Developing a Design-Based Research Methodology that Utilises Virtual-Reality (VR) Technologies to Enhance Learning for Authentic High-Risk (or Extreme) Situations.

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Year: 2026

Te Ara Poutama: Māori and indigenous development

A thesis submitted to the Auckland University of Technology in fulfilment of the requirements for the degree of Doctor of Philosophy (PhD)

Declaration

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

I confirm that this thesis has been conducted in accordance with the ethical requirements of Auckland University of Technology and that all sources of information have been acknowledged.

Signed:

Jin (Ki Myung) Hong

Date: 25 March 2026

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Clearly state the AI tools used.	
AI Tool(s) Used:	OpenAI ChatGPT and Gemini
Prompts or queries entered into the AI tool (only the instructive portion of the prompt is required). Include all relevant variations.	
Prompts Used:	1. Prompts for structural drafting (Section 4.6) These prompts show how I converted raw observations into a formal "Intervention Procedure." • Initial Draft: Transform the following field notes from the Chile and NZ expeditions into a formal academic procedure for Section 4.6: [Insert raw notes on Suunto watch fitting and VR onboarding]. Use a chronological structure. • Refinement for Theory: Rewrite the description of the AMS VR scenario to align with Mayer's (2009) Cognitive Theory of Multimedia Learning, focusing specifically on how the interface manages extraneous cognitive load. • Technical Accuracy: Based on the Suunto app screenshot showing a max HR of 109 bpm and a baseline of 64 bpm, describe the physiological arousal of the participant in a way that supports Gaba's (2004) concept of psychological fidelity. 2. Prompts for Comparative Analysis (Section 5.0)

	These prompts demonstrate how I used the tool to "cluster" your findings between the two cohorts. • Thematic Synthesis: Identify the key thematic differences between the Chilean and New Zealand participant feedback provided in these interview transcripts. Focus on environmental realism versus educational accessibility. • Data Summarization: Summarize the biometric trends recorded in Chile (Figure 4.20) and New Zealand (Figure 4.22) into a comparative table format suitable for a PhD Results chapter. 3. Prompts for Technical Formatting This shows I used the tool for "document engineering" rather than content creation. • Formatting Help: How do I break a page in Microsoft Word to allow for Roman numeral numbering in the front matter and Arabic numbering starting at Chapter 1? • Table Generation: Generate a LaTeX/Markdown table structure to display the 4.6 intervention sequence: Orientation, Pre-Intervention, Exposure, Observation, and Post-Intervention.
A summary or description of the AI-generated output. (Optional: attach output in an appendix.)	
Output Received:	1. Drafting: Initial narrative drafts of the 4.6 intervention steps and 5.0 result summaries based on raw data logs. 2. Synthesis: Thematic clustering of qualitative participant reflections from the Chile and NZ field studies. 3. Editing: Re-phrasing of dense theoretical sections to enhance readability and ensure distinct academic "voice."
Describe how the AI output was used, edited, or transformed.	
Post-AI Processing Methods:	AI outputs were used as initial structural drafts. Post-processing involved: (1) manual verification of all biometric and technical data, (2) rewriting for stylistic consistency and 'cultural situatedness' of the Chilean/NZ context, and (3) a full manual audit of all APA 7th citations against primary sources to ensure academic accuracy

You may use this free text box to explain the intent for the use of the AI generated content. *For example, rather than stating what prompt(s) were used, you may articulate the purpose for which the prompt was used (supported by examples) here:*
Explained above.

STUDENT DECLARATION					
By signing you are confirming that the AI use stated in the table(s) above are accurate and follow AUT's recommended guidelines detailed in the AI Hub and Postgraduate Handbook.					
Student Name:	Ki Myung (Jin) Hong	**Signature:**		**Date:**	25 March 2026

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List of Abbreviations

AC Abstract Conceptualisation

AE Active Experimentation

AMS Acute Mountain Sickness

AR Augmented Reality

AT Activity Theory

AUT Auckland University of Technology

CE Concrete Experience

CEM Centro de Estudio en Montaña

DOC Department of Conservation

DVR Design-Based Research

EDR Educational Design Research

EEG Electroencephalography

ELT Experiential Learning Theory

EMG Electromyography

FEACH Federación de Andinismo de Chile

GSR Galvanic Skin Response

HACE High-Altitude Cerebral Edema

HAPE High-Altitude Pulmonary Edema

HCI Human–Computer Interaction

HMD Head-Mounted Display

HR Heart Rate

HRV Heart Rate Variability

MR Mixed Reality

MSC Mountain Safety Council

NZAC New Zealand Alpine Club

PMSLA Prime Minister's Scholarship for Latin America

RO Reflective Observation

ROC Receiver Operating Characteristic

SWOT Strengths, Weaknesses, Opportunities and Threats

UX User Experience

VR Virtual Reality

ZPD Zone of Proximal Development

Abstract

While experienced mountaineers are generally aware of the inherent risks of alpine environments, errors in judgement and decision-making can still occur. Even highly skilled climbers can misjudge environmental cues or make critical decisions under stress. These challenges highlight the importance of preparing climbers to recognise risks and make appropriate decisions in complex and unpredictable environments. However, providing learners with repeated opportunities to experience challenging situations and practise decision-making in a safe and controlled environment can be difficult. Virtual Reality (VR) offers an opportunity to complement existing educational approaches by providing immersive learning experiences that allow learners to engage with realistic scenarios without exposure to unnecessary risk.

Emerging research suggests that immersive technologies—such as Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR)—hold significant promise for transforming learning in high-risk education. These technologies offer the potential to simulate authentic, hazardous scenarios in a controlled, repeatable, and safe manner, thereby enhancing both cognitive and emotional engagement. While case studies in domains such as aviation, medicine, and emergency response have begun to explore these affordances, rigorous research explicitly focused on VR applications in mountaineering education or other extreme outdoor contexts remains notably absent.

