study took place. Although only a small data set could be obtained, the results showed that the students had maintained some of the knowledge they had gained from their initial intervention sessions in the previous year. However, the data also showed that there was some degradation in knowledge from the initial post-session knowledge quiz score to the one-year later data point. Knowledge degradation over-time post-intervention is a common theme within education literature (Bahrick *et al.*, 1975; Conway *et al.*, 1991; Fisher *et al.*, 2018). One example from (Ellis *et al.*, 1998), looked at the longitudinal effect on knowledge retention for information taught at school with students aged between 3-16 years. Their study demonstrated that as time increases the knowledge retention of a student rapidly decreases until it eventually balances after seven years post-study (without subsequent interventions). This knowledge degradation is significant to the disaster risk community as it demonstrates that a single intervention session may not lead to consistent improved knowledge of hazards in the longer-term. One method to overcome this knowledge degradation is through the repetition of education and outreach interventions over time.

Repetitive intervention sessions are typically adopted within training and education fields, one such example is First Aid training which requires repeat interventions to be completed on one to three year cycles to maintain a good level of knowledge and skill (de Ruijter *et al.*, 2014). A study demonstrating this effect was completed by Anderson *et al.* (2012) who considered the best way to encourage longer-term knowledge retention of CPR skills within the workplace. The study identified that the best method to overcome observed knowledge and skill loss with time was for participants to repeat their training annually. This repetitive training was demonstrated to result in a longer term retention of the skills and knowledge required to complete CPR.

The results of the longitudinal study combined with the examples of the need for repetitive training for First Aid to maintain knowledge and skill levels, highlights an area of current weakness within disaster risk reduction practices. Often there is little time and funding available to provide repetitive interventions with the same communities (Kellett *et al.*, 2014), meaning that repeat interventions are really completed. However, by completing follow-up interventions with the same communities, this could ultimately lead to improved knowledge and awareness in the longer-term and thus, reducing community vulnerability to volcanic hazards. This presents an area for further work, to establish the optimal levels of repeat interventions and recurrence with exposed communities to maximised knowledge and awareness of natural hazards.

## 8.2. Learning through sharing experiences

The knowledge and learning gain results demonstrated a marginally higher level of learning gain for St. Vincent adult participants compared to St. Vincent student participants. This outcome was surprising as the game was not designed with adult learners in mind, and it was expected that adult learners may achieve learning but not at a comparable level to student participants. The justification for the use of serious games in this research was to engage a new generation of learner, the 'Net Generation', who are more accustomed to a digital way of life. However, this finding may reflect an underestimation of the ability of adult learners who, due to improved accessibility of digital technology, have also adopted digital lifestyles (Helsper & Eynon, 2010). A growing body of education research into the gap between 'digital natives' and 'digital migrants', - terminology coined by Prensky (2001) - has questioned the concept of a digital native altogether. Helsper and Eynon (2010) argued there are many factors that may play a role in a person's ability with digital technologies such as breadth of use, experience, gender and education levels, but despite this, they demonstrate that it is possible for adults to become digital natives, particularly in areas of learning and training. This is further supported by research by Bennett *et al.* (2008), who argue that there is a lack of empirical evidence to support concept of digital natives or that those who may fall into the digital native category learn in a different way than has been observed previously. Finally, Bennett *et al.* (2008) argue that we have come to live in a more technologically advanced world but this has happened *"through evolution not revolution"* (Bennett et al., 2008, p.783).

Within learning and education literature, it is widely accepted that adults learn differently to their younger counterparts, with a wealth of literature describing various learning theories associated with adults. One such branch of adult learning literature reflects on the constructivist path or contextualised learning, whereby learning material content is connected to the context of real life (Davtyan, 2014). In adult education, this means that individuals learn by linking the education materials to their personal experiences, leading to an adoption of a more problem-based learning style (Delisle *et al.*, 1997). For example, adult participants who have already been exposed to a natural hazard event (e.g. a wildfire) are more likely to obtain new knowledge from an outreach session relating to wildfires as the learning has context in their day-to-day life (Perry & Lindell, 2008). Many authors identify that adult learners are more likely to retain newly gained knowledge when it is applicable to a currently perceived problem, or provided in context to real world situation (Knowles *et al.*, 1998; Wlodkowski, 2003; Toman *et al.*, 2006). Toman *et al.* (2006) argue that if problem-based learning is applied to education and outreach programmes for adults that relates to something relevant to their daily life (i.e. providing context to the education situation), then it is likely that the outreach will be more effective at improving participants' knowledge on the subject. When adult data was replotted to take into consideration demographic information such as age, gender and location of residency as a bias on the data (Figure 7.4), the results suggested that level of experience of volcanic hazards contributed to higher knowledge levels of participants. This finding reflects the academic literature, providing further support that previous experience and knowledge of a subject area can lead to improved knowledge when presented during an outreach intervention (Toman *et al.*, 2006).

Experiential learning was employed as the primary underpinning learning theory within the *St. Vincent's Volcano* game (Section 4.3.3). Experiential learning theory lends itself to problem-based learning, by encouraging players to reflect on their learning experiences and adapt their knowledge based on the outcomes of their experiences before applying their newly gained knowledge (Kolb, 1984; Vince, 1998; Konak *et al.*, 2014). Although problem-based learning was not an initial consideration in the game design phase of *St. Vincent's Volcano* (due to the game being primarily designed for students), its compatibility with experiential learning (e.g. both theories requiring learning through experience) may have contributed to adults being able to use the game to improve their knowledge of volcanic hazards.

During the adult sessions, a strong level of active engagement was observed. This active engagement typically comprised writing notes, asking questions and linking aspects of the gameplay to their personal experiences of the 1979 eruption. In one case, a participant was observed to experience a strong emotive memory re-call as they played the game. The participant, whilst observing a visualisation of a pyroclastic flow travelling down the volcano flanks, began to describe the heat and noise they experienced as a pyroclastic flow descended the volcano during the 1979 eruption, referring to the flow as a ‘thunder cloud’. This emotive memory re-call was also encountered when the game was first introduced to disaster managers on St. Vincent, prior to implementation testing being undertaken. One observer commented whilst watching the historical visualisations of the 1979 eruption that the sounds within the game immediately reminded them of the events of that day. These observed strong emotive memory re-calls suggests that the levels of realism and the fidelity of the visualisations that were carefully designed into the game are significant enough to trigger this reaction. In other cases, on completion of the game, participants from the session in Fancy began to re-call their stories of 1979. Strong emotive memory re-call is not an unexpected outcome for the adult participants, particularly from those who had experienced the 1979 eruption.

Within the psychological literature there are numerous references to the links between emotion and memory (Baron, 1962; Rubin & Kozin, 1984; White, 1989; Christianson & Loftus, 1990; Revelle & Loftus, 1990; Kensinger & Schacter, 2008). The common thinking is that when a strongly emotive event is experienced, it becomes ‘coded’ into our memory in the form of a network of neuron activity (Reisberg & Hertel, 2003; LaBar & Cabeza, 2006a; Buchanan, 2007; de Byl, 2015). When the network of neuron activity becomes stimulated by a trigger, then the participants re-experience the events. Further, where the event is strongly emotive, they are often remembered with a greater accuracy and vividness than events which are slightly less emotively charged (Reisberg & Hertel, 2003; Buchanan, 2007). When applied to the participants who were observed to have strong memory recall whilst playing the game, this would indicate that the participants may have strong emotions relating to the 1979 eruption which, when the game acted as a trigger, were re-experienced vividly.

It is unsurprising that participants have strong emotional memories of the 1979 eruptions, which led to participants being evacuated from their homes to emergency shelters and upheaval of their lives for months in the aftermath. Furthermore, since 1979, the eruption events are still talked about in conversation, used as a marker in time, and are commemorated annually through outreach activities across the island (VAW). In practice, this could mean that many of the island residents, particularly those living close to La Soufriere at the time, may have very strong memories of the 1979 eruption which could translate to vivid and/or accurate memories of the events.

The implications for these strong emotive links to the 1979 eruption could have significant implications for DRR practices on the island and with other at-risk communities. There is an ethical implication with working with at-risk communities in that, activities like the *St. Vincent Volcano* game, which visualises the La Soufriere volcano in eruption (particularly where visualisations are based on historical data), may potentially cause emotive memory recall leading to fear, distress or discomfort for participants. For researchers considering a similar line of work, ethical considerations would need to be accounted for prior to interactions with communities with procedures in place to provide reassurance for participants exhibiting signs of distress or discomfort.

Despite the St. Vincent's Volcano game having primarily been designed for student participants on St. Vincent, the outcomes of the adult game sessions are encouraging. Not only does the game enable positive learning for adult participants at a similar level to students, but it also actively engages them in their learning experience. Serious games could prove a successful media for educating adults within at-risk communities, often the most difficult audience to capture for disaster risk reduction education and outreach. The flexibility of games (e.g. availability across various platforms) means that they can be accessed and completed at the pace of the adult learner. Further, serious games are by their nature designed to be engaging and effective for all learning styles (e.g. visual, kinaesthetic and audial), meaning they are compatible with diverse groups of learners (Gee, 2005). Both the flexibility of games and compatibility with various learning styles means that serious games can promote contextualised learning.

During the St. Vincent adult game sessions, the game acted as a stimulus for people to share experiences, promoting a peer-to-peer learning approach. Peer-to-peer learning can be a powerful experience, providing additional context to the learning environment. One such example of learning through peer experience is from Hicks *et al.* (2017), who identified the value of sharing experiences as a component of risk reduction activities, demonstrating that participant sharing of experiences of the 1979 eruption on St. Vincent via a series of films, led to the empowerment of communities to seek hazard and risk information, adopt preparation measures for future events and strengthen individual and community level resilience. The adoption of a similar approach with the *St. Vincent's Volcano* game for adult sessions may also produce similar results. Further, considerations can be made for how this may also work for student sessions, using community members within education sessions to act as 'experts' and to place the interventions in context by discussing their own experiences.

The results of the adult testing sessions have provided insight into how effective serious games can be at improving knowledge of volcanic hazards, but also insight into the most effective methods of deployment. Use of the game as a stand-alone application can lead to improved knowledge gain, but by far the best method of use of the game with adults is in a peer-to-peer related education session, where participants can discuss thoughts and share experiences.

## 8.3. Communicating volcanic hazard information

The results of the implementation testing have so far demonstrated the games ability to improve players' knowledge of volcanic hazards and to motivate them to learn. However, this data has provided little insight into what aspects of the game were the most successful for improving knowledge gain. To consider what aspects of the game promoted the most knowledge transfer, the results of the in-built game analytics and the volcanic hazard map assessment are reviewed.

### 8.3.1. In-built game analytics

Game analytics are an effective way to gather large quantities of data from players, with little effort or input required (Serrano-Laguna *et al.*, 2014). During the implementation testing, analytics data was gathered only from the adult participants (*N* = 18) due to a malfunction with the game (further described in Section 7.3). The collected data were analysed to assess for strengths and weakness is the games design and to identify how effective the game was in engaging participants.

Currently, with game analytics only beginning to be adopted for this style of study, little research exists as to how useful they can be or how the results can be analysed. The method for analysis was therefore based more around initial indications that game analytics can provide, testing their ability to collect data and assess the quality produced.

Game analytics data obtained relating to the *volcano quiz* were analysed by factoring the number of questions answered correctly per category of volcanic hazard (pyroclastic flows and surges, lahars and ash fall and explosions). This information was expected to provide insight into how effectively information within the game was absorbed and applied during the *volcano quiz,* potentially providing an understanding of strengths and weaknesses within the game's design and identify possible areas for improvement. A difference was observed in the number of questions per hazard category answered correctly. For questions relating to lahars, participants answered 67% of questions correctly compared to 61% for lahars and 53% for ash fall and explosions, where figures are rounded (Section 7.5).

The data obtained from the *volcano quiz* was further broken down by question to assess if patterns could be identified between those questions mostly answered correctly or mostly answered incorrectly. Identifying patterns in the way questions were answered highlighted aspects of the game that were more effective at communicating information that others (e.g. where patterns identify more questions are answered correctly about lahars than ash fall, this may indicate that the method of communication of material is better for lahars than ash fall). Where a disparity of greater than four point score difference was observed between correct and incorrect answers, this was considered to identify a knowledge gap. The volcano quiz had a bank of 36 different questions from which six questions were posed at random. The results showed there to be two negative knowledge gaps where the question was answered more times incorrectly than correctly and four positive knowledge gaps where more questions were answered correctly than incorrectly. A breakdown of the questions that were identified with significant disparities are shown in Table 7.3.

| Positive disparity (correct > incorrect) | Negative disparity (incorrect > correct) |
|---|---|
| • Why are pyroclastic flows dangerous?<br>• Give the correct definition for a lahar.<br>• Where on the volcano does a plume originate?<br>• What key factor can affect which direction a plume spreads? | • What causes a plume to expand in size?<br>• What is volcanic ash? |

**Table 8.1. Summary of questions of noted positive and negative disparity from the volcano quiz obtained through game analytics data.**

When examined further, questions where more incorrect answers were recorded than correct answers related to questions that a level of conceptual understanding. For example, to understand why plumes expand in size, participants would need to know about the concept that hot air rises via convention. It seems unsurprising that participants were better able to adopt information relating to definitions over deeper conceptual information, something also widely observed in literature (van Berkum & de Jong, 1991; de Jong & Ferguson-Hessler, 1996). However, few conclusions can be drawn from this identified pattern as there are many factors that could have influenced this result. It should also be noted here that the questions within the *volcano quiz* were not designed to test knowledge or learning, rather to enable learners to apply their potentially acquired knowledge as part of the experiential learning cycle (Section 4.3.3). For future studies, the use of cognitive testing/interviewing (Ginet & Verkampt, 2007; Memon *et al.*, 2010) could be used to try and drawn qualitative data from participants' to triangulate the identified patterns from the game analytics data.

The results obtained through game analytics, although basic, demonstrate the ability to identify weaknesses in the game's design which can be corrected for future iterations, and also identify patterns of strength and weakness within participants' knowledge. The advantages of using game analytics means that outreach sessions can be tailored to their audience to ensure all required aspects of learning are covered sufficiently. This approach to learning in the longer-term means that the delivery of outreach sessions can be more efficient, targeting the areas of knowledge gap rather than covering information already well understood in at-risk populations. It may also identify areas where common misconceptions are deeply rooted within the population's knowledge, which can then be confronted and corrected during targeted and tailored outreach sessions. Further, with no additional instructor input required, game analytics can easily and cost-effectively be used to provide impact analysis for outreach activities. Although the data obtained during the implementation testing on St. Vincent was not sufficient to fully understand the extent to which impact assessments can be completed, further studies into this with larger cohorts of participants may shed more light on this problem.

### 8.3.2. Volcanic hazard map assessment

The St. Vincent volcanic hazard map (Figure 3.5) was integrated into the game design due to stakeholder user requirement feedback identifying it as a key source of information for the St. Vincent population. The map is presented as a 3D model within the game comprising a DEM overlain by the volcanic hazard map. Building upon existing research into public understanding of maps (Haynes *et al.*, 2007; Preppernau & Jenny, 2015), a 3D representation of the volcanic hazard map for St. Vincent within the game seemed a logical progression.

The importance of the map's inclusion within the game was particularly heightened as the map was revised in 2016 to upgrade the town of Fancy from the orange volcanic hazard zone to the red volcanic hazard zone. The new updated map had not been widely circulated at the time of its inclusion within the *St. Vincent's Volcano* game. Therefore, the integration of the map within the game provided a unique opportunity to understand how effectively the game could be at communicating existing outreach materials.

The volcanic hazard map was a popular inclusion with the game with participants noted to spend a significant amount of time manipulating the model. As part of the pre- and post-session knowledge quizzes, St. Vincent participants were asked to identify the volcanic hazard zones that encompass the three towns featured in the game. The results displayed in Figure 7.11 show that 87% of participants (both adults and students) achieved a positive score improvement between the pre- and post-session knowledge quizzes. This result is extremely encouraging in support for the use of more interactive and engaging methods of presenting existing outreach materials and their link to improved comprehension of the information.

The method adopted to test how effective the inclusion of the volcanic hazard map was within the game was rudimentary, only testing participants' abilities to link communities to hazard levels. The results demonstrated that 84% of student participants and 100% of adult participants registered a score improvement between the pre- and post-session knowledge quizzes for locating towns within volcanic hazard zones. Although basic, the results provide insight into the potential for using such engaging methods to present hazard information and informs the argument for their increased adoption with DRR. However, further, more comprehensive evaluation should be conducted to constrain how useful they can be when presented in a virtual environment.

For some participants the inclusion of the volcanic hazard map within the game was the first time participants had seen it at all. Currently, the hazard map is circulated annually to the public through printing in the telephone directory (Lowe, 2010) and through presentations provided to children during VAW. However, a study by Crosweller (2009) established that only 29% of participants involved in a risk perception study on St. Vincent had seen a version of the volcanic hazard map. Therefore, the results demonstrate a potential solution for the wider communication of the volcanic hazard map on St. Vincent, in a more engaging and interactive way.

### 8.4. Reflections on game design and development process

The process adopted to establish the design of the *St. Vincent's Volcano* game was based around the 4D framework developed by de Freitas and Oliver (2006), primarily due to a lack of existing methodologies for educational game design. The methodology proved useful in ensuring that most aspects of the game design were considered, such as the audience, interactions and underpinning pedagogy. However, to ensure the game was able to match to end-users needs, input was sought from both community groups on St. Vincent through focus groups and from disaster risk agencies through an online questionnaire. This aspect is missing from the 4D framework and proved the most useful in ensuring the game design was tailored to end-user requirements. Additionally, advice was sought from visualisation and gaming industry experts – *Shadow Industries*, as detailed in Section 4.4. The advice provided was invaluable for providing insight into the capabilities of gaming software and feasibility of the game design, which enabled the game design to be scaled to an achievable level, something that could not have been drawn from academic literature.

During the game development phase, feedback was constantly sought from the wider research team and members of SRC to ensure the developed game matched desired outcomes, was accurate and relevant. This collaborative approach to the game design was considered important as it builds on academic literature that highlights the importance of involving end-users in the development of disaster risk reduction tools (Paton *et al.*, 2008; Hicks *et al.*, 2017). However, due to the time restrictions during the game development phase, it was not possible to gather feedback from community members or students on St. Vincent. Therefore, the strong input from the online questionnaire respondent and the input from SRC members during the game design and development phase meant that the game produced was very much driven by the requirements and desired outcomes of disaster risk agency members, creating a bias within the study. To address this bias in future studies, it is recommended that a more community-driven approach is adopted for the design and development phase of the game. In particular, the game should be developed in collaboration with the target audience - students and adults on St. Vincent - who should be engaged in the process from an early stage.

Overall, the process for establishing key concepts of the game design was intuitive and straight-forward. Key successes of the game design process included the gathering of user requirement data from communities on St. Vincent through focus groups (Section 4.1.2), the adoption of the 4D framework and the development of detailed and specific storyboards for the final design (Appendix D). From this research, it is recommended for future studies of a similar nature that significant efforts are made to integrate end-users as much as possible during the game design and development process, ensuring the end product matches user requirements and expectations.

### 8.4.1. Game content

During the game implementation testing phase of the study, informal feedback was received from participants playing the game relating to the game's content. Some student participants indicated they found aspects of the game boring, such as the *hazard training* scenes where players are required to read snippets of information. One student even noted on their post-session knowledge quiz score that "*using the word 'game' is misleading, it is really just a presentation in a different form".* On the contrary, adult participants were generally positive in their feedback for the game's content, with many commenting on how they enjoyed the historical eruption visualisations the most.

As the game was primarily targeted at the younger students (~14 years old), this feedback potentially identifies that some aspects of the game design were not designed to match the end-users expectations, rather proving more engaging for adult participants. This negative feedback from some student participants may reflect the lack of input from students during the game design and development phase, with feedback and opinions only sought from adults from St. Vincent and agency members, as previously identified. Although considerations were made to ensure the game design was appropriate for the students on St. Vincent, no evaluation was conducted with students during the game design or development. Students from the University of Plymouth were involved in later testing of the game but only provided feedback on usability and functionality of the game rather than content and style (Section 4.5.1). To further enhance the game as a learning tool, focus groups could be held with students on St. Vincent considered to be the target audience (~14 years old in secondary school education). Their feedback, thoughts and opinions should then be integrated into the game to focus the content to match their expectations.

For this initial version of the *St. Vincent's Volcano* game, the game content was sufficient to provide rudimental evidence to support the wider use of serious games with at-risk communities. However, considerations should be made for how the content can be improved to make it more appropriate and contextualised for the end-user. One such example of how this could be achieved for the *St. Vincent's Volcano* game is through the integration of the volcanic hazard scenario maps formally presented in as Figure 3.4. Currently, the game presents participants with their levels of exposure to volcanic hazards (receptor), before going on to present the volcanic hazards that may affect them in the future (source); however, in its current form, the game does not provide a 'pathway' to link the hazard to the level of exposure, meaning no logical progression of source-pathway-receptor exists. Considerations for future iterations of the game should consider the integration of information which links the hazard to the vulnerable communities, presenting a full picture of risk.

### 8.4.2. Game usability

Although affordances were made within the game design to facilitate its overall flow and usability, throughout implementation testing, numerous challenges were encountered relating to the usability of the game. Students often became frustrated with delays within changing scenes which affected their flow. Some students reported poor quality graphics and issues with loading scenes or even the game itself. Although specifications for the students' laptops were obtained prior to implementation testing, adjustments made for the game to improve performance were not sufficient. Further testing should be conducted with the game to ensure it is able to efficiently run on various specification of computers.

In general, most participants found navigations through the game difficult and unintuitive. This issue was raised within the initial usability testing conducted with Plymouth University students and the layout was altered to improve this. However, some affordances made within the game design (e.g. coloured lights and symbols over town names and a side menu) were insufficient at improving usability. Due to time constraints prior to the implementation testing on St. Vincent to make further adjustments to the navigation, it was decided that the use of guidance notes and direction from outreach instructors may be able to alleviate the issue for the trials. Therefore, a guidance sheet was provided to participants (Appendix C) and direction and guidance was provided by the outreach instructors.

For future iterations of the game, significant consideration should be made for the navigation and usability of the game. It is considered likely that the poor navigation and other issues encountered may have affected participant's motivations to continue playing the game, resulting in a lower knowledge gain potential (Ricci *et al.*, 1996; Garris *et al.*, 2002).

### 8.5. Implementation strategy

In this section, reflections are provided on the method and processes adopted during implementation testing. Firstly, the method of participant recruitment is discussed which is considered a particular success of this study. Second, some of the challenges that were encountered during the implementation testing with students on St. Vincent and discussed with reflections provided on how they may be overcome during similar studies in the future.

#### 8.5.1. Participant recruitment

On attendance on St. Vincent, discussions were held with members of NEMO who viewed the game and suggested methods to assist with recruitment of participants. With the support of NEMO, the Ministry of Education were asked to assist with the recruitment of schools for the game trials on St. Vincent. They sent an email to 13 secondary schools in St. Vincent via the schools circular (an email communication chain) to ask for their involvement in the game trials during VAW. They advised on the requirements to run the session (e.g. students to bring laptops) and encouraged full cooperation. The Ministry of

Education were also instrumental in gaining access to schools and providing ethical clearance prior to the intervention sessions. A letter was provided from the Ministry of Education demonstrating support for the research (Appendix I).

For adult participant recruitment, NEMO suggested asking community leaders to assist with inviting participants and arranging a suitable location within the communities to run the sessions. Contact was made with 4 community leaders who agreed to assist with setting up the sessions. The support of the community leaders was invaluable in arranging the adult trials within the short timeframes available. This approach to adult recruitment ensured that participants attended sessions willingly and without feeling pressured to attend. This combined support and willingness to help with participant recruitment from both agencies and community leaders was instrumental in ensuring the study aims could be achieved.

### 8.5.2. Session challenges

Prior to conducting the implementation testing on St. Vincent, consideration was given to how the game could be used in intervention sessions. However, communication with disaster risk agencies in St. Vincent proved difficult prior to arrival on the island and little information was available as to the format of Volcano Awareness Week and the potential for using the *St. Vincent's Volcano* game in outreach sessions. With little information available prior to the implementation testing on St. Vincent, it proved essential to approach the sessions in a dynamic manner.

Of the 13 schools visited on St. Vincent, data was only recorded from six due to either: large session sizes that proved difficult to run the game (one session had over 100 students in attendance); lack of facilities available (e.g. computers or even electricity); or a lack of time available to complete the sessions. Where these issues were encountered, the testing strategy had to be adapted to try and gather data from the sessions without comprising the education provided. This led to the adoption of the four session types (game only, presentation only and game and presentation over one or two sessions) as previously discussed in Section 6.2.1. The type of session delivered was decided based on the number of students and the time available at the beginning of each session to gather meaningful data.

In one school visited during testing, no electricity was available to power students' laptops or teaching equipment. No data could be meaningfully gathered from this session as the session conditions were not comparable with other schools (e.g. they were not provided with the same information such as the volcanic hazard map), therefore this would have added an additional variance into the study data. Where issues were encountered within schools that could not be overcome, it was considered more important to provide a robust session on volcanic hazards using traditional approaches that to try and gather data from the sessions and comprise the education provided.

The challenges encountered during the implementation testing provide valuable insight for researchers considering conducting a similar type of study with communities where similar conditions may present themselves. Some of these challenges can be overcome with the adoption of a flexible testing strategy that can be adapted easily to ensure no compromise to the education session, but still enabling the required amount of data to be obtained. One such example was the adoption of digital pre- and post-session knowledge quizzes for the sessions where large numbers of students were present, overcoming the challenges associated with administering manual versions. Some of these challenges may have been realised sooner if discussions and better collaboration with disaster risk agencies and education and outreach practitioners were conducted earlier. These parties may have been able provide information of expected conditions during the testing sessions.

## 8.6. Review of data collection methods

This research adopted a mixed-methods approach to the data collection, combining both qualitative and quantitative methodologies. The methods selected were chosen based on their successful usage to collection data from similar types of study (Vile Junod *et al.*, 2006; Dohaney *et al.*, 2012) (Section 6.3). This section provides a critical review of the data collection methods adopted and presents some suggestions for alternative data collection methods that could be used in the future.

The results of the pre- and post-session knowledge quizzes have proved the most successful in terms of their use to demonstrate knowledge and learning gain. Overall the quality of data gathered has been sufficient to achieve the aims of this research. The methods adopted proved simple to apply during the implementation testing sessions, producing a large quantity of data. However, the method can be prone to limitations and bias as previously mentioned in Section 6.3.1.

One such limitation of the data collection method can be the attitude of the students on that particular day of testing. For example, if a student is having a bad day, their results from the pre- and post-testing may not be representative of that student's abilities on a good day. Another example of the ambiguities that may exist in the data is due to the participants having already completed a pre-session knowledge quiz before their intervention, with the expectation of also completing a secondary quiz after the activity. This can lead to students focusing on only learning the necessary information to achieve good marks on the test rather than obtaining a deeper knowledge on the subject and thus a reduced motivation (Hartley, 1973). Samuels (1969) demonstrated that students who received a pre-test that comprised relevant information for the post-test were able to attain a higher score on their post-test. This shallow learning is commonly seen in pre- and post-testing and can bias the data obtained (Bellotti *et al.*, 2013b). Therefore, the results obtained may not be a true reflection of the students' abilities as they represent a snapshot data collection.

One method to overcome this limitation is to conduct a longitudinal study to establish the deeper knowledge retention of the students in the longer term. A one-year on data set was obtained as part of this research to provide some insight into longer-term knowledge retention (Section 8.2) but a data set with even long repose period would be beneficial to examine knowledge retention further.

The use of pre- and post-testing for this research proved successful in obtaining a robust and expansive data set and was simple and straight forward to implement. For an initial study such as this one the method is suitable to provide an understanding of the game's effect on learning gains, however, the data collection method could have been improved to try and match the innovative style of intervention session being implemented. For example, a more creative approach to the data collection method could have been adopted by including more interactive aspects of the quizzes such as diagram annotations rather than simple question and answer style. One creative data collection method could be the use of outcome stars, a rating based scale which asks students to reflect on their own knowledge and behavioural change, when provided with topics (MacKeith, 2011). This data collection technique would also enable data collection from very large groups of students or where time is too limited to run full formal evaluation, a challenge encountered during this research (Section 8.2.2).

The results of the pre- and post-session knowledge quizzes highlight that the quizzes provided were too difficult for all participants to answer, with the maximum score of 40.1% recorded for an adult participant on a post-session knowledge quiz. To try and mitigate this outcome in future studies, prior to the main implementation testing, cognitive testing/interviews should be conducted with a small group of participants. This method is designed to establish if the questions were understood by students in the same way as the research team expected. Cognitive testing asks students to verbalise their answers proving insight into both how effective the survey is, but also how students approach the answer (Drennan, 2003; Beatty & Willis, 2007). Utilising cognitive testing can not only help improve the questions used and ultimately the robustness and quality of the data produced (Jobe & Mingay, 1989) but also provide supplementary data collection.

The most significant issue encountered during this research was the level of data that was removed from the pre- and post-session knowledge quizzes based on evidence of students cheating. Cheating by participants constituted either using the internet or copying answers from neighbours quizzes. Participants were explicitly told to not discuss their answers to the quizzes with neighbours, to use their phones or laptops to look for answers (including the game), with the importance of the completing the quizzes constantly reiterated to the participants. Despite this, 22 St. Vincent student and one adult data sets from the 2015 data collection were removed from the study due to evidence of cheating. In some cases, participants' answers were a direct copy from the internet or identical to other participant's answers. All quizzes where participants' answers showed evidence of cheating were removed from the study to ensure reliability of the data used during the analysis. Interestingly, no UK student data sets were removed for evidence of cheating. This may be due to the more exam-like conditions adopted during the pre- and post-testing resulting in less opportunity to copy answers from friends. Therefore, for researchers considering a similar line of research, it would be prudent to ensure all participants manually complete knowledge quizzes under exam-like conditions (where possible), and emphasise the importance of the research which the participants are undertaking and their role within the study.

### 8.6.1. Data collection method bias

One additional bias that may remain in the St. Vincent student data set relates to the set-up of the student sessions. Firstly, the presentation only session comprised just eight students compared to 65 for game playing students; secondly, the game only and presentation only sessions both only used one class of students respectively, with two different classes of students used for both session styles C and D. These factors may mean that the samples of students from the game only and presentation only sessions are not representative of the wider St. Vincent population.

Despite the low number of students within the presentation-only session, the results provide a comparison point for the other intervention sessions, regardless of the student numbers present. The use of comparison groups is essential for proving validity of the research and help to establish the effect of varying intervention styles (Marsden & Torgerson, 2012).

In general the data collection methods adopted for this initial study proved successful in gathering large quantities of robust and compatible data that was able to provide insight as to how effective serious games may be as an education tool. However, the data collections such as the pre- and post-session knowledge quizzes proved boring and laborious for participants to complete. Therefore, it is recommended that for future studies a more creative and engaging approach to data collection, particularly with students, is considered. A deeper level of qualitative data would also be beneficial to the study. Further, to truly provide a robust comparison of the intervention styles adopted during this study and to measure the comparative effect of each of these methods, a quasi-experimental evaluation approach should be adopted, such as randomised control trials (RCTs) using a treatment and non-treatment group (Hutchison & Styles, 2010).

## 8.7. Serious games for volcanic hazard education

This study sought to provide insight into the use of serious games as education tools with education and outreach sessions with at-risk communities; seeking to build the empirical evidence base for their use. The results of the study were able to provide evidence to support the use of serious games in certain contexts, demonstrating improved knowledge and learning gain and their ability to encourage active engagement. With serious games currently being used to educate at-risk populations, this research has proved timely to provide insight on the effect they may have on knowledge gain and learning about natural hazards.

The results demonstrated that the *St. Vincent's Volcano* serious game was able to improve participant's knowledge of volcanic hazards, whilst also promoting active engagement. This finding adds to the body of academic literature that discusses the positive links between education and outreach interventions on improved knowledge and awareness of recipients (McKay, 1984; Johnston *et al.*, 1999; Paton *et al.*, 2000; Ronan & Johnston, 2001; Ronan & Johnston, 2003; Haynes *et al.*, 2007; Paton *et al.*, 2008). This improved knowledge was also noted in the longer-term among some participants demonstrating the game's potential at promoting knowledge retention, although with some longer-term knowledge degradation noted. For this initial study, the game was designed to test one aspect of disaster risk reduction, namely awareness of volcanic hazards, the study is not able to contribute to the debate on whether this improved knowledge and awareness resulted in an increase in participants adopting preparative measures. However, this highlights a key area for consideration for future studies of this type.

Education literature suggested that the use of serious games is more likely to promote an active type engagement, which may promote learning and motivation to learn (Wouters *et al.*, 2013). However, the opposite trend was observed within the St. Vincent student data set, with the results demonstrating that game-playing students achieved higher levels of active engagement but lower levels of knowledge and learning gain. Further, students who received the presentation as part of their session generally out performed game playing students. This trend could be contributed to the role of the instructors within the presentation sessions, who were able to provide structure, but also encourage positive engagement through their interactive teaching methods. This is of significance to the DRR community as it suggests that the instructor plays a leading role in driving the outcomes of the intervention sessions, meaning that the more motivated participants feel to learn by instructors, the higher the levels of knowledge and learning achieved. Therefore, careful considerations should be made when developing DRR education and outreach programmes to ensure that instructors play a leading role in motivating students to learn and promoting positive engagement.

An unexpected result of this research is the ability of serious games to promote knowledge gain amongst at-risk adult populations. St. Vincent adult participants actually outperformed their younger counterparts in terms of learning gains achieved from the game sessions, despite the game not being designed for use with adults. The game was also observed to promote active engagement and act as a buffer for participants to share personal experiences and knowledge. This finding builds on existing research which highlights the importance of sharing experiences within at-risk communities at promoting improve hazard awareness (Hicks *et al.*, 2017). One of the most interesting observations from the adult sessions was how playing the game sparked emotive memory recall among some participants, with them remembering vividly the events of the 1979 eruption and their personal experiences. This strong emotive memory could be used with DRR practices to encourage learning through shared experiences. For example, community members who have previous experience of volcanic eruptions can be used as ‘experts’ to assist with education programmes, provide context to the learning and promote active engagement.

One success of the game was its ability to increase knowledge and exposure of participants to existing outreach and education materials. The integration of the volcanic hazard map for St. Vincent was a particular success with 87% of participants demonstrating improved knowledge of the map post-intervention. However, at this stage the research has only provided a basic insight into the potential of gaming environments to present such information. The integration of existing outreach materials within gaming environments could present an ideal platform for DRR practitioners to increase exposure to such materials. If released across a public platform or even used as a teaching tool to support curricular studies, the level of organic reach and exposure to outreach information would increase. Games are a novel media and there is a possibility that by integrating existing communication materials for natural hazards such as hazards maps and diagrams, this could not only reach a higher percentage of the population but also lead to an improved understanding of those materials. These findings reflect those identified from the literature (Haynes *et al.*, 2007; Preppernau & Jenny, 2015) and further add to the position that the adoption of more realistic and relatable maps, such as 3D maps or oblique images, could lead to an improved knowledge and understanding of those materials for at-risk communities.

Overall, this research has provided a base of empirical evidence that supports the use of serious games for education and outreach of at-risk communities. However, careful considerations should be made for how they are designed and developed, with communities and disaster risk agencies collaboration essential to ensure they are relevant and appropriate for their end-use. When presented in a supported and instructor-led environment, serious games can be successful at achieving knowledge gain and learning whilst promoting positive engagement.

# CHAPTER 9: Conclusions and further work

This research has sought to establish how effective video games may be as an education tool with at-risk communities. The research has arisen from an increase in the use of creative media, including video games, for natural hazard education, despite there being little empirical evidence to support their use. This chapter seeks to draw final conclusions on the use of video games by revisiting each of the initial research objectives outlined in Chapter 1 and providing an overview of how these objectives were met. The chapter then reflects upon the wider potential use of video games and concludes by identifying some of the limitations of the study and suggesting some areas for further work.

## 9.1. Reflecting on the research aims and objectives

The overarching aim of this research (as outlined in Section 1.2.) was to establish how effective, video games or serious games could be when used as an educational tool for volcanic hazards with at-risk communities. This research aim was broken down into a series of objectives each of which are addressed in this section.

### *9.1.1. Design and development*

The state of the art for creative communications in natural hazard education was outlined within Chapter 2 of this work (**Objective I**). A review of the literature identified that there is common acceptance of the linkage between successful education and outreach with at-risk communities, and improved knowledge of natural hazards (McKay, 1984; Johnston *et al.*, 1999; Paton *et al.*, 2000; Ronan & Johnston, 2001; Paton *et al.*, 2008), although there is strong debate on whether improved knowledge can lead to improved resilience through the increased level of the adoption of preparative measures (Johnston *et al.*, 1999; Fişek *et al.*, 2002; Paton *et al.*, 2008). However, with the inception of the Sendai Framework which has a mandate for strengthening public awareness education and awarenes in DRR (UNISDR, 2015a), there is now a common and unified acceptance that education and outreach programmes need to become more effective at reducing people's vulnerability to the impact of natural hazards.

A review of the literature identified that there was a shift towards the adoption of creative media for natural hazards education and outreach programmes, using examples of films, board games, puppet shows and comic strips (Sharpe & Izadkhah, 2014; Watt, 2015; Mossoux *et al.*, 2016; Hicks *et al.*, 2017). This shift is thought to be a result of practitioners seeking to overcome common barriers encountered when educating at-risk communities, such as illiteracy and diverse languages. Education literature also identified that the younger generation today are frequently characterised by a more technological way-of-life, with information fed to them directly, on-demand through portable devices (Prensky, 2001; Carlson, 2005; Annetta, 2008; Bekebrede *et al.*, 2011; Sharp, 2012). This has also led to an increased demand for the use of creative media within education practices in general, particularly for video games as a method to engage this new generation of learner (Bekebrede *et al.*, 2011).

Examples of the use of video games adopted in DRR practices are UNISDR's *Stop Disasters!* and UNESCO's *Sai Fah: The flood fighter* games, used to educate communities about the impacts of natural hazards and how to prepare. However, to-date, these games have not been evaluated to establish if they are effective in achieving their aims of improved knowledge of hazards with at-risk communities. This was also echoed through other creative media with very little empirical evidence that has emerged to demonstrate the effectiveness of these new methods.

A further review of the literature, combined with an examination of existing video games used for education purposes (Chapter 2) identified key aspects of game design that could promote engagement and ultimately learning (**Objective II)** (Lee *et al.*, 2004; Gee, 2005; Kiili, 2007; Johnson, 2008; Wang & Sun, 2011). These aspects included:

- Reward systems and level ups to motivate the player;
- Stimulation of visual and audial senses and integration of kinaesthetic (hands-on) aspects to engage with all learner types;
- Instantaneous feedback to correct any misunderstanding and to reinforce the learning message;
- High levels of interactivity (e.g. clickable icons and media) to keep player engagement;
- Integration of game analytics to automatically evaluate how effective the video game works and identify areas for improvement.

These identified aspects of successful games were adopted, where possible, into the *St. Vincent's Volcano* game design and development The game design process was approached in three stages (**Objective III**).; establishing user requirements, integrating historical eruption data and the 4D framework for learning (de Freitas *et al.*, 2010) (Chapter 4).

Data obtained from a stakeholder through an online questionnaire and through community focus groups identified key themes and content considerations for the game design. This proved an essential phase in the game design stages, suggesting ideal platforms, durations and content along with expectations of how the game would be used. Although one response was received from agencies on St. Vincent, the respondent was a key player in natural hazard education in the Eastern Caribbean and was able to provide a significant level of information based on their wealth of knowledge and experiences. However, this remains a limitation of the study. Collaborating with agencies and community groups from the outset of the game design phase ensured that the game developed was appropriate, relevant and met expectations of the end-user groups. This collaboration continued with St. Vincent disaster risk agencies through the development phase, who provided continual feedback and input. This collaborative approach was invaluable for sculpting the final game design and reflects key academic literature that identifies that a participatory approach to the development of DRR tools can lead to greater knowledge and awareness of natural hazards (Paton *et al.*, 2008; Hicks *et al.*, 2017). Participation of agencies and communities in the design phase of the game was also highlighted by Hicks *et al.* (2017) as essential to ensure longevity of use.

The next stage of the game design process was to gather data of previous volcanic eruptions of the La Soufriere volcano from the literature to inform the game design. This was to ensure the visualisations within the game were as realistic and accurate as possible to the events of both the 1979 and 1902 eruptions. Considerations were then made through the adoption of the 4D framework for learning, covering aspects of mode of representation (e.g. fidelity, realism and interactivity) and integration of a sound pedagogic underpinning achieved through integration of experiential learning and cognitive load theory (Table 4.3). The 4D framework proved integral to the game design phase to ensure that as many considerations were made for player interaction and achieving the games aims as possible.

Finally, once all considerations were made for the game content, the final design was detailed in a series of storyboards to be used as a communication tool between the research team and the game developers (Appendix D). The storyboards comprised significant detail on the look-and-feel, the flow, the navigation and included all game text and audial inclusions. The storyboards were used to facilitate the game development which was completed iteratively and guided by continual feedback, input and critique from the research team. This approach meant that the final visualisations looked and behaved as close to reality as possible increasing the game's fidelity and realism.

Overall the phased approach to the game design and development ensured that the final game matches, where possible, the desired outcomes and expectations of the end-users. Improvements to this method can be made by better collaboration with community members and students on St. Vincent to ensure the game is as usable and relevant as possible for the end-users, without being driven too much by the desires of the research team or disaster risk agencies.

### *9.1.2. The implementation strategy*

Once completed, the game was implemented with students and adults in St. Vincent and students in the UK to establish how effective it was for improving participants' knowledge of volcanic hazards. The recruitment method used was of a particular success, with support from both NEMO and the Ministry of Education proving invaluable to recruiting schools to take part in the study as part of VAW. The use of community leaders for adult recruitment was also particularly successful and ensured that adult participants attended based on their own willingness to participate, rather than feeling pressured to attend.

Data was collected through a mixed-methods approach (**Objective IV**); combining both qualitative and quantitative methods to identify if knowledge gain was achieved, the levels of engagement exhibited by players and ultimately how well the game worked as a learning tool. The data collection strategy for evaluation comprised:

- Pre- and post-session knowledge quizzes consisting of 12 open-ended questions relating to the formation, behaviour and definitions of volcanic hazards. This data was collecting for varying groups of participants:
    - All student (including the presentation only outreach sessions) and adult participants in St. Vincent
    - UK students for a cohort comparison to St. Vincent student participants
    - One year later from  participants from the initial 2015 St. Vincent cohort
- Video observations for student sessions to be observed for behavioural characteristics identifying either positive or negative engagement.

- General session observations with adults to identify common behaviours demonstrating either positive or negative engagement.
- In-built game analytics (adults only) to draw data about the strengths and weaknesses of the game design

Within educational gaming literature, there were few examples of mixed-method data collection strategies for assessing the effectiveness of serious games. Therefore, this strategy was developed based around best practice and methodologies employed in wider educational literature (Vile Junod *et al.*, 2006; Dohaney *et al.*, 2012; Westera *et al.*, 2014).

Pre- and post-testing is commonly adopted to measure initial change and effect of intervention sessions and was considered the most appropriate method to collect large quantities of data from participants (Papastergiou, 2009; Habgood & Ainsworth, 2011; Bai *et al.*, 2012; Iten & Petko, 2014; Green & Bavelier, 2015). The collection of a secondary post-intervention data point one year after receiving the outreach sessions also provided some insight into the longer-term knowledge retention of participants who played the game.

Video observations made using the BOSS model (Shapiro, 2004) provided a detailed overview of the positive and negative behavioural characteristic whilst playing the game, whilst also proving a robust methodology with between 86-96% agreeance in coding between sampling repetitions.

In-built gaming analytics proved a less successful data collection method with a small data sample obtained for adult participants due to a malfunction. This indicates there may be issues relating to robustness of this data collection method but, if this can be overcome, game analytics are able to collect large quantities of data with little input required.

The combined approach to the data collection was overall able to provide a robust and extensive data set, from which patterns and trends could be identified. The quality of data produced was able to provide insight into how effective serious games were as an education tool. However, considerations should be made for similar studies to adopt more creative and engaging methods of evaluation that match the style of intervention sessions. Further, for a deeper comparison of serious games to other educational techniques quasi-experimental evaluation should be adopted.

### *9.1.3. Research findings*

The results of the data collections were used to provide understanding of how effective serious games could be for improving knowledge of volcanic hazards with at-risk communities; if they promoted positive engagement; how well they perform against a more traditional outreach session; and what is the best method of their use as outreach tools (**Objective V**).

Firstly, the game was successful in improving knowledge of volcanic hazards for 90% of participants who played the game. However, when the results were considered in terms of learning gain (Hake, 1998), it was noted that student and adults from St. Vincent achieved a similar level of learning, despite the game having not been designed for adult engagement. Further, when the student data was broken down by session type (Section 6.2.1), surprisingly, the sessions that comprised the presentation session either independently or combined with the game achieved significantly higher levels of learning than game-only sessions.

This trend is of particular interest as academic literature suggests that games are able to promote a more active-type engagement of learners which is instrumental for promoting learning (Benware & Deci, 1984; Ryan & Deci, 2000; Prince, 2004; Vile Junod *et al.*, 2006). Although higher levels of active engagement were recorded for student sessions, overall the levels of postivie engagement were lower than that of the presentation only students, who recorded 100% passive engagement.

Considerations were made for the role of the instructor as an influence on the unexpected session results. Although unsupported by examples from academic literature, the engaging and animated approach to the presentations conducted by members of SRC were considered to promote positive engagement, provide structure and remove possibilities for negative behavioural characterisitics to be exhibited. Therefore, it is concluded that the role of the instructor within outreach sessions may have an impact on the levels of postive engagement and thus, through their leadership and encouragement, they are able to promote higher levels of postive engagement (although passive), ultimately resulting in improved knowledge gain and learning.

Post-session knowledge quiz data collected from nine student participants one-year after their initial interventions in 2015 were used to identify the longer-term knowledge retention and learning potential from the *St. Vincent's Volcano* game. The results demonstrated that although there was some degradation of the data that in general, students' knowledge of volcanic hazard was still higher than prior to receiving the interventions. This result provides insight for education and outreach practitioners as it demonstrates the importance of repeat intervention sessions to ensure knowledge levels are maintained – similar to the approach adopted for First Aid training (Anderson *et al.*, 2012).