Addressing this gap, the present study investigates the potential of Virtual Reality to enhance learning for authentic, high-risk activities, using alpine mountaineering as a focal

case. The overarching goal is to develop and evaluate a prototype VR educational intervention that not only supports climbers' technical skills but also cultivates better decision-making and risk awareness. Findings from this research may offer transferable insights for other high-risk professions, including firefighting, policing, and search-and-rescue operations.

The research adopts a Design-Based Research (DBR) approach (McKenney & Reeves, 2012), integrating iterative design, empirical testing, and theoretical refinement in real-world settings. DBR is particularly well-suited for complex educational innovations because it combines theory, practice, and evaluation in real-world contexts. Guided by a constructivist paradigm, the study draws on Authentic Learning (Herrington et al., 2010), Heutagogy (Hase & Kenyon, 2001), and Engeström's Activity Theory (1987, 2001) to ensure pedagogical relevance and cultural responsiveness. Initial design principles, derived from this theoretical foundation, are tested and refined through empirical engagement with climbers and instructors in diverse alpine settings.

Mixed-methods data collection—comprising observations, interviews, questionnaires, biometric feedback, and thematic analysis—was conducted in Chile and New Zealand to capture both user experience and systemic factors influencing technology adoption. The DBR process enabled the identification of design principles informed by empirical findings and grounded in established learning theories. Activity Theory was applied to examine the broader socio-cultural and institutional contexts, revealing tensions and affordances that shaped the intervention's effectiveness.

In summary, this research contributes to the field of immersive learning by proposing and evaluating a Design-Based Research framework that leverages Virtual Reality technologies to enhance education in extreme, high-risk environments. It makes two key contributions: (1) the development of empirically validated, theory-informed design principles for VR-based training in high-risk outdoor education, and (2) the advancement of academic understanding of how immersive technologies can be integrated into culturally and institutionally diverse training systems. These contributions not only advance educational theory and practice in outdoor safety but also offer a transferable framework for improving safety, decision-making, and performance in other high-risk professions, including firefighting, policing, and search-and-rescue operations.

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Finally, I am grateful for the opportunity to pursue this research, which brings together my lifelong passion for mountaineering and my professional commitment to advancing immersive learning and safety education. I hope that this work contributes, in some small way, to improving safety and learning for future climbers and high-risk learners.

Chapter 1: Introduction

1.1 Opening and Background Context

The researcher has over 30 years of mountaineering experience in New Zealand, including active participation in alpine climbing, glacier travel, snow and ice climbing, and expeditions across the Southern Alps and other high-risk alpine environments. Through decades of firsthand engagement, the researcher has developed a comprehensive understanding of the physical, cognitive, and psychological demands of mountaineering, including hazard assessment, risk management, route-finding, and decision-making under uncertain and rapidly changing conditions. These experiences have provided valuable insight into the complex challenges climbers face and have reinforced the critical importance of effective safety education, situational awareness, and experiential learning in high-risk environments.

In addition to mountaineering experience, the researcher brings more than 25 years of professional experience as a Digital Media Producer in higher education, specialising in educational media production, digital learning technologies, and immersive learning design. Throughout a career at Auckland University of Technology, the researcher has collaborated extensively with academics, learning designers, and institutional stakeholders to develop high-quality multimedia learning resources that enhance teaching and learning. This work has included instructional video production, interactive media development, learning technology implementation, and the design of scalable digital learning solutions. This professional background has provided strong expertise in instructional media design,

technology-enabled learning, and the pedagogical integration of emerging technologies to support authentic and meaningful learning experiences.

The motivation for pursuing doctoral research in mountain safety using virtual reality (VR) emerged from the intersection of extensive mountaineering practices and professional expertise in digital and immersive learning. Through mountaineering activities, the researcher has encountered and observed numerous serious incidents and accidents, both directly and through the broader mountaineering community and documented literature. Despite advances in equipment and training, accidents and fatalities continue to occur, frequently due to human factors such as diminished situational awareness, inadequate preparation, and suboptimal decision-making under pressure. Climbers may fail to recognise early signs of altitude sickness, underestimate environmental hazards such as crevasses or avalanches, or continue ascending despite deteriorating weather conditions. These observations prompted critical questions regarding how climbers learn, how safety education might be strengthened, and how decision-making skills can be more effectively developed in preparation for high-risk environments.

Traditional mountain safety education often relies on theoretical instruction, static learning materials, and limited real-world exposure, which may not fully replicate the complexity, stress, and dynamic nature of actual alpine environments. In contrast, immersive technologies such as virtual reality offer the potential to simulate realistic mountain scenarios within safe, controlled, and repeatable environments. VR enables learners to experience hazardous situations, develop hazard perception skills, and practise critical decision-making without exposure to real-world danger. This presents a significant

opportunity to enhance experiential learning and better prepare climbers for authentic mountain conditions.

This research investigates how VR can serve as an educational intervention to improve mountain safety by enhancing experiential learning, situational awareness, and decision-making. Employing a Design-Based Research (DBR) methodology grounded in constructivist learning principles, the study aims to design, develop, and evaluate VR-based mountain safety training prototypes. The research draws upon key educational frameworks, including Authentic Learning, Heutagogy (self-determined learning), Constructivist Learning Theory, and Activity Theory, to inform the design and evaluation of immersive learning experiences. The VR prototype simulates high-altitude environments and hazardous scenarios, such as altitude sickness, crevasses, and severe weather, enabling learners to engage in realistic, embodied learning experiences.

An iterative design and evaluation process is employed, incorporating participant interviews, observational data, and biometric feedback to assess learning outcomes and refine emerging design principles. This multimodal approach enables a comprehensive understanding of how immersive technologies may support learning in high-risk environments. The outcomes of this research contribute to the development of evidence-based design principles for VR learning in mountaineering and other high-risk domains, as well as to broader theoretical discussions concerning immersive learning and educational technology.

The researcher's combined experience as a long-term mountaineer and educational media professional provides a distinctive interdisciplinary perspective that bridges real-world

mountain practice and immersive learning design. This study reflects a professional commitment to advancing digital learning innovation alongside a sustained interest in improving mountain safety practices. Ultimately, this research seeks to contribute to safer mountaineering practices by developing effective immersive training approaches that enhance learning, strengthen decision-making capabilities, and support accident reduction in high-risk environments.

1.2 Research Problem and Gap

Although there is a growing body of literature examining the use of Virtual Reality (VR) in education, most studies focus on structured, controlled learning environments such as clinical training (e.g., medicine and nursing), engineering simulations, and classroom-based education. These domains benefit from relatively predictable environments, standardised procedures, and clearly defined learning outcomes. In contrast, significantly less research has explored the application of VR in outdoor, dynamic, and high-risk environments where uncertainty, environmental variability, and human decision-making play a central role. Mountaineering represents one such domain, yet it remains substantially underrepresented in immersive learning research.

Mountaineering is a complex activity requiring not only technical skills but also advanced cognitive, perceptual, and affective capabilities, including hazard recognition, situational awareness, risk assessment, and decision-making under pressure. Traditional mountaineering safety education relies heavily on experiential learning through field-based training, mentorship, and progressive exposure to increasingly challenging environments. While these approaches are valuable and widely accepted, they are inherently constrained

by environmental unpredictability, limited accessibility, safety risks, and resource requirements. Opportunities to experience critical but dangerous scenarios—such as crevasse falls, avalanche exposure, or severe altitude sickness—are naturally limited in real-world training due to ethical and safety considerations. As a result, many climbers may encounter such situations for the first time in real environments without prior experiential preparation.

Immersive technologies such as VR offer the potential to address these limitations by creating safe, controlled, and repeatable simulations of hazardous environments. VR enables learners to experience realistic scenarios, engage in embodied interaction, and practise decision-making without exposure to actual physical danger. However, despite this potential, there remains limited empirical evidence on how VR can effectively support learning in authentic, high-risk outdoor contexts such as mountaineering. In particular, current research has insufficiently examined whether VR can replicate the complex cognitive, emotional, and psychological dimensions associated with mountaineering decision-making, including stress, uncertainty, and risk perception.

A further gap exists in understanding how immersive simulations influence climbers' vigilance, hazard perception, and reflective learning processes. Mountaineering accidents are frequently attributed not only to technical skill deficits but also to human factors such as cognitive overload, poor judgment, complacency, and inadequate situational awareness. While VR has shown promise in supporting procedural skill acquisition and spatial learning in other domains, its role in developing higher-order cognitive and metacognitive skills—such as decision-making, self-awareness, and adaptive thinking in unpredictable environments—remains underexplored.

In addition, there is a lack of research examining how VR learning interventions can be designed using established educational theories and systematic design methodologies. Many existing VR studies focus primarily on technological implementation or learner engagement, rather than on pedagogically grounded design and evaluation. There is limited application of constructivist learning theories, Authentic Learning principles, or heutagogical approaches within VR-based mountain safety education. Furthermore, the use of Design-Based Research (DBR) as a methodological framework for iteratively designing, testing, and refining VR learning interventions in high-risk outdoor contexts remains scarce.

Another important gap concerns the influence of cultural, environmental, and contextual factors on the adoption and effectiveness of VR-based safety education. Mountaineering practices vary significantly across geographical and cultural contexts, including differences in terrain, climate, training traditions, and risk perception. For example, mountaineering in New Zealand's Southern Alps differs from high-altitude climbing in Chile's Andes in environmental conditions, training pathways, and climbing culture. However, little research has examined how these contextual differences influence learners' experiences, perceptions, and acceptance of VR as a safety training tool.

Finally, there is limited empirical evidence on the extent to which VR-based learning interventions can produce transferable learning outcomes that influence real-world behaviour and decision-making in mountaineering contexts. Questions remain regarding how immersive learning experiences contribute to long-term knowledge retention, behavioural change, and improved safety outcomes. Addressing these gaps is essential for understanding the educational value of VR in high-risk outdoor learning and for developing effective, evidence-based design principles for immersive safety education.

This research seeks to address these gaps by designing, implementing, and evaluating a VR-based mountain safety training intervention using a Design-Based Research approach. The study aims to generate both practical design outcomes and theoretical contributions by examining how immersive VR environments can support experiential learning, improve hazard perception and decision-making, and enhance safety preparedness in mountaineering. In doing so, the research advances knowledge at the intersection of immersive learning, educational design, and high-risk outdoor education.

1.3 Research Aim and Objectives

This thesis aims to investigate how VR can be designed, implemented, and evaluated as an educational tool for high-risk mountaineering safety training across diverse cultural contexts.

Objectives:

- To examine the affordances and limitations of VR as a mediating tool for cognitive, affective, and behavioural learning in mountaineering
- To evaluate participants' experiences of VR-based training in Chile and New Zealand, with attention to cultural, linguistic, and contextual factors.
- To identify and refine design principles for immersive safety education based on iterative cycles of intervention and feedback.
- To assess the potential of VR as a complement—not a replacement—to traditional mountaineering instruction.
- To contribute theoretical insights into the application of Activity Theory and Experiential Learning Theory in technology-enhanced outdoor education.

1.4 Research Questions

This thesis addresses the following guiding research questions:

1. What design principles are required to develop effective VR-based interventions for high-risk mountaineering education?
2. How do participants in Chile and New Zealand experience and evaluate VR safety training?
3. To what extent can VR influence climbers' decision-making, vigilance, and reflective thinking?
4. What are the cultural, pedagogical, and systemic factors that shape the adoption and effectiveness of VR in mountaineering education?