The final significant finding from this research was the ability of the *St. Vincent's Volcano* game to improve participants' knowledge of existing outreach materials. The volcanic hazard map was integrated into the game design after research into understanding of maps with at-risk communities identified that participants were better able to understand 3D maps over traditionally used 2D maps (Haynes *et al.*, 2007; Preppernau & Jenny, 2015). The inclusion of the map proved successful at improving participants' knowledge of the map with 87% of participants registering knowledge improvement. Although the results are rudimental for this initial study, the findings are promising for demonstrating how effective the use of virtual environments and serious games could be for presenting existing outreach materials. Further, this may of significant to DRR practices as games could be used to enhance public exposure to existing materials.

### *9.1.4. Recommendations issues and challenges*

Throughout this research, many of the issues and challenges from the design, development and implementation phases have been identified with recommendations for future researchers also provided (**Objective VI**) (Table 9.1).

| | Issue, challenge or problem | Recommendation |
|---|---|---|
| **A** | Navigation and flow of the game design | Collaborative approach to game design is essential to overcoming potential issues. Cognitive testing should be conducted with the target audience to ensure the games intent matches its outcome with the end-users. |
| **B** | The lack of facilities available in schools to run implementation testing e.g. laptops/computers. | A dynamic approach to the implementation strategy. Where little facilities exist, to implement the game sessions can be run with participants playing in pairs or even as a whole group. |
| **C** | Large student numbers within outreach sessions proving challenging for data collection | A dynamic approach to data collection and using online data collection media and more innovative approaches to evaluation (e.g. outcome stars). |
| **D** | The compulsion of participants' to cheat when completing their pre- and post-session knowledge quizzes. | Reiterating to students the importance of the study and their own answers. Also collected knowledge quizzes under 'exam' conditions with phones deposited in a box at the beginning of the session. |

**Table 9.1. Summary of key issues, problems and challenges faced throughout the design, development and implementation phase of the research; with recommendations made for future researchers.**

## 9.2. Reflections on the potential wider use of serious games

This research has focused on the potential uses of serious games for education and outreach purposes for volcanic hazard education, however the findings of this study may have broader applications. Serious games are being adopted broadly across natural hazards education practices and this research is timely in providing reflections on their wider application. The findings of the study, some of which contradict educational literature (e.g. active engagement did not lead to improved knowledge), can be used to inform the education gaming arena, particularly around the potential influencing factors that may exist for the observed trends. Further, this study has also highlighted key issues associated with the use of serious games with at-risk communities, but has also provided a rich source of recommendations for practitioners seeking to use them.

Although this study has focused on the use of games for volcano education, the findings highlight that in general games can lead to improved knowledge of a targeted subject with at-risk communities. Therefore, the application of games such as *St. Vincent's Volcano* could be widespread through natural hazards education. For example, a logical progression for the use of serious games is across other natural hazards, such as earthquakes or hurricanes, which may affect large populations. Serious games released over an open platform (e.g. through social media or app stores), may enable greater exposure of at-risk communities to potentially lifesaving information. Beyond natural hazards, the findings from this research have identified how the novel use of serious games can be successful in engaging young people in education sessions. Other applications for their use with at-risk communities could be to improve knowledge and awareness for topics such as landmines, living in conflict zones or healthcare issues such as the spread of Ebola.

Additionally, the results of this research have identified the ability of serious games to achieve knowledge improvement amongst at-risk adult populations, often considered one of the most difficult demographics to engage with natural hazards education. Release of educational games for at-risk communities across a broad range of platforms, could mean they provide a unique opportunity to engage with these hard-to-reach communities. Further, once the initial expense is outlaid for the design and development of the serious game, there are few costs associated with their continued use of video games once released.

### 9.3. Limitations of the study

Due to the broad ranging nature of this study, there are limitations that must be considered. Firstly, the constraints associated with sample size and diversity. The presentation only session comprised a sample size of just eight participants from the same school. Further, both the presentation only and game only sessions were conducted with one class of students respectively, compared to two classes for the combined game and presentation sessions (e.g. two classes for C and two different classes for D). This may mean that small sample size and use of just one class of students may not be representative of the wider St. Vincent student population, although is still able to provide a useful insight into the effectiveness of the game as an education tool.

Additional limitation for sample size were reflected in the lack of male participants' involved in the adult implementation testing, which led to an over representation of female participants. Further, the adult education level was also considered to not be representative of the St. Vincent population due to the sampling strategy for the Kingstown session which invited members of the Ministry of Agriculture, Farming and Fisheries to participate who comprised predominately females educated to undergraduate level qualifications.

Due to the high expense associated with the design and development of serious games, the *St. Vincent's Volcano* game could not be developed as a complete disaster risk reduction tool. It was decided to focus on the games ability to improve knowledge of volcanic hazards instead of trying to also integrate measure for preparedness. Therefore, this research is not able to provide insight into whether serious games can be used to encourage and enhance the adoption of preparedness measure for potential future volcanic eruptions, however, this presents an area of research for future studies.

The high associated costs with game development also meant that some aspects of the game design were minimal and simplistic, compared to what may be achieved with a larger budget, resulting in slightly less sophisticated game than anticipated. This means that the results of the implementation testing only reflect the use of the *St. Vincent's Volcano* game and may be different if a higher-specification, more expensive game is used for the same application.

### 9.4. Further work

This research has explored how effective video game can be when used for volcanic hazard education and outreach programmes. As a result of the outcomes of this study, several recommendations for further work can be made to further understand the potential for using serious games in volcanic hazard education.

- A logical next step for this research is to evaluate the effectiveness of video games when applied to other natural hazards (e.g. hurricanes, earthquakes and flooding) with at-risk communities.
- This research has explored how effective serious games can be at improving players' knowledge of volcanic hazards. However, it has not been possible to explore how effective serious games can be at preparing communities for volcanic eruptions. Therefore, a future direction for research into the use of

serious games with at-risk communities is to establish how effective they can be at encouraging communities to prepare for future volcanic hazards or natural hazards in general.

- Future research can also provide further insight as to how effective serious games are as a learning tool when compared to over creative communication techniques (e.g. films, board games and comic strips), through the adoption of quasi-experimental evaluation techniques.
- Finally, future research can also provide further insight into the potential longer-term learning potential of serious games with at-risk communities and identify the most effective method of enhancing knowledge retention. This could include a comparison to traditional outreach methods and other creative communication techniques.

## APPENDIX A: Stakeholder online questionnaire outline

### A. Basic Information

Your information provided in this section is for research purposes and will not be viewed by anyone other than the research team. These questions just help the research team to understand who you are and what your role is in the organisation of which you are a part.

A.1 Name:
A.2 Organisation:
A.3 Briefly describe your role:
A.4 How long have you held this role?

### B. Outreach Activities

These questions are designed to understand the current outreach you conduct relating to volcanic hazards on St. Vincent.

B.1 What volcanic hazard outreach activities does your organisation currently carry out on St. Vincent?
B.2 Are you involved with public outreach programs and in what capacity?
B.3 How often are these outreach activities conducted?
B.4 How long typically do these outreach activities or events last?
B.5 Who are these outreach activities most often targeted for? (Demographic, age-range, schools etc.).
B.6 Does your organisation collaborate with other organisations to conduct volcanic hazard outreach activities and with which organisations do you collaborate?
B.7 How does your organisation follow up outreach activities? Do they currently measure impact from such an event and how?
B.8 Do you use or have you used any video games within your current natural hazards (not exclusive to volcanic hazards) outreach activities and for what purpose?

### C. Communication

In this section the questions relate to your experience of current methods for volcanic hazard communication.

C.1 What do you consider to be the most important information for your organisation to communicate to the public?
*Options to select: hazard maps and their implications, volcanic activity alert levels, precursory activity, potential volcanic hazards and their effects, protective measures, evacuation locations and safe zones, severity of historical eruptions and activity, other (please state).*
C.2 What methods of communication have you used?
*Options to select: maps, photographs, workshops, media platforms (newspapers, radio), school visits, website/internet, public seminars, other (please state).*
C.3 What do you think are the main challenges in effectively communicating volcanic hazard information?
C.4 To what extent do you think the general public are aware of the specific hazards related to volcanoes and how they relate to Soufriere on a scale or 1-10? (1 = Unaware; 10 = Very aware).

C.5 How would you rate the general publics' overall preparedness for a volcanic eruption at Soufriere on a scale of 1-10? (1 = unprepared; 10 = Very well prepared).

C.6 From your experience, do you think there are communities or groups of people on St Vincent that are more prepared than others and if so, why?

C.7 In what ways might using video games technology as an education tool complement or extend on the current methods of communication?

**D. User Requirements**

These questions are related to what you would like or would be looking for in the finished product.

D.1 What platform do you think will be the most suitable for use in St. Vincent and why?
*Options to select: desktop/PC, mobile device (tablet, cell), internet, other (please give detail).*

D.2 How do you envisage a video game such as this could be integrated into volcanic hazard activities?

D.3 How long do you think gameplay should last?

D.4 Visualisations within the game will be created for 4 communities. Please identify which locations on St. Vincent you think would benefit the most from these visualisations. (Please rank with 1 being the highest priority location).

D.5 During outreach sessions, is the game more likely to be played individually in small groups or both and why?

**E. Information to include**

E.1 Volcanic Hazard Information

| | **Not relevant** | **Slightly relevant** | **Relevant** | **Important** | **Very Important** |
|---|---|---|---|---|---|
| Ash plumes | | | | | |
| Ash fallout | | | | | |
| Lava flows | | | | | |
| Lava domes | | | | | |
| Pyroclastic flows (density currents) | | | | | |
| Precursory earthquakes | | | | | |
| Gas emissions | | | | | |
| Lahars (volcanic mudflows) | | | | | |
| Volcanic bombs | | | | | |

E.2 Usability

| | **Not relevant** | **Slightly relevant** | **Relevant** | **Important** | **Very Important** |
|---|---|---|---|---|---|
| Interactivity | | | | | |
| Engagement | | | | | |
| Entertainment | | | | | |
| Problem-solving | | | | | |
| Realisation | | | | | |
| Flow | | | | | |
| Mastery | | | | | |
| Rewards | | | | | |
| Motivation | | | | | |

E.3 What do you deem to be the most important aims for a game such as this?

| | **Not relevant** | **Slightly relevant** | **Relevant** | **Important** | **Very Important** |
|---|---|---|---|---|---|
| Raising awareness of existing volcanic hazard map | | | | | |
| Raising awareness of existing volcanic activity alert levels | | | | | |
| Improving knowledge of volcanic phenomena | | | | | |
| Explaining how volcanic phenomena can affect people and communities | | | | | |
| Improving preparation for volcanic events | | | | | |
| Providing clear information about evacuation locations | | | | | |
| Encouraging development of individual, family and community plans | | | | | |
| Identifying where to seek information during a volcanic crisis | | | | | |

E.4 Are you willing to be involved in piloting the game?

## APPENDIX B: Focus Group question outline

**Participants:** Members of the general public of St. Vincent with varying demographic and experience with volcanic hazards and have been residents of the island for at least 2 years.

**Obligations:** No participants are obliged to partake in the focus group. All participants that do take must read the information sheet and sign the provided consent form.

**Duration:**

- Approx. 20 mins for reading information sheet, questions and signing consent forms.
- Approx. 1 hour for focus group discussions.
- Approx. 20 mins for debrief and answering of further questions.

**Discussion Topics:**

- Personal Information: Who? What? Where?
- Experience with volcanic hazards – 1979?
- Outreach activities experienced – workshops, hikes, lectures
- Strengths and weaknesses of these outreach activities (if applicable)
- Familiarity with volcanic hazards communication techniques – maps, pamphlets etc.
- Current use of video games – platform, duration, styles
- Thoughts about use of video game for volcanic hazard communications
- Opinions on topics to be included within a potential game

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**Game Overview – to be read in advance of questions.**

The purpose of the game is to educate residents of St. Vincent about volcanic hazards in an engaging and memorable way. The game will comprise realistic-looking visualisations of hazardous volcanic phenomena from town perspectives. The towns that will be used are Chateaubelair, Fancy, Sandy Bay and Georgetown which have all been chosen due to their proximity to the volcano. The visualisations will depict hazardous volcanic phenomena including precursory activity (fumaroles and small earthquakes), ash plumes and ash fall, pyroclastic flows and volcanic mudflows. Each visualisation will be highly interactive with the player able to click around the screen to unveil information about the phenomena. There will also be a scene from within the communities where the player can find information about how to prepare and respond to an eruption by completing short tasks.

There will be a further gaming element after these stages where the players must complete scenarios using the information provided throughout the initial visualisation phase. This will include using maps to help identify safe evacuation points and understanding information provided during a simulated eruption. The visualisations will be produced based on historical information from the 1979 and 1902 eruption events and will utilise volcanic hazard information currently used across the island of which players may not be familiar. The game will be used within current outreach activities and events across the island.

**Focus Group Questions:**

| | |
|---|---|
| ***Opening Questions***<br>*Round-robin questions to identify characteristics participants have in common. Factual instead of opinion-based or attitude based.* | • Tell me your name and where you live on the island.<br>• Has anyone had first-hand experience of volcanic hazards? |
| ***Introductory Questions***<br>*Questions to introduce the general topic of discussion and allow the opportunity to reflect on past experiences* | *This focus group has been arranged to discuss the development of a new video game to aid volcanic hazard outreach on St. Vincent.*<br>• Has anyone experienced an outreach activity or event relating to volcanic hazards, can you tell us about it? |
| ***Transition Questions***<br>*Questions move the conversation into the key questions that drive the study.* | • Can you describe an outreach session you've attended for volcanic hazards and what you thought was good about that session?<br>• Are you familiar with the volcanic hazard zonation map for the island or the activity alert levels?<br>• Where do you currently obtain information about volcanic hazards? (Internet, TV, radio, newspapers etc.)<br>• Do you think you are informed enough about volcanic hazards to be prepared in case of an eruption?<br>• Where do expect information about what to do during a volcanic eruption to come from? (UWI Seismic Research Centre, NEMO, Red Cross…) |
| ***Key Questions***<br>*These questions drive the study. Two to five questions in this section.* | *Explain the game concept by reading the 'game overview' (above).*<br>• What are your initial thoughts about the development of such a game for this purpose?<br>• Do you play video games? If so what types of games and do you play them often?<br>• What aspects of volcanic hazards do you think should be included? E.g. information about the hazards, preparation measures, precursory activity, historic eruption information.<br>• How long do you think the video game should be?<br>• What would be the best platform for a game like this? (Desktop, tablet, phone, internet…).<br>• Who do you think will be the most interested in this game? (age groups/communities etc.).<br>• Do you foresee any issues with a game of this type and style? |
| ***Ending Questions***<br>*These questions bring closure to the discussions, enabling participants to reflect back on their previous comments* | • Our intention is to implement the game during volcanic hazard awareness week. Do you have any advice on how we can arrange for people to play the game? |

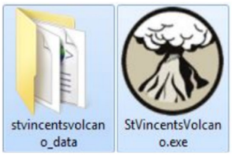
## APPENDIX C: Game Guidance Notes

# St. Vincent's Volcano Game
## *Guidance Notes*

St. Vincent's Volcano Game brings to life the La Soufriere volcano and provides information about the associated hazards that may be experienced during a future eruption.

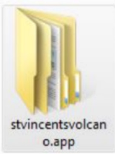
### Game Install for PC & Mac

***PC Version***




- Stvincentsvolcano_data
- Stvincentsvolcano.exe

***Apple Mac***




- Stvincentsvolcano.app

1. Download the game files depending on your computer type (see left).

2. Save the files directly onto your computer as it will run faster!

3. Keep all files together, <u>do not</u> edit or delete any files as this will prevent the game from working correctly.

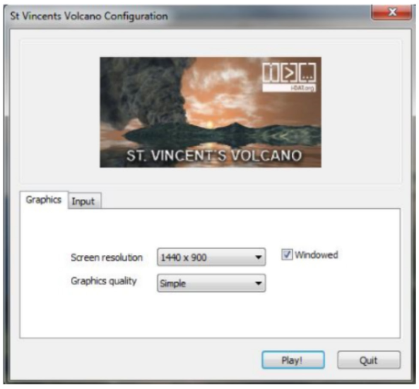
4. You can launch the game by double clicking the icon.

**Game Configuration**
The game configuration window will open. It should automatically select the correct setting for your computer.

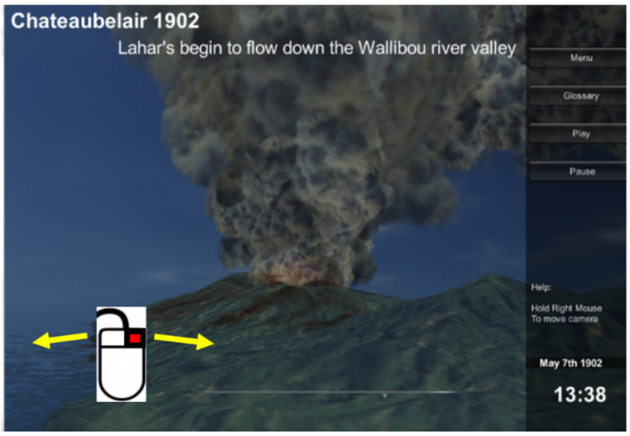
*Make sure the 'windowed' option is ticked!*

If your settings do not change try using:

- Screen resolution—1440 x 900
- Graphics quality—Simple




### Mouse Control




Use the mouse right-click during the eruptions and hazard training scenes to move around the screen.

The game has 4 stages to complete and should last around 15 minutes.

*Please ask a member of the outreach team if you require any help during the session.*

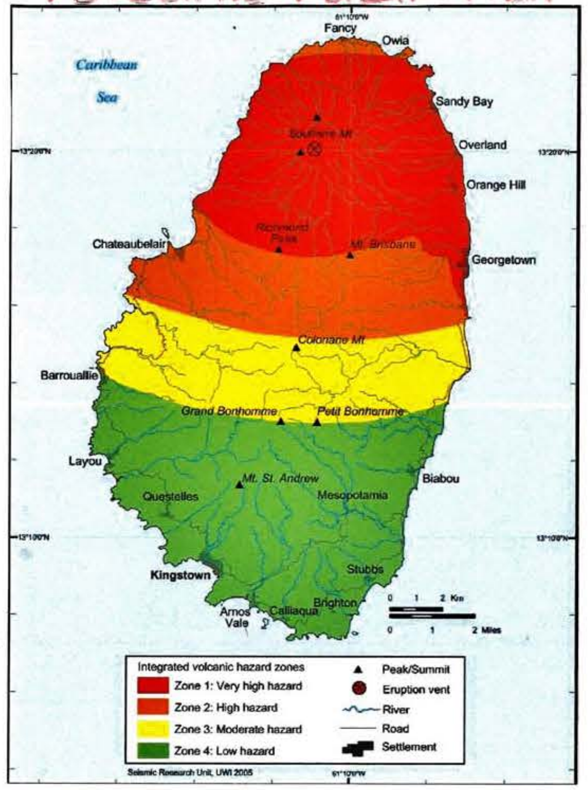
**Game creators contact details:**
lara.mani@plymouth.ac.uk

EARTH SCIENCES WITH PLYMOUTH UNIVERSITY

## APPENDIX D: Game design Storyboards

# Existing information

## Volcanic Hazard Map




## Activity Alert System

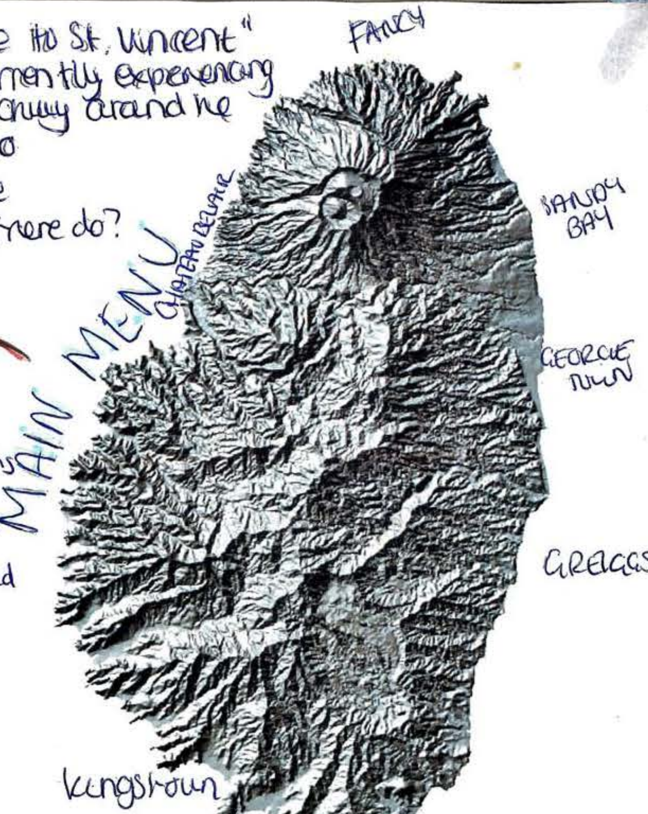
- (red) Eruption in progress or may begin without warning.
- (orange) highly elevated level of seismic and fumarolic activity. Eruption <24hrs notice
- (yellow) Volcano is restless, seismic and fumarolic activity above historical level
- (green) Volcano is quiet no unusual activity

Lava flows + Domes - viscous lava rarely leaves crater creates domes which can collapse causing PDCs when interacts with water can be explosive

# Concept Ideas

"Welcome to St. Vincent" The island is currently experiencing some unusual activity around the Soufriere Volcano

or maybe more What can Soufriere do?

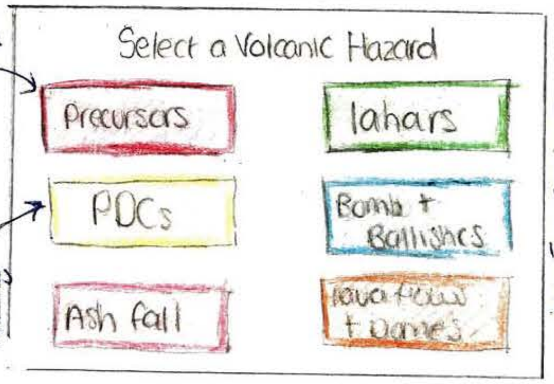



MAIN MENU

Choose location?

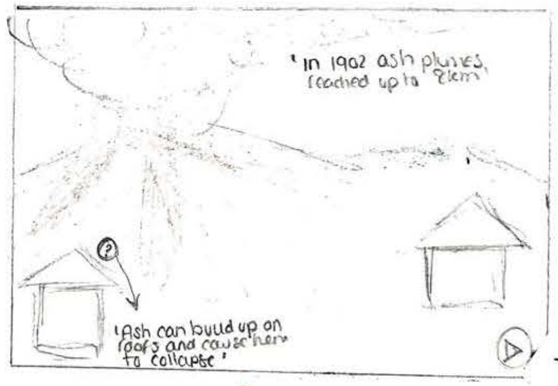
each section provides basic information and visualisations of the activity with information on prevention, preparations and actions.

Information about Hazards




Precursors would be nice to have ~10-15s animation of the activity.

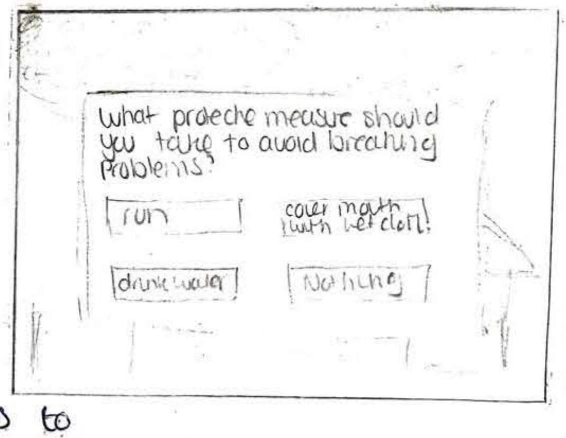
can we integrate videos or I think top-down would be most effective




Visualisation of the hazard
→ animation using photography
→ possible to click on locations and it recall information?
→ animation to run whilst user clicks on interactive sections.

→ next button to lead to section on preparation and then onto a new section.

Testing of knowledge
→ 3/5 multiple choice questions in each section
→ built in analytics to measure progress
→ instant feedback for wrong answers throughout.
→ introduction of levels.




Ash fall - hazardous to health, dangerous to aeroplanes covers whole areas, in rain becomes like mud.
→ connected to wind direction
→ volcano can cause contamination of water supplies.

Precursors
→ fumarolic activity → increased heat and new locations → smell
→ seismic activity → low strength shaking over prolonged periods.

TOPOGRAPHICALLY CONTROLLED

## Phenomena

PDCs - difficult to visualise but also not a problem if so, could use videos. key message - speed, temperature + TOPOGRAPHIC CONTROL
↳ Top down map with 1902 data?
→ Travel over water

Lahars - occur anytime pre/post/during eruption. Need significant water
→ rain events / hurricanes / storm surges
→ debris / temperature / speed
→ Damage infrastructure → Rabacca bridge
TOPOGRAPHIC CONTROL

Bombs + Ballistics - occur randomly very large (>house/carsize) No external controls. Travel extremely quickly no warning.

# Home Hub Screen

# Screen Design

(B)

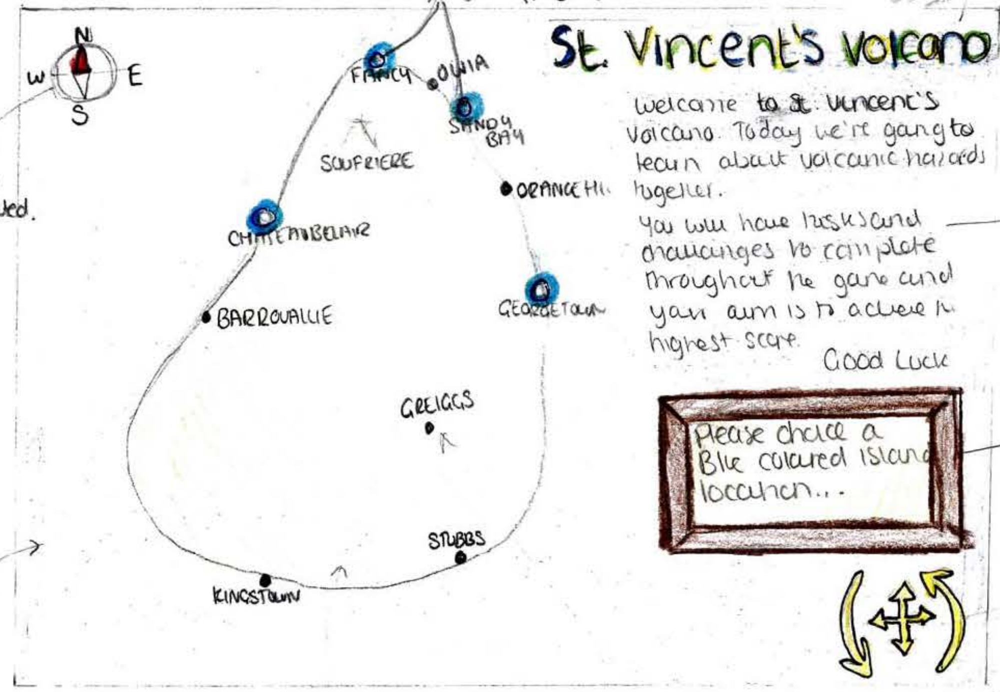
- The initial screen that the player encounters as part of the gameplay.
- Screen is designed to allow players to be aquainted with what the island looks like
- will identify locations on island where visualisations are based
- The overview will be the island DEM painted model to appear as realistic as possible
- the 4 island locations - expected to be Fancy, Sandy Bay, Georgetown and Chateaubelair will be highlighted.
  → locations highlighted by → tunnel lights?
- The player should be able to manipulate the model to explore the island.

INTERACTIONS: 4 clickable locations (leading to next screens)
Hover locations over non-visualised locations.

- Expected on 4 chosen towns will be visualised to a high zoom, other locations can be aerial photography

Clickable island locations leading to second scene they should 'pulse'

Compass direction should change as island is manipulated.




→ game title to be coloured colour scheme to match island flag colours. BRIGHT + CLEAR!

→ game description light and fun. Presented on a scroll?

game instructions will be presented in an island frame.

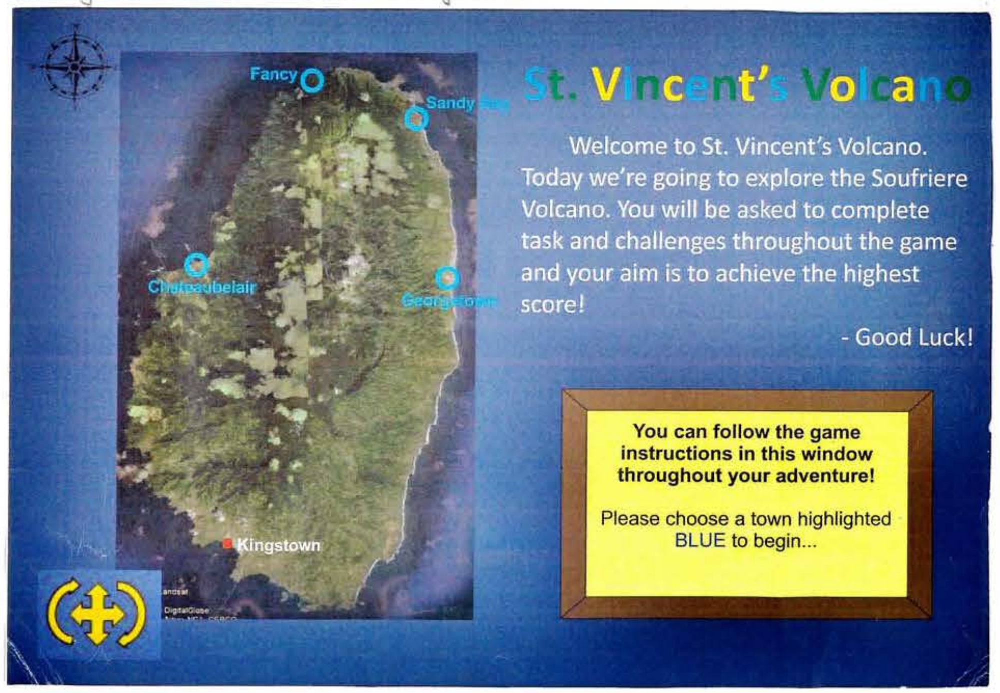
Background should be the sea → add boats?

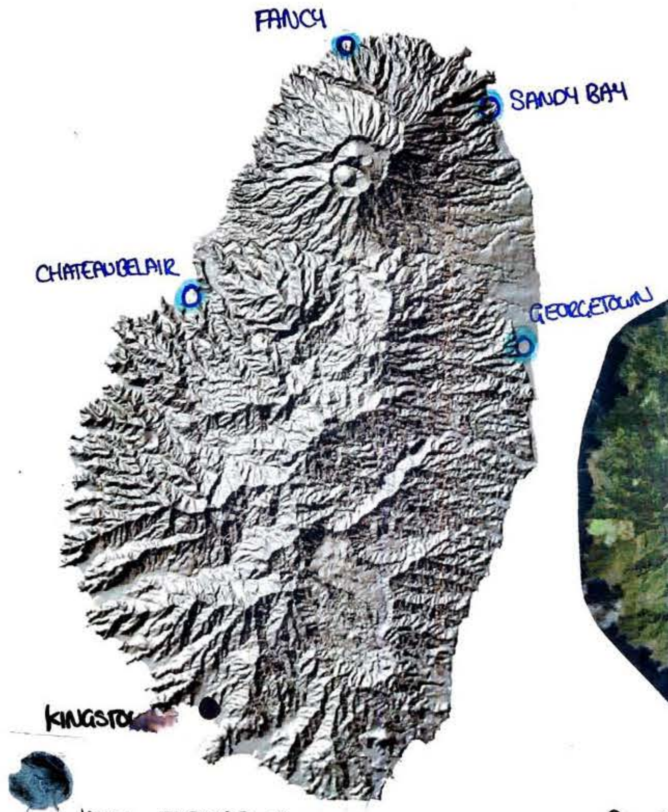
controls for player to manipulate the island model. Perhaps in left bottom corner.

Island model will aerial photograph overlay

Hoverable island town locations NO interactions.

Background should be much lighter.




...ITAL ELEVATION MODEL

GOOGLE EARTH AERIAL VIEW.

# Ash plume visualisations

- The same eruption visable from 4 Island locations
- Two eruption scenario interactive video snippets - 1979 + 1902

AIM : learn about ash fall hazards and understand what historical eruptions were like. How wind affects ash plumes.

## 1902

DATE : 7th May 1902

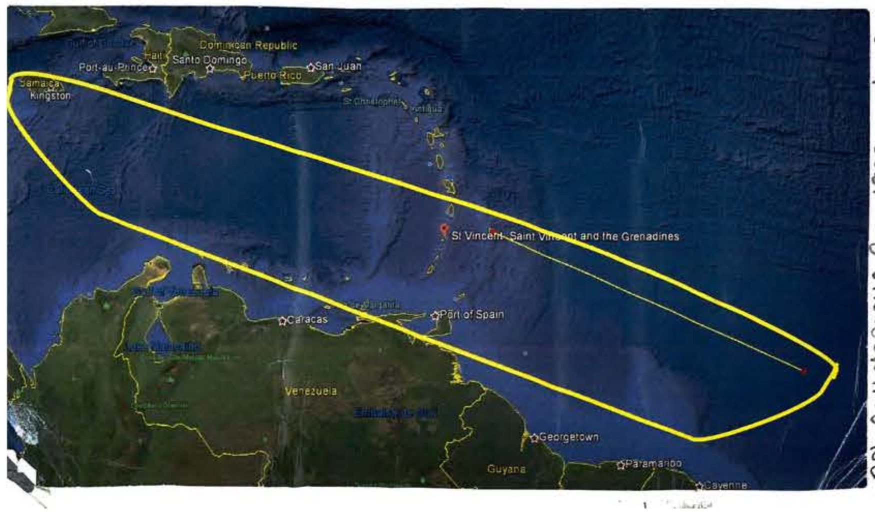
TIMELINE : 0740 plume reaches 10km
1030 begins to spread laterally into umbrella phase becomes darker
1100 fine ash fall begins
1110 lighting in ash plume
1400 Large explosion followed by pumice fall close to volcano
1430 pumice fall in kingstown becoming fine ash

Area affected : Grenadines - fine ash fall in afternoon
Barbados - quite heavy ashfall evening
Trinidad - light ash fall in evening
Jamaica - very fine ashfall (11th may)

Grain - size classification :
- Blocks and Bombs ~ 64mm +
- lapilli ~ 2-64mm
- coarse ash ~ 1/16 - 2mm
- fine ash < 1/16mm (0.063mm)

wind dispersal : NW - SE over caribbean region

MAX plume Height : 18km then interaction with tropopause triggering umbrella phase lateral spreading.




Ash fall deposits from 1902 eruption.

# Timeline of events

C1

Chateaubelair

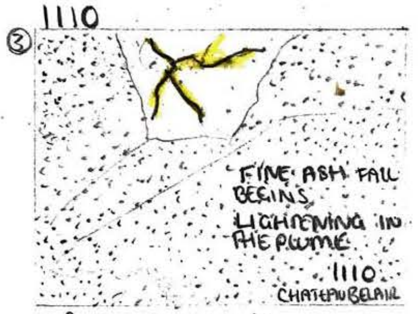
① 0530


- Volcano not erupting
- quiet morning in st. vincent
- were there earthquakes on the day?

② 0740


- Plume height reaches 10km
- zoomable so can appreciate height
- explanation of why plumes rise

③ 1110

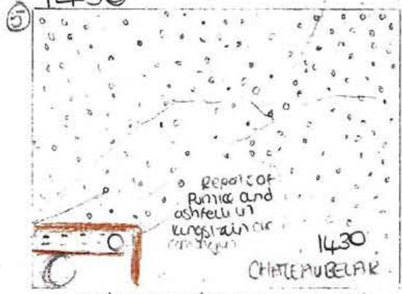



- fine ash fall (less than 1mm) begins to fall
- sky becomes darker
- lightning begins in the ash plume.

④ 1400

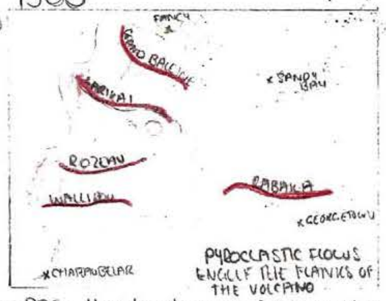

- large explosion - sound effects vibrations and a shockwave?
- Pumice begins to fall close to the volcano (larger in Fancy + Chateau, lighter in Sandy Bay and Georgetown)

⑤ 1430




- a radio provides news of ash + pumice fall reaching kingstown
- ash and pumice fall ongoing in locations

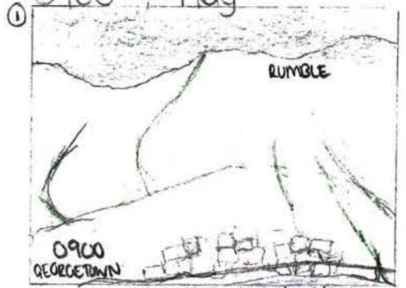
⑥ 1500




- PDCs thunder down the flanks of the volcano highly concentrated in the river valleys
- Travel over the sea in some areas
- Short duration - few minutes, buildings singed
- after followed by heavy lapilli fall.
- use videos + other media to show (TRC)

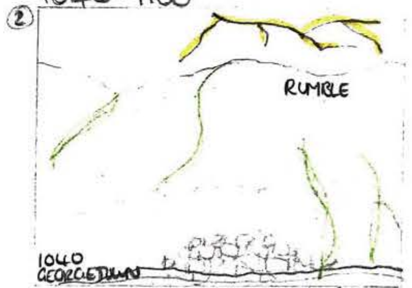
Georgetown

① 0900 - 7th May



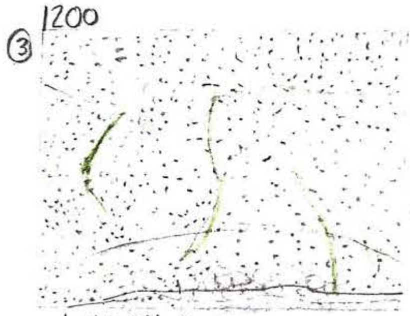

- Rumbling and earthquakes throughout tuesday and into 7th may
- becomes more intense throughout morning.

② 1040 - 1100




- thunder and lighting begins above volcano and ash continue.
- no activity visible
- rumours reveal of eruption

③ 1200

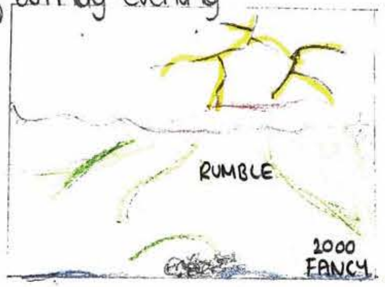


- light ash fall
- becoming lapilli

Georgetown then follows similar storyboard to Chateaubelair from scene ⑥

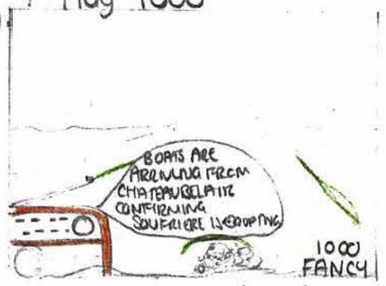
## Fancy

① 6th May - evening



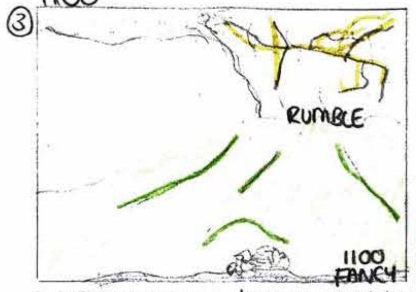

- low cloud base covered summit.
- rumbling, lightning + EQs heightened.
- red glow in cloud base
- Shaking/vibrating to represent EQs

② 7th May - 1000



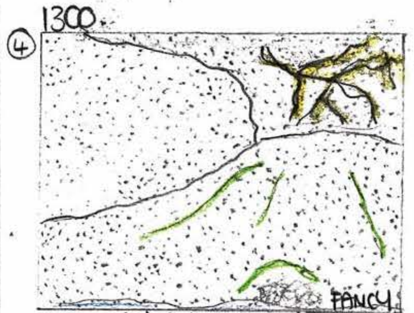

- addition of radio from ① with news of boats arriving from chateaubelair saying Soufriere is erupting.

③ 1100



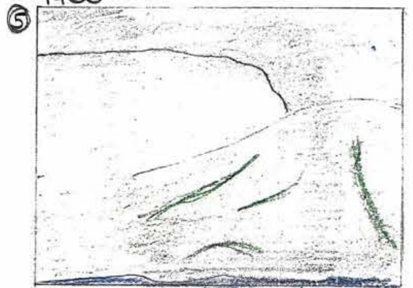

- Volcano summit becomes visible
- large black plume ascending over the volcano
- rumbling continues

④ 1300.




- rain of hot liquid mud
- fine ash of nearer flanks of volcano
- 1300-1345 rain continues.

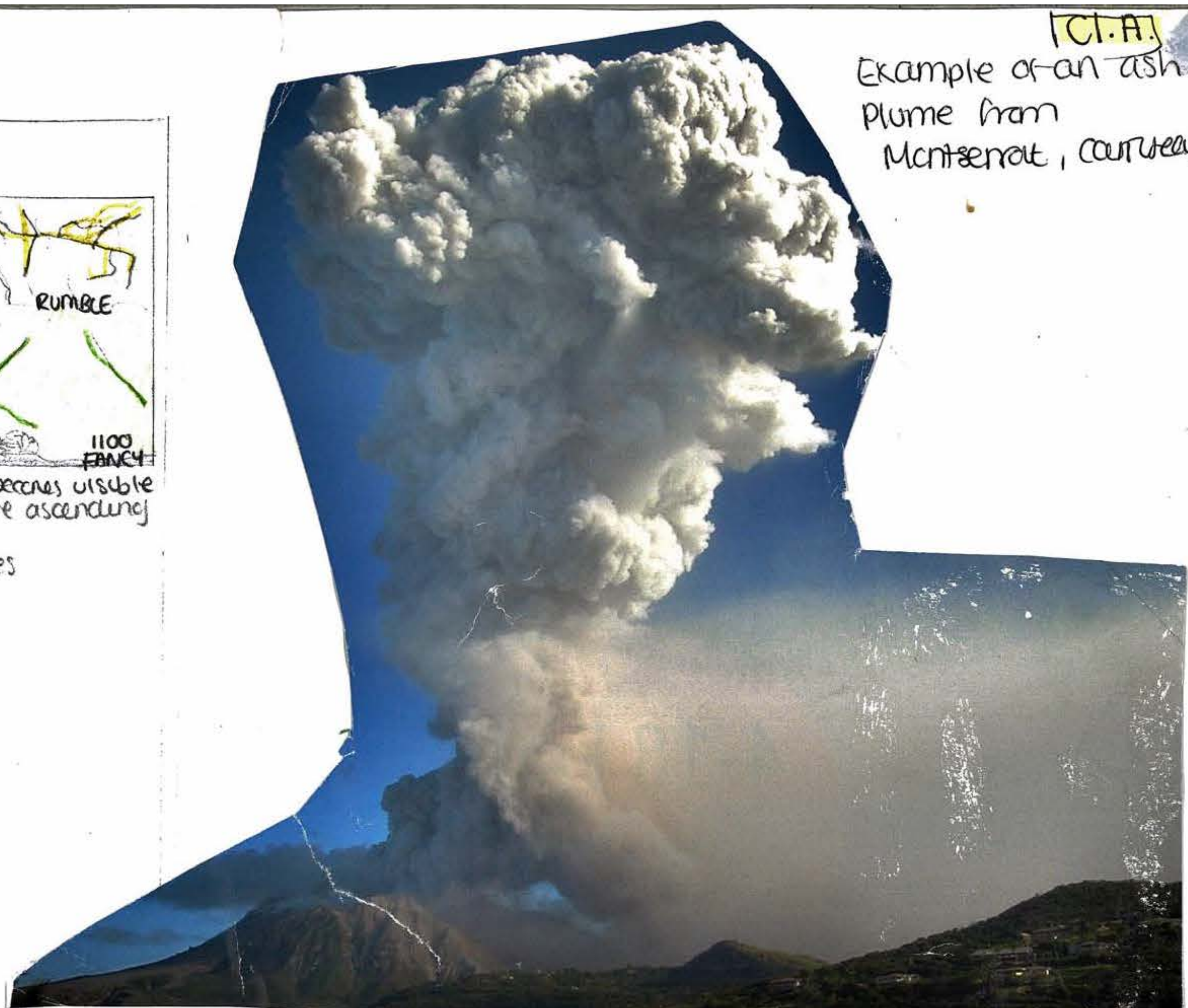
⑤ 1400



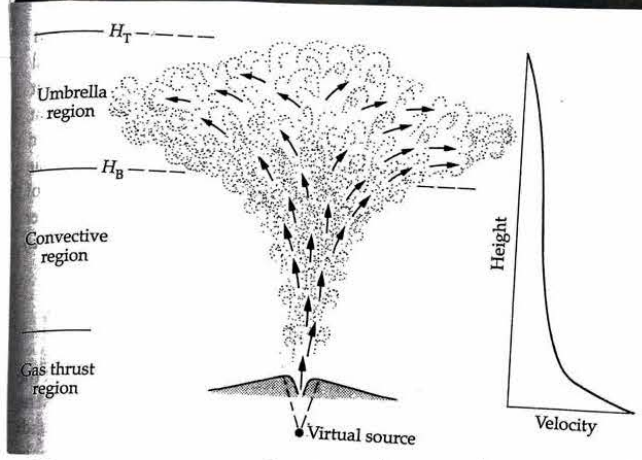
- Sky becomes dark and a suffocating heat
- related to PDCs but none struck fancy
- lasts a few minutes.

C1.A.