1.5 Significance of the Study

This study is significant for three reasons:

- Theoretical Contribution: This work extends Engeström's (2001) Third-Generation Activity Theory (AT) and Kolb's (1984) Experiential Learning Theory into the underexplored field of immersive outdoor education, demonstrating how contradictions and tensions within activity systems can drive innovation.
- Practical Contribution: The findings inform mountaineering instructors, federations (e.g., FEACH, NZAC), and outdoor educators about how VR can complement traditional training by providing safe exposure to high-risk scenarios, including altitude sickness, avalanches, and sudden weather changes.

- Methodological Contribution: This study employs a Design-Based Research (DBR) approach to demonstrate an iterative, cross-cultural method for developing VR interventions that balance theory with real-world practice.

1.6 Scope and Limitations

This research is situated within two national contexts—Chile and New Zealand—which were deliberately selected due to their globally recognised mountaineering environments, distinct climbing cultures, and contrasting geographical and environmental conditions. Both countries offer diverse alpine terrain, active mountaineering communities, and established traditions of outdoor education and guiding, making them appropriate contexts for investigating mountain safety education. The inclusion of these two settings enables cross-contextual analysis and provides insight into how immersive learning interventions may function across different cultural, environmental, and training frameworks. However, the findings are necessarily bounded by these contexts. They may not be directly generalisable to other mountaineering environments, such as the Himalayas or European Alps, where environmental, cultural, and institutional conditions differ.

This study focuses on the design, implementation, and evaluation of a virtual reality (VR) prototype as an educational intervention to support learning about mountain safety. The research primarily concerns cognitive, perceptual, and experiential dimensions of learning, including hazard recognition, situational awareness, risk perception, and decision-making processes. The VR prototype was designed to simulate realistic alpine scenarios, enabling participants to engage with environmental hazards such as crevasses, altitude-related risks, and terrain navigation in a safe and controlled virtual environment.

However, the VR intervention does not fully replicate the physiological and physical stressors associated with real mountaineering environments. Factors such as extreme cold, altitude-induced hypoxia, physical fatigue, and environmental exposure cannot be authentically reproduced with current VR technologies. As a result, the immersive experience primarily focuses on cognitive and emotional realism rather than physiological realism. While this limitation reflects current technological constraints, it is consistent with the research aim of investigating learning, perception, and decision-making rather than physical performance.

The scale and composition of participant cohorts also limit the study. Due to logistical, geographical, and resource constraints, the research involved relatively small participant groups drawn from specific mountaineering communities in Chile and New Zealand. While this sample size is appropriate for a Design-Based Research (DBR) methodology, which prioritises iterative design, in-depth analysis, and contextual understanding, it limits the statistical generalisability of findings. Instead, the research emphasises analytical generalisation, focusing on developing transferable design principles and theoretical insights rather than population-level conclusions.

In addition, the research focuses specifically on mountaineering safety education. It does not attempt to address all aspects of mountaineering training, such as technical rope skills, physical conditioning, or long-term experiential development. The VR intervention is not intended to replace traditional field-based training, which remains essential for developing physical competence, embodied skill, and environmental familiarity. Rather, the study explores the potential of VR as a complementary educational tool within a blended learning

framework, supporting preparation, reflection, and experiential learning before or alongside real-world training.

Methodologically, the research adopts a Design-Based Research approach, which emphasises iterative development, contextual validity, and practical applicability. While this approach allows for deep engagement with real-world educational problems, it also involves context-specific design decisions that may influence outcomes. The findings should therefore be interpreted within the specific design, technological, and pedagogical parameters of the VR prototype developed in this study.

Technological limitations also influence the scope of the research. The VR prototype was developed using available hardware and software platforms, which impose constraints on graphical fidelity, interaction design, and sensory realism. While the prototype provides a high level of visual and experiential immersion, it does not incorporate advanced sensory feedback such as haptic resistance, thermal feedback, or multisensory environmental simulation. Future technological developments may enable more comprehensive simulation of physical and environmental conditions.

Finally, the research focuses on learning processes, user experience, and educational design outcomes rather than long-term behavioural change or accident reduction. While the study examines participants' perceptions, engagement, and learning responses, it does not measure actual accident rates or long-term behavioural outcomes in real mountaineering environments. Longitudinal research would be required to assess the sustained impact of VR-based safety training on real-world mountaineering practice.

Despite these limitations, the research provides valuable insights into the potential of immersive technologies to support learning in high-risk environments. By focusing on experiential learning, design principles, and learner engagement, the study advances knowledge in immersive learning design. It provides a foundation for future research and development in VR-based safety education.

1.7 Conceptual and Theoretical Orientation

This research is grounded in a constructivist paradigm, which views learning as an active, socially mediated process through which individuals construct knowledge through experience, interaction, and reflection. Constructivist perspectives emphasise the importance of authentic contexts, learner agency, and experiential engagement, particularly in complex and high-risk domains such as mountaineering. Within this paradigm, immersive virtual reality (VR) is conceptualised not simply as a technological tool, but as a mediating learning environment that enables learners to engage with realistic scenarios, develop situational awareness, and reflect on their decision-making processes.

The primary theoretical framework guiding the analysis is Activity Theory, as developed by Engeström (1987, 2001). Activity Theory provides a systemic lens for examining human activity as a socially and culturally situated phenomenon mediated by tools, rules, and community structures. In this research, VR is conceptualised as a mediating artefact within the mountaineering learning activity system. The framework enables analysis of how learners (subjects) interact with immersive VR environments (tools) to pursue safety knowledge and decision-making competence (object), within broader social and cultural contexts that involve mountaineering communities, training practices, and institutional

norms. Activity Theory also enables the identification of tensions and contradictions within and between activity systems, such as differences between traditional field-based learning and technology-mediated learning environments. These contradictions are understood as potential drivers of learning, innovation, and transformation. By applying Activity Theory, this research examines how VR reshapes learning practices, influences learner engagement, and supports the development of new forms of experiential learning in high-risk educational contexts.