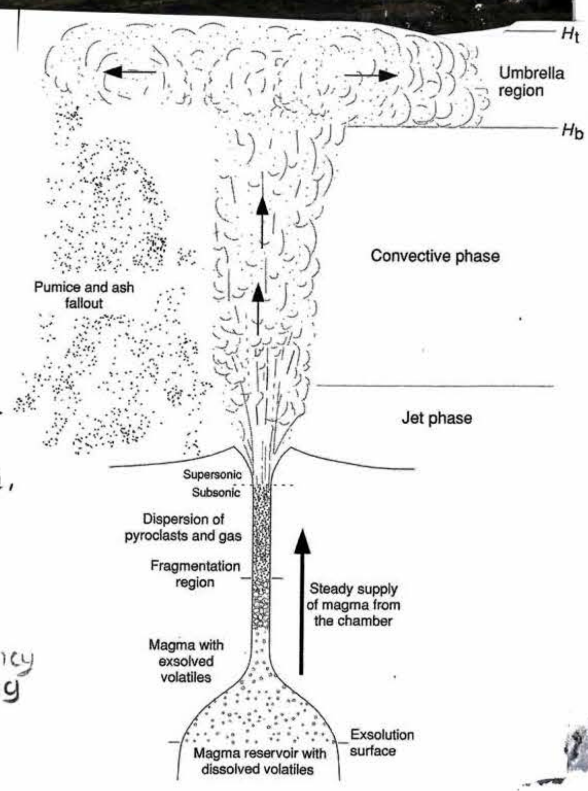
Example of an ash plume from Montserrat, courtesy



## Ash Plume mechanics




- Plumes comprise 3 main phases: Jet, convective, and umbrella.
- Jet phase - close to source (crater) is where the plume moves at highest velocity.
- convection phase - the hot material entrains colder air and the column widens.
- umbrella region - the cloud reaches buoyancy and spreads lateral driven by further upcoming hot material.



C2

## END of eruption

Timeline:

- 7th May evening - dark and heavy cloud continued lightning and rumbling from volcano
- everything covered in 2-3inches of ash and material.
- small dark - ash laden plume still ascends above plume
- Thursday 8th May - steaming valleys, plume, lightning.
- Friday 9th May - rumbling continues, 7am large plume still visible and hot lahars seen in the Wallibu valley. in Georgetown large rumble and ash and lapilli rain. ongoing lightning
  Fancy - dark with ongoing ash + lapilli and lightning
- Saturday 10th May - small dark (slate-coloured) plume
- Sunday 11th - Monday 12th May - small plume, intermittent low rumbling, rain of lapilli (shot) near Chateaubelair. lahars on south side of volcano.

## 1979

Date: 13th April - June 1979

Overview of eruption: minor earthquakes detected but not felt by people on 12th April.

12th April: Government warned of unrest. (2300)

13th April: 0800 loud rumbles, fine ash falling (5cm SE + SW)
0930 column of ash + steam, evacuation begins
1015 explosion + ash plume >8km
↓ intermittent explosions and ashplumes >10km
1515 dark cauliflower ash laden cloud, fine ash fall in Rabacca
2005, 2108, 2350 - explosions with large plume 17-18km high intermittent with gas/water vapor plumes which don't breach cloud bank.
2108 explosion forms PDCs which engulf the Wallibou and part of Rabacca.

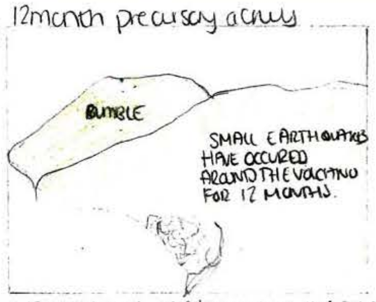
14th April: 0108 similar to (2108)
1600 PDCs in Larikai and 10km out to sea. Roseau valley including blocks up to 600mm ash + lapilli

14th - 17th April: - mudflows (lahars) in upper valleys
- mainly steam emissions with intermittent explosive phases.

..th April: 2057 explosive phase, Roseau + Wallibou, Larikai PDCs lapilli fall in Chateaubelair + Georgetown. lightning

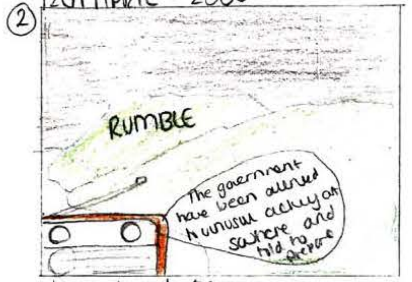
## Timeline of events

① 12month precursory activity




- 12 months of earthquakes increasing in intensity and number closer to eruption.
- demonstrate using vibrations.

② 12th APRIL - 2300




- heightened EQs
- radio reports that the gov. has been alerted to an unusual situation at Soufriere and told to prepare.

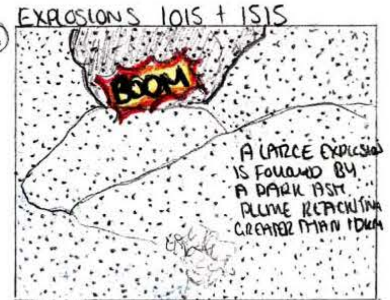
③ 13th APRIL - 0800-0900


- as people awaken + hustle + bustle begins the volcano is raining ash
- cloud is light grey / dirty white
- Plume height 8km - Fine ash fall.
- ongoing until 1515

Small explosions - 13/4 @ 1015 1515 (8km)

Large explosions - 13/4 @ 2005, 2108, 2350 (18km). 14/4 @ 0108, 0706, 1550

④ EXPLOSIONS 1015 + 1515



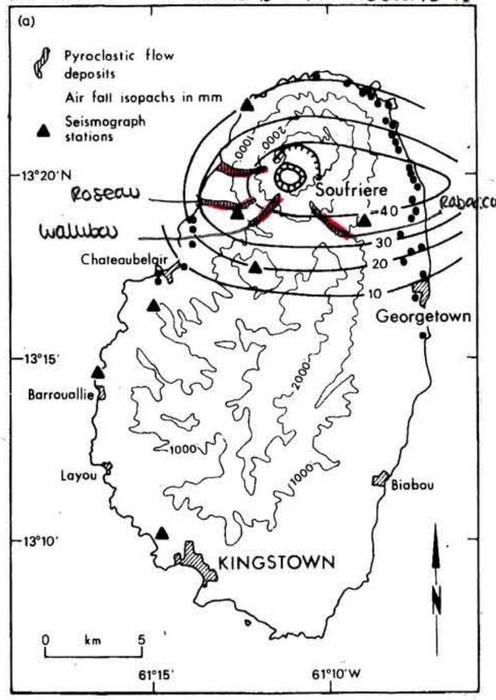

- small explosions* followed by a slate-grey ashplume reaching >10km
- cauliflower shaped cloud
- continued ash fall
- Player should be able to establish plume height.

⑤ 2108


- large explosions* which last approx 1hr diminishing in ash content.
- PDCs rush down Wallibou and Rabacca. (see map).
- rumbling loud noises and darkness.
- Ash and scoria up to 70mm in size.

For PDCs see sheet C3 intermittent explosive activity continues throughout 14th - 17th April with PDCs descending. when non explosive plume is white + 1-2km high.

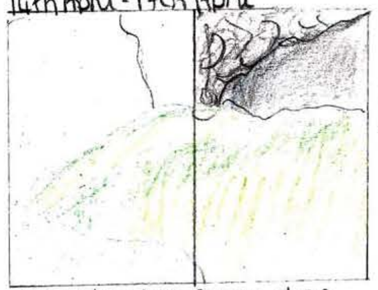
Ash thickness variations + PDC locations




⑥ 14th - 15th April

- rain and water in river valley re-works loose ash material causing mudflows
- Wallibou and Rabacca valleys
- rain important, sediment in sea (see next sheet).

⑦ 14th April - 17th April



14/4/79 - 1600 ←

- mainly white steam plume with intermittent type ④ activity with ash clouds only reaching 1-2km.
- around 6 explosions? mostly on 14th + 17th.

22nd April: 1037 explosive activity, plume - 12km small PDCs in Larikai divide. PDCs travel across Chateaubelair bay

26th April: 0353 explosive activity 8km plume and earthquake activity

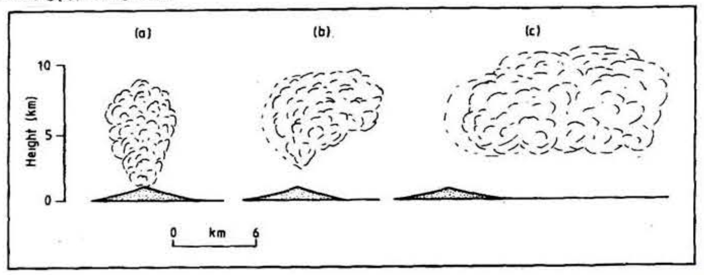
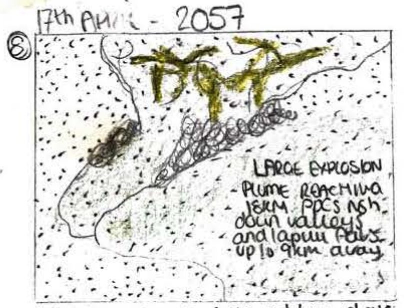



Fig. 14. Cartoons illustrating the ascent and downwind dispersal of April 26th ash column.

# 179 eruption timeline cont.

17th April - 2057

⑧ 


- loud explosion followed by dark cauliflower cloud ascending to 18km, lapilli fall
- lightning in the cloud (1 flash/s)
- PDCs rush down larikai, wallibou + Roseau valleys
- 17th - 22nd follows ⑦

⑨ 22nd April - 1037
→ Similar to ⑧ without lightning.
→ small PDCs (dilute)
→ ash plume up to 15km
→ chateaubelair bay becomes dark

⑩ 26th April - 0353
→ small ash plume (ash laden) dark grey; 8km high

⑪ END OF ERUPTION
No further explosions diminishing steam cloud.
All activity is in crater and not visible.

## Pyroclastic flows

(C3)

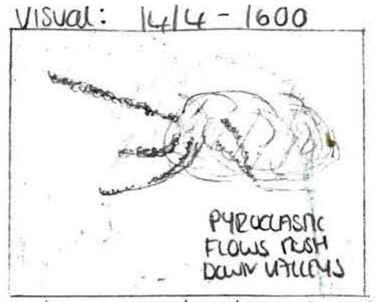
- topographically controlled
- mainly in upper valleys of larikai, Rabacca, wallibou and roseau.
- thunderous cloud formations which move very quickly
- The more material the further it travels

Visualisation
- If possible it would be great to show how they move in the visualisation. I know this is hard
- If not possible then for all locations use same visual top down map showing them moving through valleys.

Events
- largest 14/4/179. 1600 PDCs rush 3km down larikai and 10km out to sea. (They travel just the same over water)
- when - 2108 13/4 descending into wallibou + Rabacca.
~~0108 14/14 similar (discard)~~
1600 14/4 See above (most significant).
~~2057 17/4 PDCs in larikai, roseau, wallibou~~
1037 22/4 small in upper valleys - dilute, cross chateaubelair bay.

If too much to include all include the 14/4 1600 event only.

Visual: 14/4 - 1600



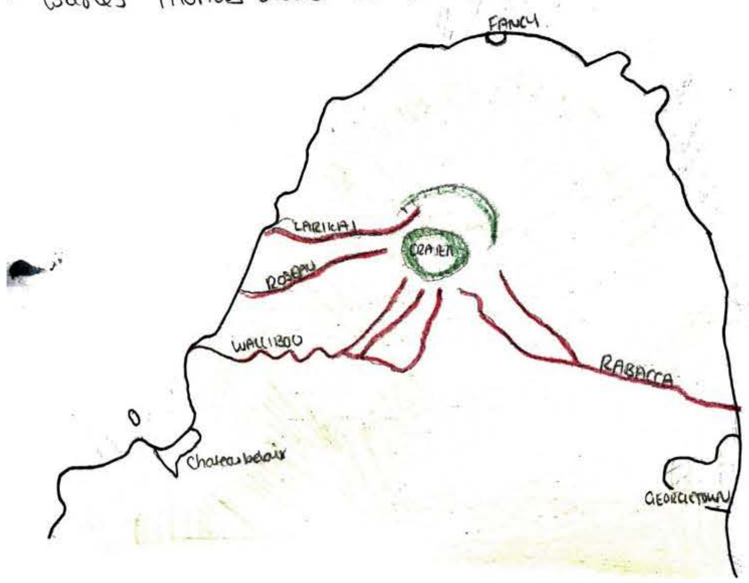

- show ash plume too - translucent needs to show they can happen simultaneously.

Also see videos to watchlist!

## Lahars

- use same visualisation for all locations.
→ Chateaubelair - wallibou
→ Georgetown - Rabacca
→ Fancy - 'reports of mudflows near Georgetown' Rabacca.

- rain and rivers re-work loose material in river valleys and wash down valley sides
- high water levels, murky and fast
- contains blocks up to 2m and is murky and ash laden, thick.
- confined to valleys
- washes murky water out to sea.



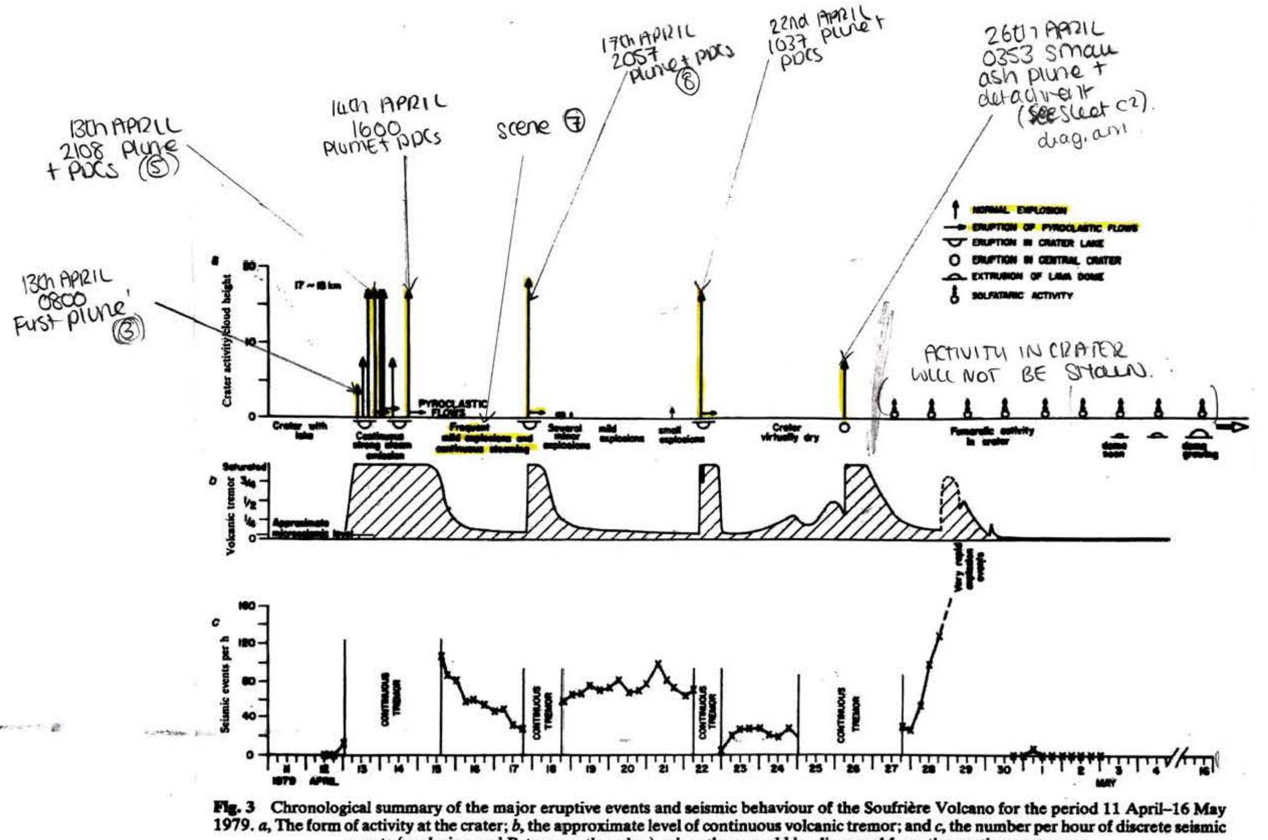
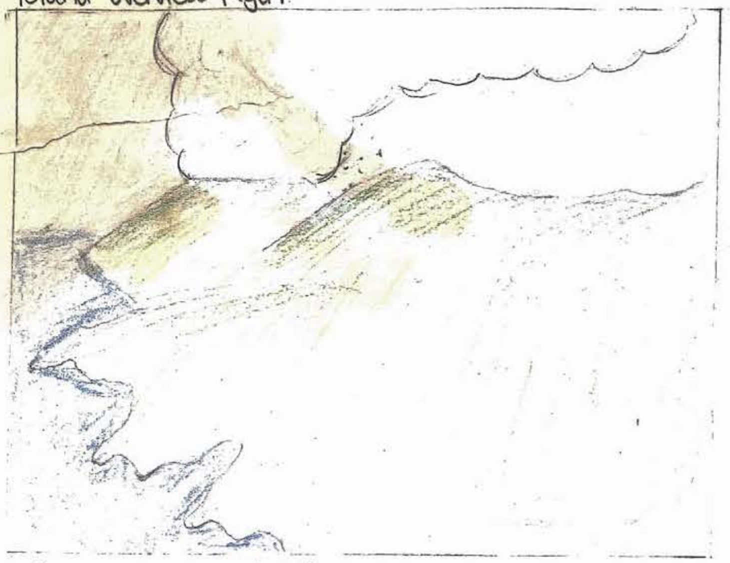




**Fig. 3** Chronological summary of the major eruptive events and seismic behaviour of the Soufrière Volcano for the period 11 April–16 May 1979. *a*, The form of activity at the crater; *b*, the approximate level of continuous volcanic tremor; and *c*, the number per hour of discrete seismic events (explosion and B-type earthquakes), when these could be discerned from the continuous tremor.

# Interactive Scenes - Chateaubelair

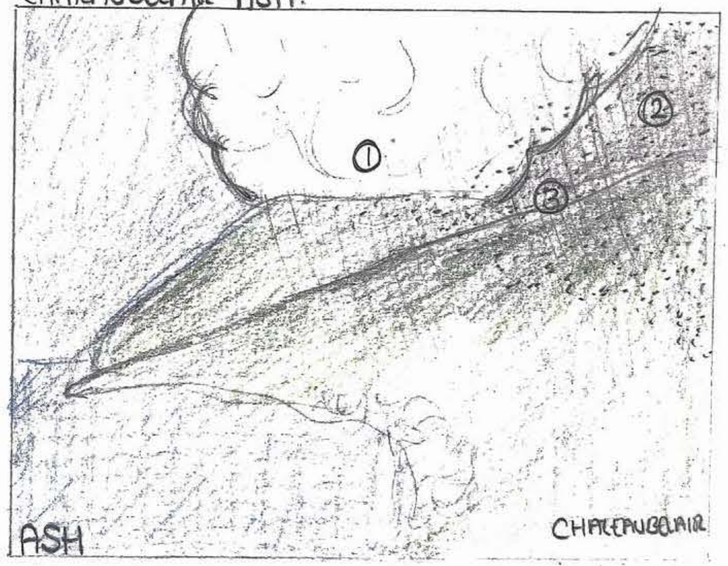
D1A

Island overview flyin.



- Fly up the leeward side
- designed to show the entire plume height + shape
- This should look like the Mt. Tavurvur photo...

CHATEAUBELAIR-ASH.

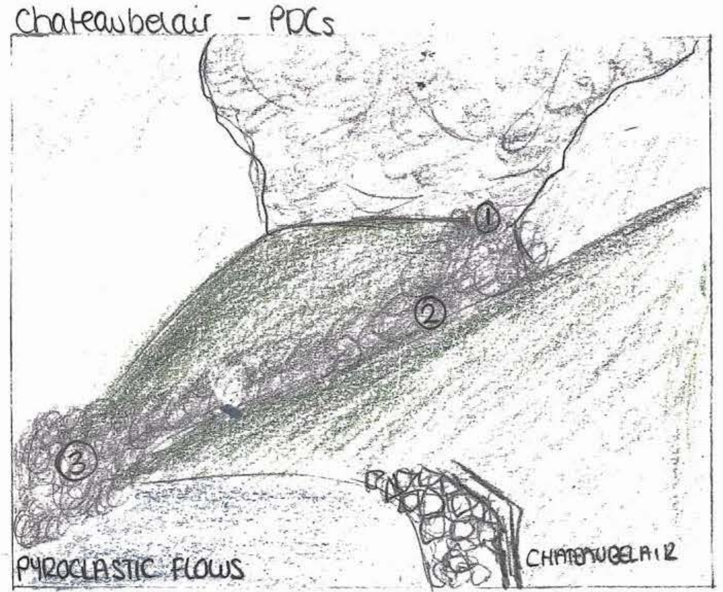



- Lands on chateaubelair vantage point above Chateaubelair.
- Needs clear label of what phenomena we're looking at
- 'Live' stream of ash plume ascend whilst in interactive
whast

This is a nice example of what I'd like....

Plume from Mt. Tavurvur, Papua New Guinea. 29/8/14.

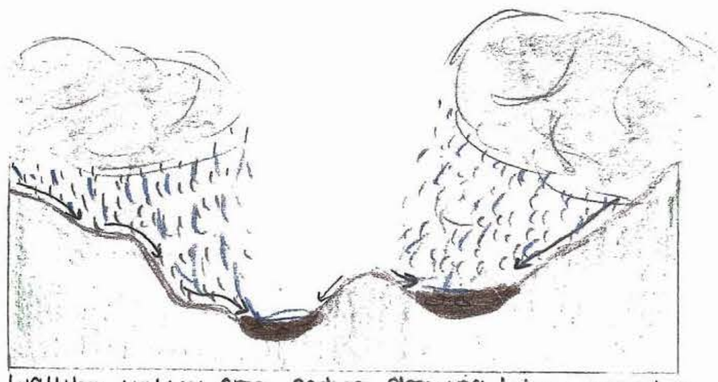
Chateaubelair - PDCs




- Not sure if this is possible but a basic cloud would be ideal
- coming down the wallibou valley and crossing over the sea
- minimal detail required as videos and photos will also be used

Chateaubelair - lahars


- Muddy fast flowing river valleys. wallibou to North of chateaubelair.
- material washed out into sea
- refined to valley bottoms
- Use the cross section



Wallibou valley cross section showing lahar generation

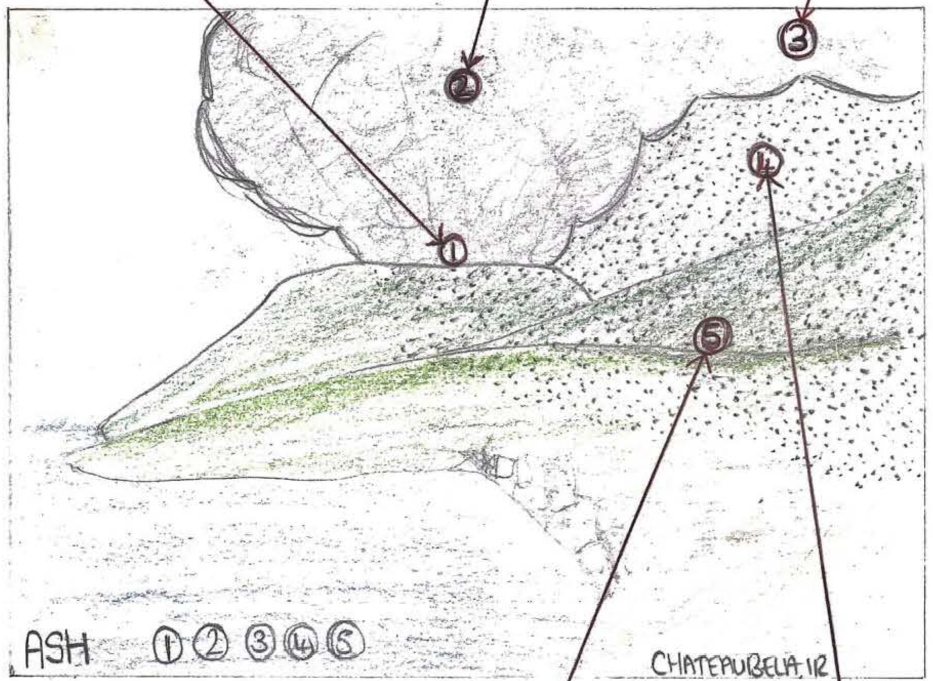
- rainfall river reworking loose ash material causes lahars in river valleys
- dark + muddy fast flowing and containing larger blocks
- hot material.