Kolb's Experiential Learning Theory (1984) provides a complementary framework for understanding the cognitive and experiential processes through which learning occurs within immersive VR environments. Kolb conceptualises learning as a cyclical process involving four stages: concrete experience, reflective observation, abstract conceptualisation, and active experimentation. VR simulations provide learners with opportunities to engage in concrete experiences by interacting with realistic virtual environments that simulate mountaineering hazards. Learners can then reflect on their experiences, evaluate their decisions, and develop a conceptual understanding of risk, safety, and environmental awareness. These insights can subsequently inform future actions, both within the simulation and in real-world mountaineering contexts. This cyclical process aligns closely with the iterative and experiential nature of learning in mountaineering, where experience, reflection, and adaptation are essential components of developing expertise and safety competence.

The research is further informed by literature on immersive learning, presence, and psychological fidelity. Immersive learning environments are characterised by their capacity to create a sense of presence—the subjective experience of "being there" within a

virtual environment (Slater & Sanchez-Vives, 2016). Psychological fidelity refers to the extent to which a simulation replicates the cognitive and emotional demands of real-world situations, even when physical realism is limited (Gaba, 2004). In high-risk domains, psychological fidelity is particularly important, as learning often involves developing situational awareness, risk perception, and decision-making under conditions of uncertainty and stress. VR has the potential to create immersive experiences that evoke emotional and cognitive responses similar to those experienced in real mountaineering environments, thereby supporting deeper learning and improving transfer of knowledge and skills.

The concept of transfer of learning is central to this research. Transfer refers to the extent to which knowledge and skills acquired in one context can be applied in another, particularly in real-world situations (Perkins & Salomon, 1992). Immersive VR environments may enhance transfer by providing learners with realistic, contextually rich experiences that promote deeper cognitive processing and embodied learning. By enabling learners to experience and respond to simulated hazards, VR can support the development of mental models and decision-making strategies that may be transferable to real-world mountaineering environments.

In addition, this research is informed by principles of Authentic Learning (Herrington, Reeves, & Oliver, 2010), which emphasise the importance of learning in realistic contexts that reflect real-world complexity. Authentic learning environments provide opportunities for learners to engage with meaningful tasks, make decisions, and reflect on their actions. VR simulations offer the potential to create authentic learning environments by replicating

real-world mountaineering scenarios that would otherwise be difficult or unsafe to reproduce in traditional training contexts.

Heutagogy, or self-determined learning (Hase & Kenyon, 2000; Blaschke, 2012), also informs the conceptual orientation of this study. Heutagogical approaches emphasise learner autonomy, capability development, and reflective practice. Immersive VR environments enable learners to explore scenarios, make independent decisions, and reflect on the consequences of their actions, supporting the development of adaptive expertise and self-regulated learning. This is particularly relevant in mountaineering, where climbers must make independent decisions in unpredictable and high-risk environments.

Together, these theoretical perspectives provide a comprehensive framework for examining immersive VR as a mediating tool for experiential learning in mountaineering safety education. Activity Theory enables systemic analysis of the broader socio-cultural and technological learning context; Experiential Learning Theory explains the cognitive and reflective processes involved in learning through simulation; immersive learning theory and psychological fidelity explain how VR supports engagement and transfer of learning; and Authentic Learning and Heutagogy provide pedagogical foundations for designing meaningful, learner-centred experiences.

This integrated conceptual framework supports both the design and analysis of the VR intervention. It enables a deeper understanding of how immersive technologies can enhance experiential learning, improve hazard perception, and support safer decision-making in high-risk environments such as mountaineering.

1.8 Methodological Preview

This study adopts a Design-Based Research (DBR) methodology to investigate the design, implementation, and evaluation of a virtual reality (VR) intervention for mountain safety education. DBR is particularly appropriate for this research because it enables the systematic development and evaluation of educational innovations within authentic learning contexts while simultaneously generating practical design outcomes and theoretical contributions (Reeves, 2006; McKenney & Reeves, 2019). Unlike experimental approaches that seek to isolate variables in controlled environments, DBR focuses on iterative cycles of design, intervention, analysis, and refinement in real-world settings. This approach aligns closely with the constructivist and Activity Theory perspectives underpinning this research, as it allows for the examination of learning as a dynamic, contextually embedded process mediated by technological tools.

The research was conducted across two case study contexts—New Zealand and Chile—selected for their distinct mountaineering cultures, environmental conditions, and educational practices. These dual contexts enabled cross-case analysis and offered opportunities to explore how immersive VR learning interventions operate across different cultural and environmental settings. The DBR methodology involved multiple iterative phases, including needs analysis, prototype design, implementation, evaluation, and refinement. The VR prototype was developed to simulate realistic mountaineering scenarios, enabling participants to engage in immersive experiential learning and decision-making tasks within a safe virtual environment.

A mixed-methods approach was employed to capture a comprehensive understanding of participant experiences, learning processes, and physiological responses. Data collection included pre- and post-intervention questionnaires to assess participants' prior experience, perceptions, and changes in confidence and awareness related to mountain safety. Semi-structured interviews were conducted to explore participants' subjective experiences, perceptions of realism, engagement, and perceived learning outcomes. Observational data, including video recordings of participant interactions with the VR system, provided insight into behavioural responses, decision-making processes, and engagement during the immersive experience.

In addition to qualitative and self-reported data, biometric measures were collected to examine participants' physiological responses during the VR intervention. Heart rate variability (HRV) was used as an indicator of cognitive and emotional engagement, stress, and arousal. These physiological measures provided an additional dimension of analysis, enabling the triangulation of subjective and behavioural data with objective indicators of participant response. This multimodal data collection approach supports a richer and more nuanced understanding of the immersive learning experience.

Data analysis involved both qualitative and quantitative techniques. Thematic analysis was used to examine interview transcripts and observational data, thereby identifying recurring patterns, themes, and participant perspectives related to learning, engagement, and usability. Descriptive statistical analysis was applied to questionnaire responses and biometric data to identify trends and changes associated with the VR intervention. The integration of qualitative, quantitative, and physiological data supported methodological triangulation, enhancing the validity and robustness of the findings.

Consistent with the Design-Based Research approach, findings from each iteration informed subsequent refinement of the VR prototype and the underlying design principles. This iterative process enabled the development of evidence-informed design insights and contributed to both practical and theoretical understanding of immersive learning in high-risk environments. The methodology therefore supports the dual aims of the research: to design and evaluate an effective VR-based mountain safety intervention, and to generate transferable design principles and theoretical contributions relevant to immersive learning and educational technology.

Further details regarding the research design, participant recruitment, data collection procedures, analytical framework, and ethical considerations are presented in Chapter 3.

1.9 Thesis Structure

The thesis is organised into nine chapters:

- Chapter 1 introduces the research background, problem, aims, and significance.
- Chapter 2 reviews theoretical frameworks, including Activity Theory, Experiential Learning, and immersive learning.
- Chapter 3 outlines the Design-Based Research methodology.
- Chapter 4 details the development of the VR prototype and intervention design.
- Chapters 5–7 present the findings from Chile and New Zealand, including pre- and post-intervention data and thematic analyses.
- Chapter 8 synthesises findings into emerging design principles and reflections on theory.

- Chapter 9 discusses implications, limitations, and recommendations for future research, policy, and practice.

Having established the research problem, aims, and methodological approach, the next chapter explores the conceptual and theoretical foundations that underpin this study. Chapter 2 reviews the relevant literature on experiential and immersive learning, Activity Theory, and VR in education, highlighting the frameworks that guided the intervention's design and evaluation. This review situates the research within existing scholarship and identifies the theoretical lenses through which the role of VR in high-risk mountaineering education is examined.

Chapter 2: Literature Review

2.1 Introduction

This chapter provides a comprehensive review of the literature that informs the design, implementation, and analysis of virtual reality (VR)-assisted mountain safety education. Given the high-risk nature of mountaineering activities, there is a pressing need for training approaches that foster not only technical proficiency but also situational awareness, risk perception, and sound decision-making under pressure. Traditional outdoor education, while effective in providing embodied learning experiences, faces limitations related to safety, accessibility, environmental unpredictability, and cost. These challenges have prompted interest in leveraging immersive technologies, particularly VR, as supplementary tools for enhancing learner preparedness and cognitive resilience in alpine environments.

The literature review is structured into three interrelated sections: (1) traditional mountain safety education and its pedagogical challenges; (2) learning theories that provide conceptual tools for designing and analysing training in high-risk environments; and (3) empirical research on immersive learning technologies, especially VR, in domains with similar educational demands.

The first section explores existing scholarship on mountain safety education, highlighting the pedagogical practices, limitations, and regional differences between countries such as Aotearoa New Zealand and Chile. Particular attention is paid to how socio-cultural norms, environmental conditions, and institutional infrastructures shape access to and engagement with safety training programmes. While both countries possess vibrant mountaineering

communities, they differ markedly in terms of digital readiness, instructional frameworks, and policy support for integrating new technologies into outdoor learning.

The second section examines foundational and contemporary learning theories relevant to high-risk and experiential education. It begins with Constructivism and Social Constructivism. Constructivism emphasises active, reflective, and collaborative learning, where students take ownership of their learning through personal experience and peer interaction. Social Constructivism, influenced by Vygotsky (1978), highlights learning as a social process shaped by culture and context. Knowledge is co-constructed through collaboration, especially within the Zone of Proximal Development (ZPD), where learners develop new skills with the support of teachers or more capable peers. This is followed by an exploration of Heutagogy (Hase & Kenyon, 2000), which supports learner autonomy, self-determined learning, and adaptability in unpredictable environments. The section concludes with an in-depth discussion of Engeström's Third-Generation Activity Theory (1987, 2001), which provides a powerful socio-cultural framework for analysing the complex interactions among learners, tools, communities, and institutional systems. Activity Theory is particularly useful for identifying contradictions and developmental tensions that arise when integrating novel technologies like VR into established educational systems.

The final section reviews the current state of research on immersive learning technologies, focusing on the educational affordances and constraints of virtual reality. Empirical studies have demonstrated VR's potential to support situated cognition, emotional engagement, and embodied learning through high-fidelity simulations. Research also identifies challenges such as sensory misalignment, hardware discomfort, cognitive overload, and

the risk of overconfidence in risk-free environments. This section further considers how VR can be designed to support scaffolded learning, cultural localisation, and learner diversity through features like multilingual interfaces, onboarding tutorials, and scenario branching.

Together, these strands of literature establish the theoretical and empirical foundation for this study's investigation into the design and implementation of VR-based mountain safety training in New Zealand and Chile. The purpose of this review is not only to identify current best practices but also to expose critical gaps and tensions in the literature that this study seeks to address. Specifically, it aims to provide a theoretically informed foundation for the development and evaluation of VR-assisted mountain safety interventions in diverse geographical and cultural contexts, such as Aotearoa New Zealand and Chile.

By synthesising these bodies of literature, this chapter sets the stage for a nuanced understanding of how immersive technologies can be meaningfully integrated into outdoor education. It argues that the pedagogical success of VR-based training lies not merely in its ability to simulate risk, but in its capacity to support situated learning, foster adaptive expertise, and respond to the cultural and contextual realities of the learners it serves.

2.2 Context: Mountain Safety and Education

Mountaineering is widely recognised as a high-risk activity requiring both technical competence and effective decision-making under pressure (Furrer & Nigg, 2018; Brewin & Boulware, 2018). Traditional mountain safety education relies heavily on field-based instruction, where learners acquire skills through guided experience in authentic outdoor

settings. While this approach fosters embodied learning, it also presents logistical and safety challenges, particularly in unpredictable environments or remote regions.