# Chateaubelair - Ash

① Summit crater - the ash plume ascends from the summit crater at speeds of up to 500m/s and can be many 100s of °C.
The cloud is often dark grey in colour due to the ash content.

② Ash plume growth - As the hot ash ascends it pulls in surrounding colder air creating a wide plume. The cloud resembles a cauliflower growing higher and higher.

③ Spreading outwards - as the plume ascends it begins to cool. It can then be seen spreading sidewards. The plume in 1979 reached up to 18km high.




⑤ Ash accumulation - ash builds up in valleys and vegetated surfaces causing a blanket layer. When mixed with water it can become a liquid.

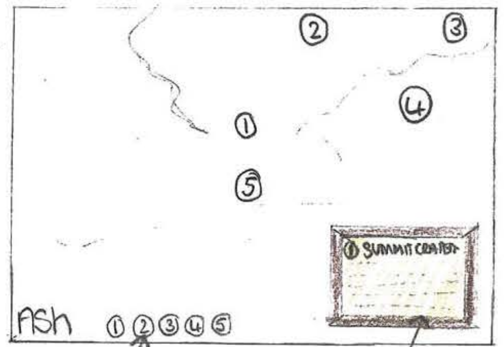
④ Ash fall - As the speed of the material slows ash begins to fall. This usually occurs under the clouds umbrella and can be extremely fine.

## Screen Specifications

- The scene should be a visualisation loop on continuously during player interactions
- Preferably using the same visuals from the 1902 + 1979 visuals.
- The numbers should only be clickable after the number prior has been clicked.
- The information should appear in a small box in the corner and needs to be dismissed for each number.
  If possible when each number is clicked it would be good to zoom in to what they're looking at (not essential).
- overall the scene should be smooth and easily navigatable

once all ⑤ are achieved there should be a button to allow them to proceed to the next hazard

▷ PROCEED




Numbers should highlight at the bottom of the screen to show user progress

When each number is clicked information should appear in a box on the screen (design may change).

# Chateaubelair - PDCs (Preferential)

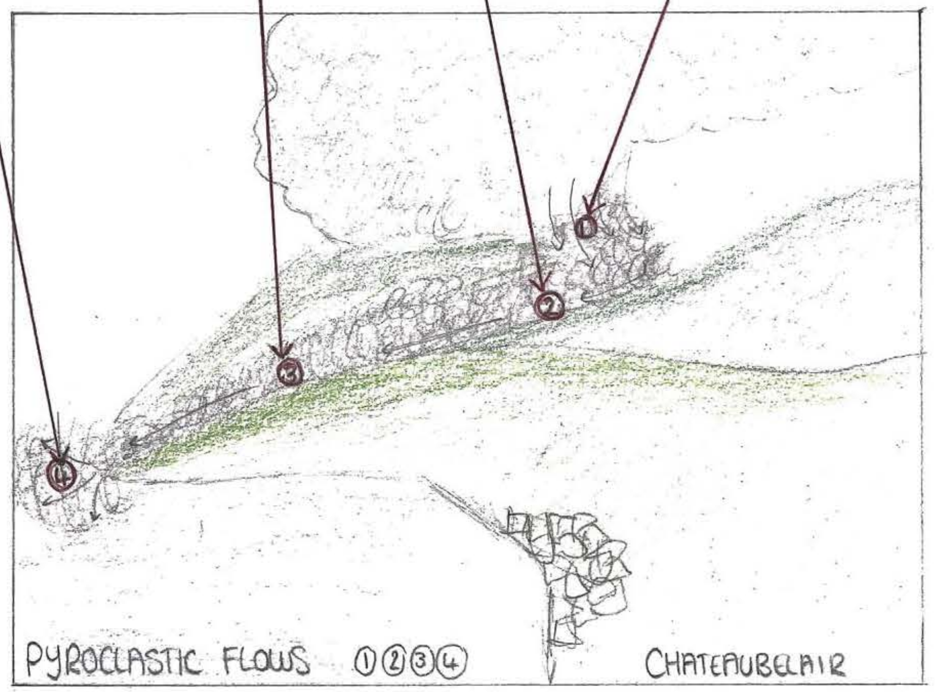
1D1B

④ Over water - when pyroclastic flows reach the sea they can carry on travelling over the water for 10's kms. eventually the pyroclastic flow will cool and stop. *VIDEO*

② Composition - pyroclastic flows are made of hot ash, gas and rocks that flow at speeds between 30m/s to 100m/s. *VIDEO*

① Source - Pyroclastic flows generate in several ways but most commonly from the collapse of the ash cloud. In St. Vincent this can also happen due to the large lava dome in the crater collapsing under its own weight. *VIDEO*

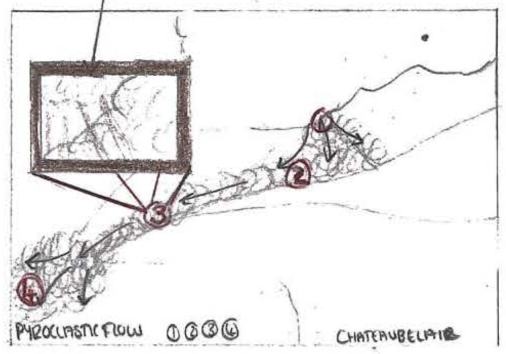
③ Movement - pyroclastic flows move under gravity downslope primarily in river valleys and steep slopes, whichever route is easiest.




## Screen Specifications

- This is the preferential screen for pyroclastic flows but an alternative is also included. It's your choice on what you think you can achieve.
- The PDC needs to follow the Wallibou river valley coming from the back of the volcano and head towards the sea.
- The flow will need to be accompanied by a loud rumbling.
- needs to contain blocks + trees etc.

Some numbers will show both information and also video/photo footage. This should appear in a window to the top left of the screen

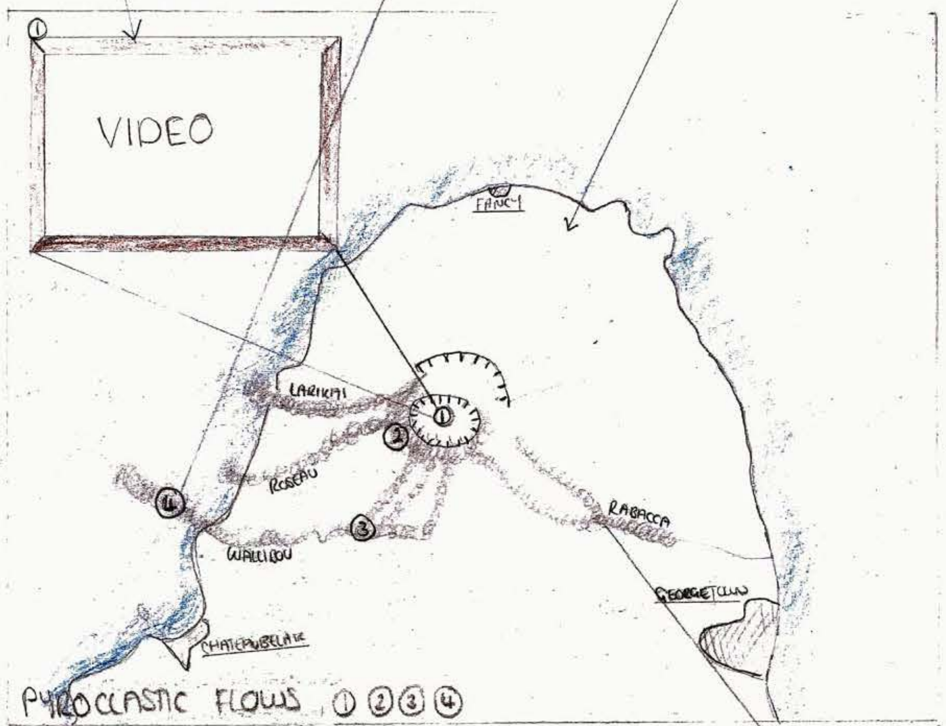


# Chateaubelair - PDCs (2)

Each clickable stage will show information (see previous sheet) here followed by a video.

velocity of flow should reduce as the flow reaches the water.

DEM model with coloured overlay and town models. No interaction required with towns.




at Rabacca the flows diminish drastically before reaching the end of valley.

Screen specifications

- This screen should only be made if the initial PDCs screen can't be produced.
- The model should show PDCs progression down valleys in real-time.
- Each clickable number will show the information as shown on the initial PDCs sheet and then also include a video/photo
- Images will be provided later (need licences)
- This should include something (photo or diagram) about their generation (tbc).
- This same screen can be used for all 3 locations opposed to individual location visuals if time is limited

# Chateaubelair - lahars

DIC

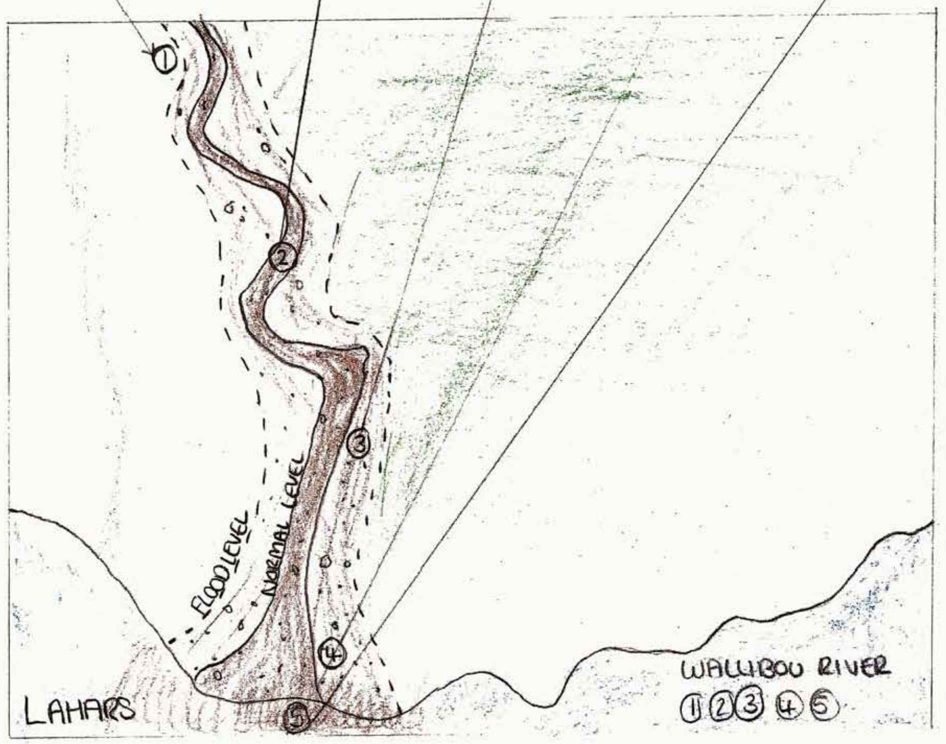
① Heavy rain and reworking of loose volcanic materials by rivers causes the fluidisation and movement of materials creating a volcanic mudflow or lahar (display image below).

② The lahars move downslope in river valleys, and contain hot ash + material + water. They can carry large blocks several meters in size.

③ As the material moves down the channel it undercuts the banks of the channel. More material is deposited and the channel widens in size.

④ the lahars can reach up to 12km/h eventually reaching the sea where they deposit the sediment they carry.

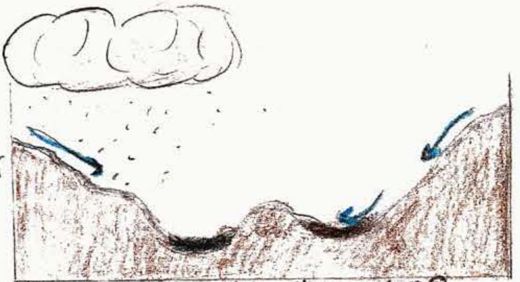
⑤ lahars can be triggered at any time including months after an eruption event when water activates loose volcanic material. These are cold lahars.




Scene Specifications

- Scene comprises 5 stages similar to previous
- Scene ① contains the generation diagram shown below.
- The visualisation should begin with the river channel at normal levels and then show a 'wave' which then shows the channel much wider covering a larger area and carry material.
- The channel should contain blocks up to 2m in size and be fast moving.
- It's a hot deposit and so should be steaming.

①



lahar generation model - show under ①

# Question Design

## Pyroclastic flow questions!

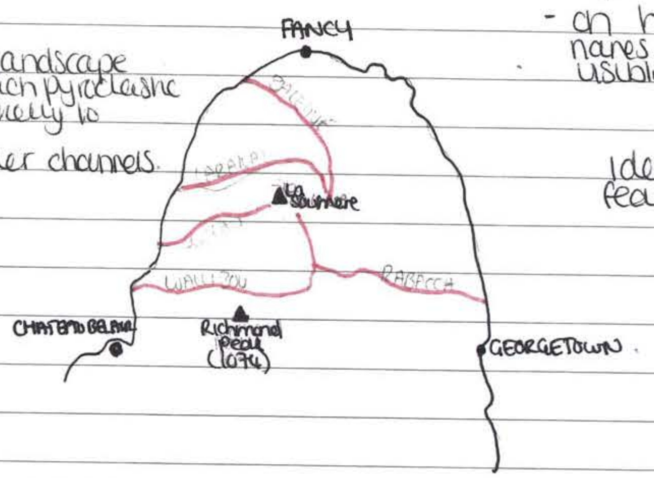
### Interactive question ①

Add features to map?

- top down view of the island
- on hover on features the names and labels become visible.

Choose two landscape features in which pyroclastic flows are likely to flow.
→ any of the river channels.

Identify topographic features.




### Interactive question ②

Drag and drop the correct phrase to the correct part of the diagram.

- Show frame image of PDC descending down volcano flank.
- If possible show within a river valley.

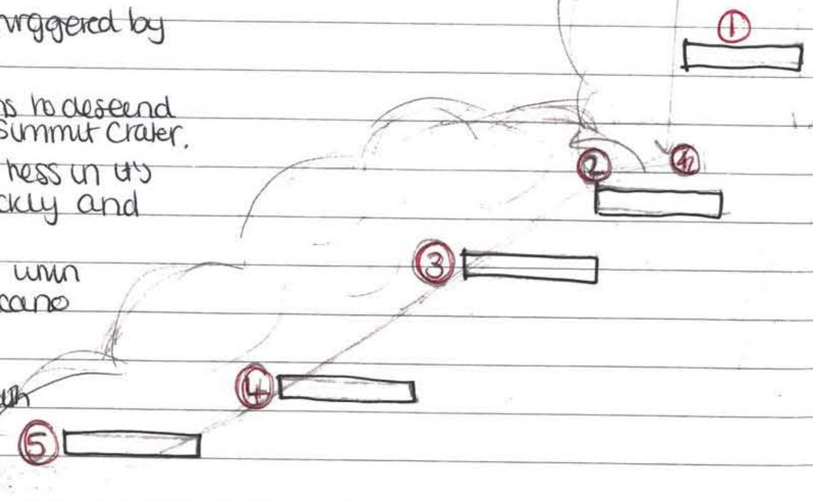
① a pyroclastic flow can be triggered by the collapse of a plume.

② The pyroclastic flow begins to descend down the volcano from the summit crater.

③ They destroy buildings and trees in it's path travelling very quickly and can be very hot.

④ Pyroclastic flows often travel within river valleys down the volcano flanks.

⑤ when they meet the sea PDCs travel both on and underneath the water and can travel for several kms.




## Ash plumes and fall questions.

### Interactive question ①

How wind affects plume direction.

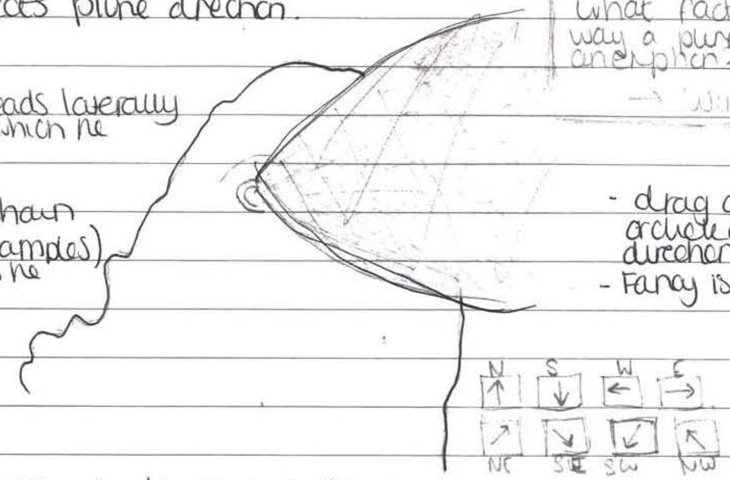
What factor affects the way a plume spreads during an eruption?

→ wind

An ash plume spreads laterally in the direction of which the wind is blowing.

during the eruption shown (use '79 and '02 examples) which direction was the wind blowing.

- drag and drop an arrow in correct directional arrow.
- Fancy is North of island




can we use 3 different direction tests within the same question?

### Interactive Question ②

Drag and drop the definitions to the correct section in the ash plume.

Visual scenario using actual pictures?

① plume ascends from the summit crater throwing ash and rocks in the surrounding area.

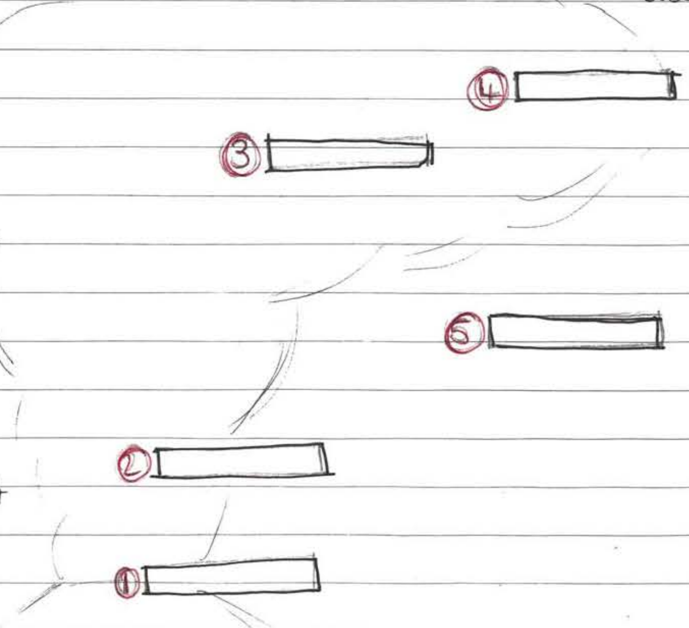
② The hot plume mixes with cooler surrounding air as it rises causing it to grow

③ the plume cools as it rises and eventually stops. It then begins to spread laterally

④ it spreads in the direction of the prominent wind.

⑤ Ash fall rains back down from the plume.

⑥



## APPENDIX E: *Hazard Training* Scene information

### *Explosions & Eruption column*

| # | Location | Text |
|---|---|---|
| 1 | Summit Crater | A column of debris is ejected very quickly from the summit crater high into the atmosphere including large blocks and bombs (projectiles). The column can be several 100's of °C in temperature as it is erupted. |
| 2 | Base/middle of ash plume | Blocks and bombs can land up to a kilometre from the crater but during previous eruptions of La Soufriere have been known to reach up to 5 km from the crater. Blocks and bombs are heavy and fall at incredible speeds, smashing buildings in their path. |
| 3 | Where the plume bends over | Fine rock fragments < 2mm in diameter (ash) are forced upwards in the eruption column. The amount of ash erupted varies dependent on the size and duration of an eruption. |
| 4 | In ash fall | As the column of hot ash continues to rise it mixes with colder surrounding air which causes it to expand. Eventually the column gradually cools and stalls. At this point the ash particles begin to spread laterally depending on the prevailing wind direction. During the 1902 & 1979 eruptions the column reached 18km high before being spread towards Barbados (190km east). |
| 5 | In river valley (ground level) | Some of the ash particles begin to settle out of the column in the down wind direction. When ash falls it can blanket an entire landscape. Where the ash deposits are thick, the weight of the ash can collapse buildings and destroy vegetation. |

### *Pyroclastic Flows & Surges*

| # | Location | Text |
|---|---|---|
| 1 | Summit Crater at base of ash plume | Lava from the La Soufriere volcano is thick and viscous and forms lava domes as is currently seen within the summit crater. When a lava dome becomes unstable and collapses or when a large explosion occurs at the crater, a pyroclastic flow can be formed. |
| 2 | Where the plume begins to ascend from the crater | A pyroclastic flow is an avalanche of hot ash and rock fragments in a turbulent gas cloud that moves very quickly down the flanks of the volcano. |
| 3 | As the pyroclastic flow begins to flow down the valley | Pyroclastic flows move at speeds of up to 100 m/s and can exceed temperatures of 500°C. They cause total devastation knocking down trees and destroying buildings in their path. |
| 4 | Further along the flow path | The finer part of the flow is called a pyroclastic surge and can quickly climb terrain such as ridges and hills. In 1902 pyroclastic surges reached the top of Richmond Peak (1079 m high) located over 5 km from the crater. |
| 5 | Where the flow meets the sea. | When a pyroclastic flow meets the sea, the flow continues to travel beneath the water whilst the surge continues across the surface of the water. This can be hazardous for passing ships and fishing vessels. Pyroclastic flows are impossible to predict and difficult to outrun and are a major cause of loss of life during eruptions. |

*Lahars (Mud flows)*

| # | Location | Text |
|---|---|---|
| 1 | In the upper valley | During heavy rainfall loose volcanic debris may mix with water to produce a dense fluid rock mixture known as a lahar or volcanic mudflow. |
| 2 | Further down the river channel | Lahars act like wet concrete as they rush down valleys around the volcano picking up more debris as they go. They are capable of carrying large blocks several metres in size. |
| 3 | Continues further down the channel | Some lahars are capable of flowing up to 90 kilometres an hour destroying everything in their path including bridges and buildings. In 1902 large lahars flowed down many of the larger river valleys destroying the bridges connecting the northern communities to the south of the island. |
| 4 | At coast edge where it meets the sea | Eventually, the lahar will reach the sea where they deposit the material, turning the water brown. Sometimes they can deposit material at narrow points in the river channel, such as at bridges or turns in the river channel. |
| 5 | At sea interaction | The threat from lahars may last for years after an eruption has ended. On St. Vincent they are most likely to occur after periods of heavy rainfall such a tropical storm or a trough system. |

## APPENDIX F: *Volcano Quiz* scene questions

### *Plumes & Ash Fall*

| Question | Correct Answer | Incorrect Answer | Feedback |
|---|---|---|---|
| Where on the volcano does a plume originate? | The crater | • The northern flanks<br>• The eastern flanks<br>• The western flanks | A plume generally ascends from the open vent which is normally within the summit crater of the volcano. |
| What causes a plume to expand in size? | The hot plume draws in surrounding cooler air as it rises | • It mixes with cold water in the crater<br>• Nothing it just expands<br>• Gas emissions from the crater | As the plume of hot ash rises it mixes with colder surrounding air which causes it to expand. |
| What key factor can affect which direction a plume spreads? | Wind | • Storms<br>• Snow fall<br>• Sunlight | The direction a plume spread is dependent on the way in which the wind is blowing during the eruption. |
| What is volcanic ash? | Fine rock fragments <2mm in size | • Large rock boulders up to 2 metres in size<br>• A large plume that ascends high above a volcano<br>• Small rocks >2mm in size | Ash is made of rock fragments less than 2mm in size. Ash particles fall out of the plume and rain down around the volcano. |
| What happens when volcanic ash mixes with rain water? | It becomes cement-like | • Nothing happens<br>• The ash changes colour<br>• Gas is released | When ash is mixed with rain water it becomes cement-like. |

***Pyroclastic Flows***

| Question | Correct Answer | Incorrect Answer | Feedback |
|---|---|---|---|
| Give the correct definition for a pyroclastic flow. | A hot cloud of gas, ash and larger blocks which travel very quickly down the flanks of the volcano. | • A flood of ash-rich water which flows in river valleys<br>• A loud explosion which occurs during an eruption<br>• A hot cloud of gas that is erupted from the crater | A pyroclastic flow is a hot cloud of gas, ash and larger blocks which travel very quickly down the flanks of the volcano and can travel out to sea. |
| What are the two typical methods of formation of pyroclastic flow? | Collapse of the eruption plume or collapse of lava dome | • Collapse of the eruption plume and water flowing over loose eruption deposits<br>• Thick lava building up in the crater and wind affecting the plume.<br>• Collapse of the eruption plume and release of high levels of gas. | The two typical methods of formation of a pyroclastic flow are due to the collapse of the plume as material falls back down to Earth under gravity and the collapse of a lava dome as it grows larger and becomes unstable. |
| Why are pyroclastic flows dangerous? | All of the above | • They destroy everything in its path including trees and buildings<br>• They travel very quickly and can be very hot<br>• They are impossible to outrun | All of the answers in this question are correct. Pyroclastic flows move at speeds of up to 100m/s and can reach temperatures of typically 500°C. They knock down trees and destroy buildings in their path. Due to the speed at which they travel they are impossible to outrun and are for a major cause of loss of life during an eruption. |
| Where are pyroclastic flows most likely to travel? | Downslope following river valleys | • Upslope towards the crater<br>• Downslope along ridges<br>• They stay within the summit crater | Pyroclastic flows move under the influence of gravity and are often channelled within river valleys. |
| What happens when pyroclastic flows reach the sea? | They can keep flowing over the water. | • The pyroclastic flow stops, they can't travel over water.<br>• An explosion occurs<br>• The begin to travel underwater | When a pyroclastic flow meets the sea, they can keep on flowing over the water. This can be dangerous for passing ships and fishing vessels. |

***Lahars***

| **Question** | **Correct Answer** | **Incorrect Answer** | **Feedback** |
|---|---|---|---|
| Give the correct definition for a lahar. | A fast moving flow of water mixed with ash and larger rocks. | • A thick cloud which rises high into the air made from ash and gases.<br>• The gases released from the volcano<br>• An instrument that is used to measure how much material is erupted from the volcano. | A lahar is a fast moving flow of water mixed with ash and larger rocks. They are also termed volcanic mudflows. |
| What is the key trigger for a lahar to form? | Heavy rainfall | • Wind conditions<br>• Nothing, they just happen<br>• Hot and dry weather | Lahars generally form when large amounts of water flow over loose ash deposits from the volcano. Generally this is after periods of heavy rainfall, such as a tropical storms or snow melt which washes material down into river valleys. |
| How is more material added to a lahar as it flows down through river valleys? | By eroding the river banks as it flows | • People throwing things into the flow<br>• No material is added<br>• By wind blowing loose material into the flow | As the lahar continues to move down the river valleys, it picks up more material by eroding the river banks. |
| Where do lahars deposit their material? | Where they reach the sea, at narrow points in the river valley such as bridges or turns in the river channel. | • Material is deposited all the way along the river channel<br>• At wider points in the river channel<br>• Where the flow is moving at its fastest such as straight points in the river channel | Some lahars are capable of flowing up to 90 kilometres an hour. Eventually, the lahar will reach the sea where they deposit the material, turning the water brown. Sometimes they can deposit material at narrow points in the river channel, such as at bridges or turns in the river channel. |
| When does a lahar event occur? | All of the above | • During an eruption<br>• A month after the eruption<br>• Years after the last eruption | All of the answers are correct. Lahars are very dangerous as they can be triggered during and even years after the last eruption. |

# APPENDIX G: Research ethics approval forms

**PLYMOUTH UNIVERSITY FACULTY OF SCIENCE AND ENVIRONMENT**

**Research Ethics Committee**

APPLICATION FOR ETHICAL APPROVAL OF RESEARCH INVOLVING HUMAN PARTICIPANTS

**All applicants should read the guidelines which are available via the following link:**
https://staff.plymouth.ac.uk//SciEnv/humanethics/intranet.htm

This is a WORD document. Please complete in WORD and extend space where necessary.

*All applications must be word processed. Handwritten applications* ***will*** *be returned.*

***Please submit with interview schedules and/or questionnaires appropriately.***

*Postgraduate and Staff must submit a signed copy to SciEnvHumanEthics@plymouth.ac.uk*

*Undergraduate students should contact their School Representative of the Science and Environment Research Ethics Committee or dissertation advisor prior to completing this form to confirm the process within their School.*

---

## *1. TYPE OF PROJECT*

***1.1 What is the type of project? (Put an X next to one only)***

**STAFF should put an X next to one of the three options below:**

Specific project

Thematic programme of research

Practical / Laboratory Class

.

***1.2 Put an X next to one only***

**POSTGRADUATE STUDENTS should put an X next to one of the options below:**

Taught Masters Project

M.Phil / PhD by research **X**

**UNDERGRADUATE STUDENTS should put an X next to one of the options below:**

Student research project

Practical / Laboratory class where you are acting as the experimenter

## *2. APPLICATION*

| ***2.1 TITLE of Research project*** |
| --- |
| 3D Visualisation of Volcanic Hazards |
| ***2.2 General summary of the proposed research for which ethical clearance is sought, briefly outlining the aims and objectives and providing details of interventions/procedures involving participants (no jargon)*** |

The fundamental aim of this research is to increase community resilience to volcanic hazards through improved education and communication. This will be achieved through the development of an educational Serious Game which raises awareness about hazardous volcanic phenomena (e.g. pyroclastic flows, ash fall and volcanic mudflows). A Serious Game is a game that does not have entertainment or fun as its primary function, in this instance education is the primary function.

The study location for this research is the Eastern Caribbean island of St. Vincent. The last eruption of the Soufriere volcano was in 1979 and since then a generation has passed with little to no experience of volcanic hazards. Added to the prioritisation of other natural hazards which pose more of a threat to day-to-day life (e.g. hurricanes, flooding & landslides); a challenge arises in raising awareness of the potential for a future eruption of Soufriere.

Natural hazards education and communication often encounters issues relating to complacency, misconceptions and, most common of all, illiteracy. By developing a Serious Game such as this, it's hoped some of these common issues can be overcome by creating an immersive virtual experience and using a hands-on learning approach.

The objectives of this research are to:

- Provide a new interactive and engaging tool that can be used for volcanic hazard outreach across St. Vincent and the wider Caribbean region.
- Improve knowledge of volcanic hazards on St. Vincent.
- Establish the effectiveness of video games technology to communicate volcanic hazard information.
-

Ethics approval is being sought for the game testing and implementation phase of this research. An application for ethics relating to this project to fun focus groups and online questionnaires was previously granted in July 2014.

A copy of the completed video game this application refers to is available on request.

**Participant involvement**

This application seeks ethical approval for the involvement of participants in this study. The participants will be involved in different activities as detailed below.

*Agencies*

In this instance 'agencies' refers to anybody who is involved with volcanic hazard education and outreach on St. Vincent. This is likely to be school teachers, members of the Red Cross, the National Emergency Management Organisation (NEMO) and the University of the West Indies Seismic Research Centre (UWI SRC). All agencies will be asked to attend a meeting in which they will be told about the game and how to include it within their current education and outreach activities. They will be asked to conduct a session with their students using the game and to then feedback to the research team on their thoughts and opinions on how that session went.

*Outreach Participants*

Outreach participants will be members of the community who are the target of volcanic hazard education and outreach programmes. They will be asked to be involved in one of three phases of research. Phase one involves the participants undertaking one of three outreach sessions: one session will be an outreach session as it is currently conducted on St. Vincent by then organisations mentioned above, the second session is the use of the game with no additional educational techniques used and the third session is an augmented outreach session with the game included. Before and after the outreach session participants will be asked to complete a short quiz on volcanic hazards to measure their knowledge gain through the process. They will also be observed by a member of the research team and/or video recorded to monitor levels of engagement, participation and motivation throughout. Additionally, when playing the game information about a player's progress and about how they play the game will be recorded through in-built game analytics.

Phase two will involve participants undergoing a full outreach session which includes the use of the video game. The difference from session to session is the manner in which the game is played: by individuals, small groups of 3-4 and one large group (15+). As previously, all participants will be asked to complete a volcanic hazard knowledge quiz before and after the

session, be observed and/or video recorded throughout and their progress, when playing the game, recorded through in-built game analytics.
All participants involved in the first two phases will also be asked their personal thoughts and opinions on the game via focus groups or semi-structured interviews.

*Human Eye Tracking*

A separate study will be undertaken using human eye tracking technology whilst participants play the game. This study is aimed to determine the usability of the game and to identify distractions or fixation points whilst playing. The study will be undertaken with three groups of participants: adults with no volcanic experience, children with no volcanic experience and adults with volcanic experience. In some instances, some participants may be asked questions relating to their specific eye traces to understand further the data collected.

***2.3 Physical site(s) where research will be carried out***

The fieldwork for this research will be conducted on the East Caribbean island of St. Vincent within communities across the island, primarily in four locations: Chateaubelair, Fancy, Georgetown and Kingstown.
The sessions will take place within school classrooms or community centres within each town on St. Vincent.

***2.4 External Institutions involved in the research (e.g. other university, hospital, prison etc.)***

University of the West Indies, Seismic Research Centre (UWI SRC)
National Emergency Management Organisation (NEMO) St. Vincent
The Red Cross, St. Vincent
Primary and Secondary Schools ion St. Vincent: Tourama Primary school, Dixon Primary school, Langley Park Government school, Petit Bordel secondary school, Troumaca Ontario secondary School, Buccament Bay secondary school, Central Leeward secondary school, Sandy Bay secondary school and Georgetown secondary school.

***2.5 Name, telephone number, e-mail address and position of lead person for this project (plus full details of Project Supervisor if applicable)***

Lara Mani (PhD Research Student), mob: 07791 670593, email: lara.mani@plymouth.ac.uk, **Project supervisors:** Dr Paul Cole (paul.cole@plymouth.ac.uk), Prof Iain Stewart (iain.stewart@plymouth.ac.uk), Prof Mike Phillips (M.Phillips@plymouth.ac.uk) & Dr Stephanie Lavau (stephanie.lavau@plymouth.ac.uk) – all Plymouth University.

***2.6 Start and end date for research for which ethical clearance is sought (NB maximum period is 3 years)***

**Start date:** March 2015 **End date:** October 2016

***2.7 Has this same project received ethical approval from another Ethics Committee?***

Delete as applicable: **No** ~~**Yes**~~

Yes, but this application seeks approval for different ethics approval for which the original does not apply.

***2.8 If yes, do you want Chairman's action?***

Delete as applicable: **No** ~~**Yes**~~

***If yes, please include other application and approval letter and STOP HERE. If no, please continue***

## *3. PROCEDURE*

***3.1 Describe procedures that participants will engage in, Please do not use jargon***

**Agencies**

The first phase of this research will be undertaken with people involved in volcanic hazard education and outreach in St. Vincent. The agencies will initially be asked to attend a meeting in which the game will be introduced and fully explained. They will then be asked to play the game but no information will be recorded about their progress as the aim is to demonstrate the game and provide a level of familiarity so it can be used within their session. Agencies will also be asked to provide their thoughts and opinions about the game and the likelihood of them using it in their own sessions. The discussion will be undertaken in a focus group style with semi-structured questions and facilitated by a member of the research team. The session is designed as a briefing and the game will be provided to all educators to use in their own outreach session with guidance notes at the end.

The second phase will involve re-meeting with the agencies that have used the game within an outreach session of their own. In the style of a semi-structured interview they will be asked questions about if and how they used the game and about how they felt their audience engaged in the session.

**Outreach Participants**

This testing involves community members testing the outreach sessions and will be undertaken in 3 phases. The three phases involve different implementation strategies for the game and a participant will be asked to undertake one session from either phases one or two and all participants will be asked to complete phase three.

*Phase one* is designed to help determine if the game is successful in enhancing volcanic education and outreach and is split into three sessions. The first session requires participants to undertake a normal outreach session that is currently given on St. Vincent without the use of the game. The second session will be playing the game without the use of any other educational techniques and the third session will be an outreach session which involves the use of the game. Each participant will be asked to complete a short volcanic hazard knowledge quiz prior to the outreach session and again after the session has concluded. An example of the quiz is included with this application. Participants will be observed throughout and/or video recorded to monitor levels of engagement and motivation. These sessions will be undertaken with primary and secondary aged school children and with adult participants.

*Phase two* will test the best strategy for using the game in an outreach session. Participants will be asked to take part in one of three outreach sessions. All sessions will be identical except how they will be asked to play the game. Each session will have a slightly different strategy: the first session will have participants playing the game individually, the second session will be played in small groups of 3-4 and the third session will be played as an entire group (15+). As in phase one, all participants will be asked to complete a volcanic hazard knowledge quiz before and after the outreach session. Participants will be observed throughout and/or video recorded to monitor levels of engagement and motivation. This testing will be undertaken primarily with secondary school aged children and adult participants.

*Phase three* involved the same participants from phases one and two. The participants will be asked to discuss with a member of the research team their thoughts and opinions about the game and the outreach sessions. The discussions will be run as focus groups or one-to-one discussions and will take place after the participants have completed an outreach sessions. The participants will be voice recorded but no personal information about the participants will be obtained.

It is intended that all outreach sessions will be observed and/or video recorded and focus groups and group discussions voice recorded. When playing the video game, information about participant's progress and data about how they play the game will also be recorded through in-built game analytics. This information will include the number of times activities in the game are completed or the number of correct answers given. This option will be an opt-in selection and the player will be prompted before playing the game. This method does not record any personal information about the players.

***Human Eye Tracking***

For this study, participants will be asked to play the game whilst using human eye tracking technology. The participants may be selected from participants from the outreach studies or may be recruited separately to this study. Three types of participants will be tested: adults with no volcanic hazard experience, children with no volcanic hazard experience and adults with volcanic hazard experience. Only information about the participant's age and volcanic hazard experience will be obtained for this study. In some instances, follow up questions may be asked to the participants whilst reviewing the eye traces in an interview style. These questions will relate to the specific eye trace recordings and may include questions to understand further areas of fixation or distraction (i.e. what is it about that particular object that caught your eye?).

***3.2 How long will the procedures take? Give details***

**Agencies**

The initial meeting should take no longer than one hour to run. The secondary semi-structured interviews are expected to last 20-30 minutes.

**Outreach Participants**

| |
|---|
| Each outreach session is expected to last around one hour. The phase three focus groups and semi-structured interviews will last between 40 to 60 minutes.<br>***Human Eye Tracking***<br>These sessions are not expected to last longer than 40 minutes. Where applicable, any follow up questions will last around 30 minutes. |
| ***3.3 Does your research involve deception?*** |
| Delete as applicable: **No** ~~**Yes**~~ |
| ***3.4 If yes, please explain why the following conditions apply to your research:*** |
| ***a) Deception is completely unavoidable if the purpose of the research is to be met*** |
| |
| ***b) The research objective has strong scientific merit*** |
| |
| ***c) Any potential harm arising from the proposed deception can be effectively neutralised or reversed by the proposed debriefing procedures (see section below)*** |
| |
| ***3.5 Describe how you will debrief your participants*** |
| At the end of all outreach sessions the facilitator or a member of the research team will explain the purpose of the research and again and will provide the opportunity to ask questions. The participants will also be reminded once again about their right to withdraw part or all of their data at any time and that they can contact the research team if required. |
| ***3.6 Are there any ethical issues (e.g. sensitive material)?*** |
| Delete as applicable: **No** ~~**Yes**~~ |
| ***3.7 If yes, please explain. You may be asked to provide ethically sensitive material. See also section 11*** |
| |

## *4. BREAKDOWN OF PARTICIPANTS*

### *4.1 Summary of participants*

| ***Type of participant*** | ***Number of participants*** |
|---|---|
| *Non-vulnerable Adults* | *75* |
| *Minors (< 16 years)* | *96* |
| *Minors (16-18 years)* | *-* |
| *Vulnerable Participants (other than by virtue of being a minor)* | *-* |
| *Other (please specify)* | *-* |
| ***TOTAL*** | *172* |

| ***4.2 How were the sample sizes determined?*** |
|---|
| The sample sizes have been calculated based on the minimum number of people required per session to provide a statistically viable dataset. The participant numbers are divided as follows:<br>- Agencies sessions – 20 non-vulnerable adults<br>- Outreach phase one testing – 45 minors (primary to secondary aged) and 45 non-vulnerable adults based on 15 participants per stage of testing.<br>- Outreach phase two – 41 minors (primary to secondary aged) allowing for at least 10 participants for the first stage, 16 participants comprising 4 groups of 3-4 participants for stage two and one large group of at least 15 participants.<br>- Outreach phase three – using participants that have already been accounted for in phases one and two.<br>- Human eye tracking study – Some participants will be used form the outreach session studies with an extra 10 Minors and 10 adult participants allowed for where additional participants are required. |
| ***4.3 How will subjects be recruited?*** |
| **Agencies**<br>The participants for this study will be selected based on their expertise. Many of the educators that will be<br>involved with the study are already known to the research team. They will include outreach coordinators from<br>the Seismic Research Centre of the University of the West Indies, National Emergency Management Office<br>(NEMO) on St. Vincent and local school teachers. Many of the expected participants are already aware of the research project and will first be approached via email. A follow up phone call will also be given closer to the time of the session.<br><br>**Outreach participants**<br>Members of the public will be recruited through posters and flyers in local shops, social media and with the<br>assistance of organisations such as NEMO & STREVA in St. Vincent.<br><br>**Human Eye Tracking** |

Some participants will be used from the phase one and phase two studies. Other participants, such as the adults with volcanic hazard experience, will be directly targeted. This is likely to be through word of mouth or through community leaders and stakeholder suggestions.

***4.4 Will subjects be financially rewarded? If yes, please give details.***

*Agencies* – no financial award will be offered.
*Outreach participants & Human Eye Tracking* – Travel expenses will be provided to participants who have travelled outside of their communities to the outreach sessions and focus groups.

## *5. NON-VULNERABLE ADULTS*

***5.1 Are some or all of the participants non-vulnerable adults?***

Delete as applicable: ~~**No**~~ **Yes**

***5.2 Inclusion / exclusion criteria***

**Inclusion criteria:**
*Agencies* – working within volcanic hazard education and outreach across St. Vincent.
*Outreach participants* – a resident of the island of St. Vincent for more than 2 years.
*Human Eye Tracking* – a resident of St. Vincent for more than 2 years. Some participants will require an experience of volcanic hazards.

***5.3 How will participants give informed consent?***

Prior to commencing any of the sessions for all participants (stakeholder, outreach and eye tracking), the researcher will provide information sheets and consent forms to read and allow for any questions to be answered. Where possible the forms will be issued at least 24 hours prior to the study.

***5.4 Consent form(s) attached***

Delete as applicable: ~~**No**~~ **Yes**

***If no, why not?***

***5.5 Information sheet(s) attached***

Delete as applicable: ~~**No**~~ **Yes**

***If no, why not?***

***5.6 How will participants be made aware of their right to withdraw at any time?***

The information sheet that will be provided to the participants explains their right to withdraw and withdraw their data at any time. This will be provided to all participants prior to completing any of the research activities. All participants will be provided with the research teams contact details in case they wish to withdraw their information. In cases where a participant wishes to withdraw from a focus group style discussion, it will be explained that although they may wish to withdraw from the study the information they have contributed to the discussions will remain unless specifically requested to also be withdrawn.

***5.7 How will confidentiality be maintained, including archiving / destruction of primary data where appropriate, and how will the security of the data be maintained?***

The confidentiality of all participants will be maintained in line with the research ethics requirements of Plymouth University. All participants' personal information will be kept separate from their data and any forms of identifying participants will be removed from focus group transcripts. It may instead be necessary to use codes or pseudonyms to identify participants.

All data provided by the participants will be stored digitally or in hard-copies. These will be safely stored by locking them into filling cabinets or by password protected digital files. Only the research team will be able to access the data and it will be securely archived for 5 years from publication of results from the research project and then will be destroyed.

Participants personal details will not be included in any publications or presentations relating to the research
project. Identification will only happen where participants give written consent.

## *6. MINORS <16 YEARS*

***6.1 Are some or all of the participants under the age of 16?***

Delete as applicable: ~~**No**~~ **Yes**

***If yes, please consult special guidelines for working with minors. If no, please continue.***

***6.2 Age range(s) of minors***

Primary and Secondary aged school children – ages between 8-15

***6.3 Inclusion / exclusion criteria***

Inclusion criteria – full-time students in primary or secondary schools on St. Vincent. All participants will require written consent from their parents/guardians.

***6.4 How will minors give informed consent? Please tick appropriate box and explain (See guidelines)***

Delete as applicable: **Opt-in** ~~**Opt-out**~~

***6.5 Consent form(s) for minor attached***

Delete as applicable: ~~**No**~~ **Yes**

***If no, why not?***

***6.6 Information sheet(s) for minor attached***

Delete as applicable: ~~**No**~~ **Yes**

***If no, why not?***

***6.7 Consent form(s) for parent / legal guardian attached***

Delete as applicable: ~~**No**~~ **Yes**

***If no, why not?***

***6.8 Information sheet(s) for parent / legal guardian attached***

Delete as applicable: ~~**No**~~ **Yes**

***If no, why not?***

***6.9 How will minors be made aware of their right to withdraw at any time?***

Information sheet will be provided for both children and parents/guardians explaining their right to withdraw at any time. The information sheets and consent forms will first be provided to parents/guardians before being given to child participants to avoid unnecessary conflict. All forms will be provided to parents/guardians and child participants at least 48 hours prior to the study.
All participants will be provided with the research teams contact details in case they wish to withdraw their information at any time. During the session debrief the participants will also be reminded again of their right to withdraw their information.

***6.10 How will confidentiality be maintained, including archiving / destruction of primary data where appropriate, and how will the security of the data be maintained?***

The confidentiality of all participants will be maintained in line with the research ethics requirements of Plymouth University. All participants' personal information will be kept separate from their data and any forms of identifying participants will be removed from focus group transcripts. It may instead be necessary to use codes or pseudonyms to identify participants.