In New Zealand, mountain safety training benefits from structured programmes supported by organisations such as the New Zealand Alpine Club and the Mountain Safety Council. These institutions have established a culture of outdoor education and risk management, facilitating widespread access to high-quality training resources. In contrast, Chilean mountain safety education is shaped by geographical diversity and regional disparities in institutional support and infrastructure. Many participants in Chile come from areas with limited access to training centres or digital resources, creating barriers to entry.

These contextual differences underscore the need for adaptable, scalable solutions that can reach diverse learner populations. VR technologies offer one such solution by simulating high-risk scenarios in controlled, repeatable environments. However, the success of these tools depends on how well they align with local educational needs, cultural practices, and environmental conditions.

2.2.1 High-Risk Mountaineering

Mountaineering remains one of the most hazardous outdoor pursuits, and fatalities continue to occur despite advances in equipment, forecasting, and safety practices. Many of these incidents are attributed to human factors, including errors in judgment, inadequate preparation, and failure to respond appropriately to environmental warning signs (McCammon, 2009). Such losses extend beyond the individual climber, profoundly affecting families, friends, and mountaineering communities, often resulting in long-term emotional, psychological, and social consequences. Public discourse frequently attributes

these incidents to individual negligence or poor decision-making; however, this perspective oversimplifies the complex interaction of cognitive, environmental, and experiential factors that shape climbers' behaviour in high-risk alpine environments.

Mountaineering involves ongoing learning, adaptation, and decision-making in environments characterised by uncertainty, changing conditions, and exposure to risk. Climbers must continually assess environmental hazards, their own capabilities, and the actions of others when making decisions in mountain environments (McCammon, 2004; Zweifel & Haegeli, 2014). Research has also shown that experience alone does not necessarily prevent poor decisions, as experienced individuals can still be influenced by heuristic traps, familiarity, social factors, and other cognitive biases (McCammon, 2004). This highlights the importance of understanding how climbers develop situational awareness, risk perception, and decision-making skills in high-risk environments.

Traditional mountaineering education has placed considerable emphasis on technical skills and experience gained in the field. While experiential learning is an important part of developing mountaineering competence, learning through direct exposure to hazardous environments has limitations because dangerous situations cannot always be deliberately or repeatedly recreated for training purposes. Research in other high-risk fields has demonstrated the value of simulation for allowing learners to practise decision-making and responses to hazardous situations within controlled environments (Salas et al., 1998). This suggests an opportunity to complement existing mountaineering education with approaches that provide structured and repeatable practice without exposing learners to unnecessary physical risk.

Immersive technologies such as virtual reality provide one possible approach to addressing this challenge. VR can place learners within simulated situations where they can practise recognising hazards, making decisions, and reflecting on the consequences of their actions without experiencing the physical danger associated with the real environment (Radianti et al., 2020). However, VR does not fully reproduce the physical and sensory conditions of an alpine environment, and its educational value depends on appropriate learning design rather than immersion alone (Makransky & Petersen, 2021). In this study, VR is therefore considered as a potential complement to, rather than a replacement for, existing experiential and field-based mountaineering education.

Existing mountaineering safety resources commonly provide information about equipment, techniques, environmental hazards, and practical approaches to mountain safety. Such resources make an important contribution to climbers' knowledge and preparation. However, written materials alone provide limited opportunities for learners to repeatedly practise complex decision-making in changing and potentially dangerous situations. Research into avalanche decision-making, for example, demonstrates that accidents cannot always be explained simply by a lack of technical knowledge, as human factors, heuristic traps, group dynamics, and situational pressures can also influence decisions (McCammon, 2004). This reinforces the need to consider how safety education can support not only technical knowledge but also the development of decision-making skills.

Over recent decades, high-altitude mountaineering and trekking have become increasingly accessible through commercial expedition services and developments in equipment, infrastructure, and guiding. This has enabled climbers with varying levels of experience to

attempt high-altitude objectives, including Mount Everest and other Himalayan peaks (Huey et al., 2020). Greater accessibility has also raised questions about experience, preparation, risk management, and decision-making among participants in commercial high-altitude expeditions. These changes provide an important context for considering how mountaineering safety education can prepare climbers for complex and high-risk environments.

According to Beedie and Hudson (2003), mountaineering at high altitudes is no longer restricted to experienced mountaineers. The boundaries between mountaineering and tourism are increasingly blurred due to the diversification and commercialisation of mountaineering. However, ironically, these new phenomena have generated a high incidence of deaths of mountaineers, both professional and non-professional, Sherpas, and porters in the Himalayan range. It is the most disturbing result since the new commercial guide companies launched. Eight climbers died near the summit of Mount Everest during the 1996 disaster, largely due to rapidly deteriorating weather conditions and failures to adhere to established turnaround times in the so-called “death zone” (Krakauer, 1997). These eight climbers had poor judgment and planning in complex situations. They were stuck in a severe storm as they descended to Camp 4. Ultimately, the climbers were unable to descend safely and died during the storm. Three mountain guides had died, including five of their clients.

Elmes and Frame (2008) use a Foucauldian lens to critique the portrayal of the 1996 Mount Everest disaster in popular media. They argue that influential texts like Krakauer’s *Into Thin Air* created a narrow "disaster and tragedy" discourse that blamed

the deaths primarily on individual flaws, such as poor decision-making, failed leadership, and a lack of proper organisational control (p. 213).

According to Elmes and Frame (2008), this tragedy in the world's most iconic mountain attracted media coverage, including the covers of Time and Newsweek.

The practical context of the research is high-risk mountain climbing at altitudes between 3000 m and 8000 m by relatively experienced climbers. Relatively experienced climbers are defined as those who have climbed at least ten times at high altitudes. These climbers, though experienced, still lack some practical experience in dangerous situations. This research aims to enhance the education of relatively experienced mountain climbers, helping them better prepare for danger spotting and improve decision-making in dangerous and complex situations.