All data provided by the participants will be stored digitally or in hard-copies. These will be safely stored by locking them into filling cabinets or by password protected digital files. Only the research team will be able to access the data and it will be securely archived for 5 years from publication of results from the research project and then will be destroyed.

Participants personal details will not be included in any publications or presentations relating to the research project. Identification will only happen where participants give written consent.

### *7. MINORS 16-18 YEARS OLD*

| |
|---|
| ***7.1 Are some or all of the participants between the ages of 16 and 18?*** |
| Delete as applicable: **No** ~~**Yes**~~ |
| ***If yes, please consult special guidelines for working with minors. If no, please continue.*** |
| ***7.2 Inclusion / exclusion criteria*** |
| |
| ***7.3 How will minors give informed consent? (See guidelines)*** |
| |
| ***7.4 Consent form(s) for minor attached*** |
| Delete as applicable: **No** **Yes** |
| ***If no, why not?*** |
| |
| ***7.5 Information sheet(s) for minor attached*** |
| Delete as applicable: **No** **Yes** |
| ***If no, why not?*** |
| |
| ***7.6 Consent form(s) for parent / legal guardian attached*** |
| Delete as applicable: **No** **Yes** |
| ***If no, why not?*** |
| |
| ***7.7 Information sheet(s) for parent / legal guardian attached*** |
| Delete as applicable: **No** **Yes** |
| ***If no, why not?*** |
| |
| ***7.8 How will minors be made aware of their right to withdraw at any time?*** |
| |

| |
|---|
| ***7.9 How will confidentiality be maintained, including archiving / destruction of primary data where appropriate, and how will the security of the data be maintained?*** |
| |

## *8. VULNERABLE GROUPS*

| |
|---|
| ***8.1 Are some or all of the participants vulnerable? (See guidelines)*** |
| Delete as applicable: **No** **~~Yes~~** |
| ***If yes, please consult special guidelines for working with vulnerable groups. If no, please continue.*** |
| ***8.2 Describe vulnerability (apart from possibly being a minor)*** |
| |
| ***8.3 Inclusion / exclusion criteria*** |
| |
| ***8.4 How will participants give informed consent?*** |
| |
| ***8.5 Consent form(s) for vulnerable person attached*** |
| Delete as applicable: **No** **Yes** |
| ***If no, why not?*** |
| |
| ***8.6 Information sheet(s) for vulnerable person attached*** |
| Delete as applicable: **No** **Yes** |
| ***If no, why not?*** |
| |
| ***8.7 Consent form(s) for parent / legal guardian attached*** |
| Delete as applicable: **No** **Yes** |
| ***If no, why not?*** |
| |
| ***8.8 Information sheet(s) for parent / legal guardian attached*** |
| Delete as applicable: **No** **Yes** |
| ***If no, why not?*** |
| |
| ***8.9 How will participants be made aware of their right to withdraw at any time?*** |
| |
| ***8.10 How will confidentiality be maintained, including archiving / destruction of primary data where appropriate, and how will the security of the data be maintained?*** |
| |

## *9. EXTERNAL CLEARANCES*

***Investigators working with children and vulnerable adults legally require clearance from the Disclosure and Barring Service (DBS)***

| |
|---|
| ***9.1 Do ALL experimenters in contact with children and vulnerable adults have <u>current</u> DBS clearance? Please include photocopies.*** |
| Delete as applicable: **No** ~~**Yes**~~ ~~**N/A**~~ |
| ***If no, explain*** |
| Application is currently being processed, a photocopy will be provided to the committee upon receipt. |
| ***9.2 If your research involves external institutions (school, social service, prison, hospital etc) please provide cover letter(s) from institutional heads permitting you to carry out research on their clients, and where applicable, on their site(s). Are these included?*** |
| Delete as applicable: **No** ~~**Yes**~~ ~~**N/A**~~ |
| ***If not, why not?*** |
| All participating external institutions will be asked to participate by a third party (NEMO) as part of their annual outreach activities on St. Vincent. The game developed will be included within these outreach sessions and not held as sessions on their own. As the outreach activities held during volcano awareness week are arranged by NEMO, no institutes will be approached by the research team to participate. Letters will be obtained from the participating institutes or from NEMO and submitted to the ethics committee when received. Where an institute is approached by the research team, letters of consent will be provided to the ethics committee before research is carried out. |

## *10. PHYSICAL RISK ASSESSMENT*

| |
|---|
| ***10.1 Will participants be at risk of physical harm (e.g. from electrodes, other equipment)? (See guidelines)*** |
| Delete as applicable: **No** ~~**Yes**~~ |
| ***10.2 If yes, please describe*** |
| |
| ***10.3 What measures have been taken to minimise risk? Include risk assessment proformas which has been signed by the Head of Department*** |
| |
| ***10.4 How will you handle participants who appear to have been harmed?*** |
| |

## *11. PSYCHOLOGICAL RISK ASSESSMENT*

| |
|---|
| ***11.1 Will participants be at risk of psychological harm (e.g. viewing explicit or emotionally sensitive material, being stressed, recounting traumatic events)? (See guidelines)*** |
| Delete as applicable: ~~**No**~~ **Yes** |
| ***11.2 If yes, please describe*** |
| Outreach and human eye tracking participants will be asked to play a video game that shows their volcano in a realistic looking eruption. The simulations are based on historical accounts and records and some of the outreach and many of the eye tracking participants are expected to have lived through the last eruption in 1979. Residents of St. Vincent are aware of the risk the volcano poses and the video game is seen as a measure of alleviating the risk by providing information about what to expect and the likelihood of causing distress is considered to be low. |
| ***11.3 What measures have been taken to minimise risk?*** |
| Prior to playing the video game all outreach and eye tracking participants will be provided with an information sheet about what the research entails and will be given the chance to ask any questions. After they have played the game and outreach session is concluded, outreach participants will be debriefed and given the chance to ask any further questions. They will also |

| |
|---|
| be provided with the research team's information in case they have any questions after the session is concluded. Members of the research team have been advised and sessions facilitated by outreach officers who are extremely experienced. |
| ***11.4 How will you handle participants who appear to have been harmed?*** |
| In the unlikely event that outreach or eye tracking participants appears to be harmed, they will be withdrawn from the study and given the opportunity to talk one-to-one with a member of the research team about their concerns. |

## *12. RESEARCH OVER THE INTERNET*

| |
|---|
| ***12.1 Will research be carried out over the internet?*** |
| Delete as applicable: **No** ~~**Yes**~~ |
| ***12.2 If yes, please explain protocol in detail, explaining how informed consent will be given, right to withdraw maintained, and confidentiality maintained. Give details of how you will guard against abuse by participants or others (see guidelines)*** |
| |

## *13. CONFLICTS OF INTEREST & THIRD PARTY INTERESTS*

| |
|---|
| ***13.1 Do any of the experimenters have a conflict of interest? (See guidelines)*** |
| Delete as applicable: **No** ~~**Yes**~~ |
| ***13.2 If yes, please describe*** |
| |
| ***13.3 Are there any third parties involved? (See guidelines)*** |
| Delete as applicable: ~~**No**~~ **Yes** |
| ***13.4 If yes, please describe*** |
| Members of the outreach and education team of the University of the West Indies Seismic Research Centre will help to organise and run some of the outreach sessions.<br>The National Emergency Management Organisation of St. Vincent will also help to organise the sessions and recruit participants. |
| ***13.5 Do any of the third parties have a conflict of interest?*** |
| Delete as applicable: **No** ~~**Yes**~~ |
| ***13.6 If yes, please describe*** |
| |

## *14. ADDITIONAL INFORMATION*

| |
|---|
| ***14.1 [Optional] Give details of any professional bodies whose ethical policies apply to this research*** |
| |
| ***14.2 [Optional] Please give any additional information that you wish to be considered in this application*** |
| |

## *15. ETHICAL PROTOCOL & DECLARATION*

To the best of our knowledge and belief, this research conforms to the ethical principles laid down by the University of Plymouth and by any professional body specified in section 14 above.

This research conforms to the University's Ethical Principles for Research Involving Human Participants with regard to openness and honesty, protection from harm, right to withdraw, debriefing, confidentiality, and informed consent

**Sign below where appropriate:**

**STAFF / RESEARCH POSTGRADUATES**

| | Print Name | Signature | Date |
|---|---|---|---|
| Principal Investigator: | ______________ | ______________________ | ______________ |
| Other researchers: | ______________ | ______________________ | ______________ |
| | ______________ | ______________________ | ______________ |
| | ______________ | ______________________ | ______________ |

**Staff and Research Postgraduates should email the completed and signed copy of this form to Paula Simson.**
**UG Students**

| | Print Name | Signature | Date |
|---|---|---|---|
| Student: | ______________ | ______________________ | ______________ |
| Supervisor / Advisor: | ______________ | ______________________ | ______________ |
| | ______________ | ______________________ | ______________ |
| | ______________ | ______________________ | ______________ |

**Undergraduate students should pass on the completed and signed copy of this form to their School Representative on the Science and Environment Human Ethics Committee.**

| | Signature | Date |
|---|---|---|
| School Representative on Science and Environment Faculty Human Ethics Committee | ______________________ | ______________ |

**Faculty of Science and Environment Research Ethics Committee List of School Representatives**

School of Geography, Earth and Environmental Sciences Dr Sanzidur Rahman

| | |
|---|---|
| | Dr Agnieszka Kosinska |
| School of Biological Sciences | Dr Victor Kuri |
| School of Biomedical and Healthcare Sciences | Dr David J Price |
| School of Marine Science & Engineering | Dr Gillian Glegg (Chair) |
| | Dr Liz Hodgkinson |
| School of Computing & Mathematics | Mr Martin Beck |
| | Dr Mark Dixon |
| External Representative | Prof Linda La Velle |
| Lay Member | Rev. David Evans |

Committee Secretary:  Mrs Paula Simson

email: paula.simson@plymouth.ac.uk

tel: 01752 584503

## APPENDIX H: Pre (A) and Post (B)-test knowledge quiz (Adults and students)

## Volcanic Hazards Quiz A.

***Adults***

The following quiz contains 12 questions about volcanic hazards. Please complete *all questions* with as much detail as you can. If you require any assistance please ask a member of the outreach team.

*Before filling out this questionnaire please make sure you have read and completed the research information sheets and consent forms.*

## Personal Information

**Name:** **Date:**

**Age Range (please circle):**

| | | |
|---|---|---|
| 18 – 29 | 40 – 49 | 60 – 69 |
| 30 – 39 | 50 – 59 | 70+ |

**Town of Residence:**

**Occupation:**

**What is your highest level of education?**

- ☐ School leaving certificate (CSEC)
- ☐ GCE O'Levels or CSEC
- ☐ GCE A'Levels, CXC or CAPE
- ☐ Undergraduate diploma
- ☐ None

Professional qualification (*please state*) ________________________________

Other (*please state*) ________________________________

**Have you ever done any outreach or education sessions relating to volcanic hazards? If yes, please give detail.**

Please indicate what you consider to be your level of knowledge of volcanic hazards (where 1 is no knowledge and 5 is a very good knowledge)

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

**How did you hear about this research?**

## Questions

1. What is the name of the volcano on St. Vincent?

2. When was the last eruption of this volcano?

3. This volcano has had many historical eruptions, can you give the years when historic eruptions have occurred?

4. Please describe what is meant by the phrase 'volcanic hazard'?

5. Describe what is meant by the term 'lahar'.

6. When is a lahar most likely to occur?

7. Volcanic ash is produced during an eruption. What exactly is volcanic ash?

8. What colour zone of the 'volcanic hazard map' are these towns in? (Red, Orange, Yellow or Green).

Chateaubelair ☐

Fancy ☐

Georgetown ☐

9. What is your understanding of a 'pyroclastic flow'?

10. Sometimes there are signs (precursors) that can be detected that may indicate that a volcano may erupt, what precursory activity might be experience on St. Vincent?

11. How long can a volcanic eruption last?

12. Please select from the following list all hazardous phenomena that are associated with the volcano on St. Vincent.

- ☐ Ash fall
- ☐ Lava flows
- ☐ Pyroclastic flows & surges
- ☐ Earthquakes
- ☐ Ballistics / volcanic bombs
- ☐ Gas release / fumaroles
- ☐ Fire fountains
- ☐ Volcanic mudflows / lahars

Other: ______________________________

***Thank you for completing this quiz!***

***Please make sure you have filled in all of your information and then return it to a member of the outreach team.***

If you have any questions please do not hesitate to ask a member of the outreach team

or email: lara.mani@plymouth.ac.uk

## Volcanic Hazards Quiz B.
***Adults***

The following quiz contains 12 questions about volcanic hazards. Please complete *all questions* with as much detail as you can. If you require any assistance please ask a member of the outreach team.

*Before filling out this questionnaire please make sure you have read and completed the research information sheets and consent forms.*

## Personal Information

**Name:** **Date:**

**Town of Residence:**

**Please indicate which outreach session you have undertaken (date and location).**

---

## Questions

1. What is meant by the term 'volcanic hazard'?

2. What volcanic hazards may be seen on St. Vincent during a future volcanic eruption?

3. St. Vincent has experienced many historical volcanic eruptions. In what years did these eruptions occur?

4. What is the name of the volcano that experienced these eruptions?

5. When was the last eruption from this volcano?

6. What is your understanding of a ‘lahar’?

7. When might a lahar occur?

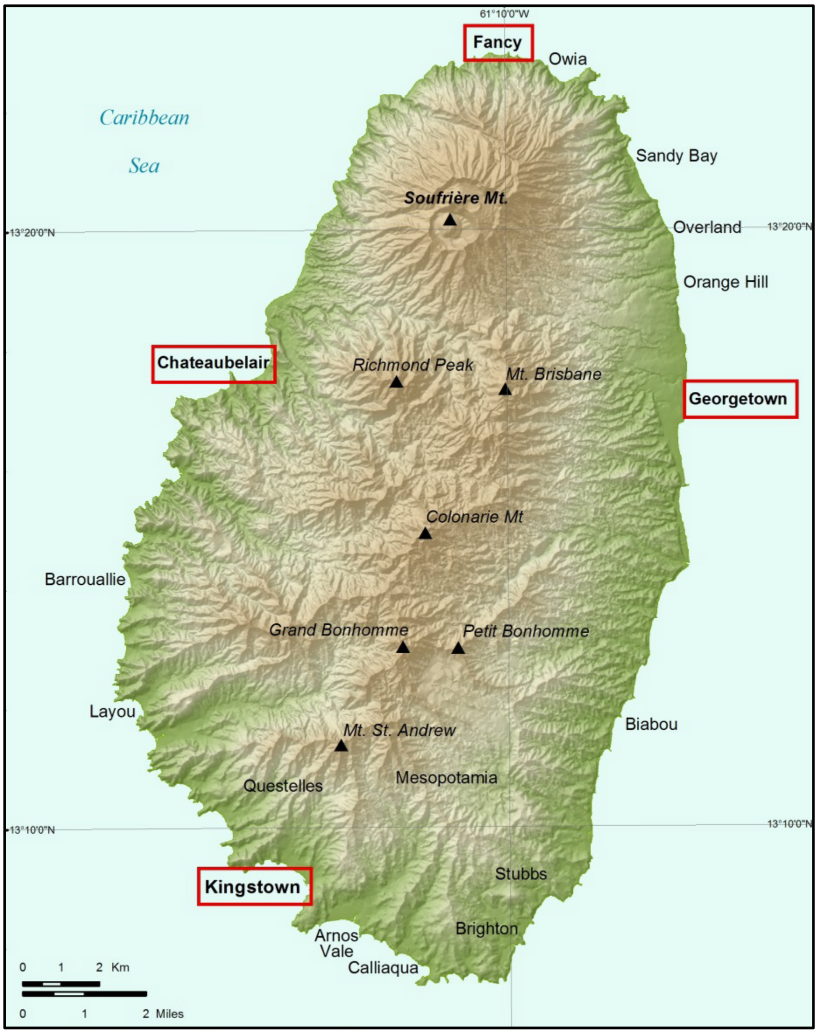
8. Pyroclastic flows are often associated with volcanic eruptions. What exactly is a pyroclastic flow?

9. Precursory activity (signs or unusual activity) at a volcano may indicate that it is ready to erupt. What precursory activity might be experience on St. Vincent prior to an eruption?

10. How long can a volcanic eruption last?

11. Volcanic ash is often associated with volcanic eruptions. What is volcanic ash?

12. Below is a picture of St. Vincent. Draw on and label the different colour volcanic hazard zones as shown on the 'volcanic hazard map' for the island.




***Thank you for completing this quiz!***
***Please make sure you have filled in all of your information and then return it to a member of the outreach team.***

If you have any questions please do not hesitate to ask a member of the outreach team or email: lara.mani@plymouth.ac.uk

## Volcano Quiz A.
***Students***

The following quiz contains 12 questions about volcanic hazards. Please complete *all questions* with as much detail as you can. You can also use diagrams to answer the questions.

If you require any assistance, please ask a member of the outreach team.

**Name:** **Date:**

**School / College:**

**Year & Class:**

## Questions

1. What is the name of the volcano on St. Vincent?

2. What year did this volcano last erupt?

3. Can you name any other years when this volcano has erupted?

4. Volcanoes have many 'volcanic hazards' that occur during eruptions. What does the phrase 'volcanic hazard' mean?

5. Volcanic ash is produced by many eruptions around the world including those on St. Vincent but what exactly is volcanic ash?

6. Where does volcanic ash come from?

7. Lahars are common during and after volcanic eruptions. Why do lahars form?

8. How long after a volcanic eruption can lahars occur?

9. What is a pyroclastic flow?

10. Why are pyroclastic flows dangerous?

11. What colour zone of the 'volcanic hazard map' are these towns in? (Red, Orange, Yellow or Green).

| | |
|---|---|
| Chateaubelair | |
| Fancy | |
| Georgetown | |

12. How long can a volcanic eruption last?

---

***Thank you for completing this quiz!***
***Please make sure you have filled in all of your information and then return it to a member of the outreach team.***

If you have any questions please do not hesitate to ask a member of the outreach team or email: lara.mani@plymouth.ac.uk

## Volcano Quiz B.
***Students***

The following quiz contains 12 questions about volcanic hazards. Please complete *all questions* with as much detail as you can. You can also use diagrams to answer the questions.

If you require any assistance, please ask a member of the outreach team.

**Name:** **Date:**

**School / College:**

**Year & Class:**

## Questions

1. What is the name of the volcano on St. Vincent?

2. When was the last eruption of this volcano?

3. Can you name any other dates when this volcano has erupted?

4. How long can a volcanic eruption last?

5. What is meant by the term 'volcanic hazard'?

6. Please describe in detail what a pyroclastic flow is.

7. What makes a pyroclastic flow dangerous?

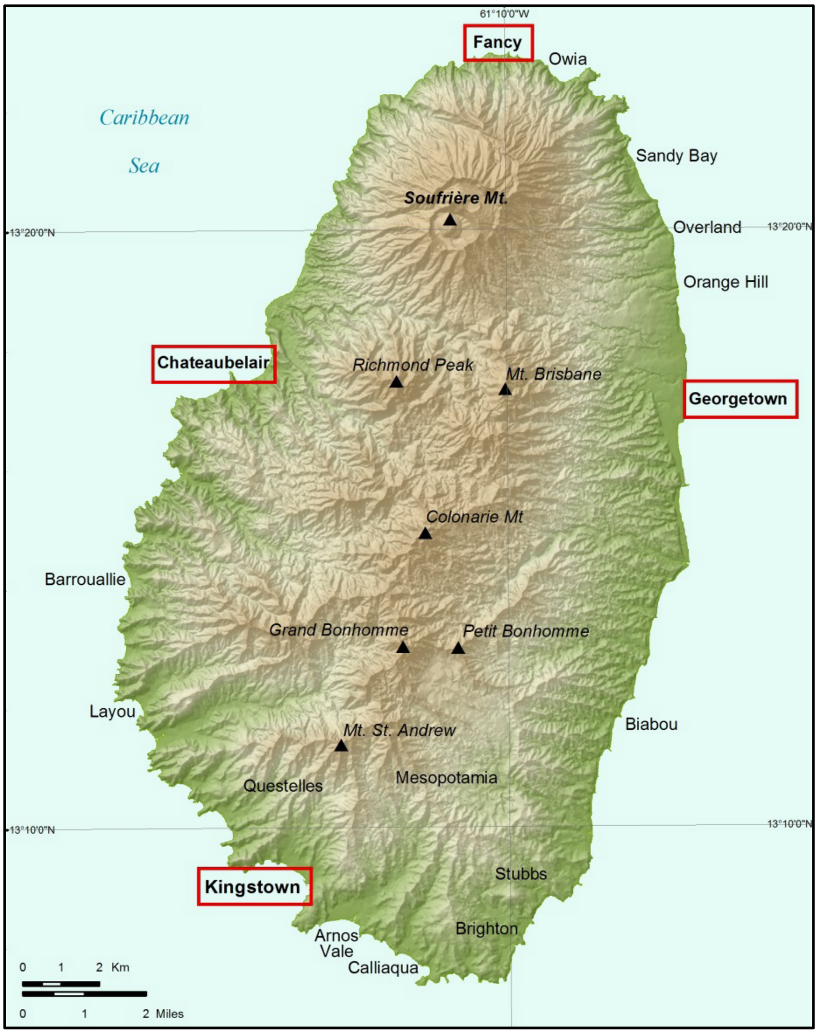
8. What is volcanic ash?

9. Where does volcanic ash come from during an eruption?

10. How does a lahar form?

11. When can a lahar occur?

12. Below is a picture of St. Vincent. Draw on and label the different colour volcanic hazard zones.




***Thank you for completing this quiz!***
***Please make sure you have filled in all of your information and then return it to a member of the outreach team.***

If you have any questions please do not hesitate to ask a member of the outreach team or email: lara.mani@plymouth.ac.uk

**APPENDIX I: Letter of approval for game trials – Ministry of Education, St. Vincent and the Grenadines.**

Ref No:
In replying the date and number
Above of this letter should be quoted
Tel: 1(784) 457-1104/1(784) 457-2676
Fax: 1(784) 457-1114

**MINISTRY OF EDUCATION**
**Halifax Street, Kingstown**
**St. Vincent and the Grenadines**

10 April, 2015

Miss Lara Mani
School of Geography, Earth
& Environmental Science
Plymouth University
Drake Circus
Plymouth, PL4 8AA
United Kingdom

Dear Ms. Mani,

The Ministry of Education St. Vincent and the Grenadines is pleased that you have chosen to undertake your research on volcanic hazards within our schools. The trial of the volcanic game during the annual volcano awareness week and hazard education is in keeping with the plans to integrate disaster risk reduction into the education programme.

Permission is therefore granted to conduct the sessions with the students without individual parental consent since the activity is being done during scheduled class times and in no way infringes on the rights of our students.

All the best with your research and we look forward to having access to the game as a teaching tool for other schools.

Sincerely yours,

MINISTRY OF EDUCATION

Gilchrist ...............

Lou-Anne Gilchrist (Miss)
Chief Education Officer

ST. VINCENT & THE GRENADINES

Email:

| | | | |
|---|---|---|---|
| Administration: | office.education@mail.gov.vc | UNESCO: | unesco.education@mail.gov.vc |
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