The literature indicates that many deaths in high-altitude mountains result from avalanches, falls, high-altitude sickness, and changing weather conditions that can lead to injury or death from hypothermia, blindness, and frostbite. Also, aside from those above factors, several factors contribute to tragic outcomes, such as crowded conditions, inexperienced climbers, and, most importantly, a series of bad decisions. The inherent danger of elite mountaineering is underscored by research into Everest expeditions over a twenty-year period. Goucher and Horace (2012) found that with nearly seven deaths occurring for every 750 climbers at risk, the resulting 0.87% mortality rate is high enough to provide researchers with "fairly precise" longitudinal data. This suggests that the "high-risk" nature of the environment is a constant, measurable factor rather than a series of isolated accidents (p. 29).

Apollo (2017) also notes that several accessibility factors complicate access to high-altitude mountain ranges. He points out that weather conditions are one of the main factors in successful climbing, as there is a very narrow weather window for climbing in high-altitude mountains. Another risk factor is that many inexperienced mountaineers are in high-altitude mountain ranges, as high-altitude mountaineering is no longer restricted to experienced mountaineers. Beedie and Hudson (2003) observe that the distinction between traditional mountaineering and commercial tourism has become less clear. They attribute this shift to the increasing commercialisation of the sport, which has diversified the ways in which people access and experience high-altitude environments (p. 626).

Since commercial high-altitude expeditions were introduced in the 1990s, high-altitude climbing has been a significant component of the adventure tourism industry in the Himalayan ranges. It helps inexperienced climbers to ascend high-altitude mountains. However, even with fully guided expeditions, the extreme altitude and fickle weather in high-altitude mountains remain a serious risk for inexperienced climbers and even experienced mountaineers. For example, people were struck by Images of the 1996 tragedy on Everest, where eight climbers lost their lives. A ferocious storm and deadly decisions had claimed the lives of eight climbers, including highly experienced expedition leaders Scott Fischer and Rob Hall.

In the six decades spanning from 1952 to 2014, the *Himalayan Database* (2014) recorded 259 fatalities among those attempting to reach Everest's peak. When viewed alongside the increasing commercialisation of the mountain, these figures highlight a persistent safety gap that has remained a challenge for the mountaineering community despite advances in equipment and technology.

Barry and Elmes (1999) contend that the "commodification" of elite climbing has eroded the leadership and collaboration necessary for mountain safety. They highlight how the pressure to deliver results for paying clients forces expedition leaders into a precarious balance between business profitability and risk management, ultimately creating a "safety gap" as teamwork is replaced by individualistic and commercial motivations (p. 183).

Karinen et al (2010) found that acute mountain sickness (AMS), high-altitude cerebral edema (HACE), and high-altitude pulmonary edema (HAPE) are common problems while ascending at high-altitude mountain ranges and progress rapidly to fatal results if the acclimatisation process fails and the ascent continues. It can become severe and cause lung, heart, and brain complications. Most mountaineers who live at low altitudes visit high mountains in ever-increasing numbers. Rapid climbing of a lowlander to high altitude, resulting in acute mountain sickness (AMS) or deadly high-altitude cerebral edema (HACE) and high-altitude pulmonary edema (HAPE). The symptoms are headache, fatigue, shortness of breath, dizziness, and vomiting. Therefore, the research will explore these risk factors in-depth and include the following areas:

- Environmental factors: High altitude, cold, and avalanches.
- Human factors: Biological factors and psychological factors

2.2.2 Risk Factor - Environmental factors

Environmental factors are a major source of risk in high-altitude mountaineering. Climbers are exposed to rapidly changing weather, extreme cold, strong winds, difficult terrain, and reduced oxygen levels as altitude increases. These conditions can affect both physical performance and the ability to make safe decisions, particularly when several

environmental hazards occur at the same time. This section examines the main environmental factors relevant to this study, beginning with the effects of altitude and altitude-related illnesses.

2.2.2.1 Altitude: Mountain Altitude Sickness (AMS, HAPE, HACE)

High-altitude environments present a significant respiratory challenge due to the linear decline in oxygen availability during ascent. While previously viewed as an exclusive concern for expert climbers, hypoxia now affects a wider demographic; approximately 40% of those reaching 3,000 m without proper acclimatisation will experience acute symptoms (Hackett & Roach, 2001). This condition is driven by reduced atmospheric pressure, which prevents the body from maintaining adequate oxygen saturation (Keller et al., 2015). To contextualise the extreme hypoxia at Everest's peak, where oxygen levels drop to nearly one-third of sea-level values, researchers often use the metaphor of performing high-intensity exercise while restricted to breathing through a narrow straw (Keller et al., 2015, p. 2).

Populations that have lived at high altitude for many generations have developed physiological and genetic adaptations that help them function under conditions of reduced oxygen availability. However, these adaptations are not the same across all high-altitude populations. Research comparing Tibetan, Andean, and Ethiopian populations has identified different patterns of adaptation to hypoxia, including differences in haemoglobin concentration and oxygen saturation (Beall, 2006, 2007). For example, Andean highlanders generally show higher haemoglobin concentrations, whereas Tibetan populations maintain comparatively lower haemoglobin levels while using other physiological mechanisms to

adapt to hypoxia (Beall, 2007). These findings demonstrate that adaptation to high altitude is complex and cannot simply be explained by an increased red blood cell count.

People who are physically fit are not necessarily protected against altitude sickness. Acute mountain sickness (AMS) can affect otherwise healthy and fit individuals, and physical fitness alone does not provide protection against its development (Imray et al., 2013). Individual susceptibility varies considerably, while factors such as the altitude reached, rate of ascent, previous acclimatisation, and intensity of physical activity can influence the likelihood of developing symptoms (Imray et al., 2013; Luks et al., 2024). Physical exertion at altitude may also increase the risk or severity of AMS because of the additional demand for oxygen under hypoxic conditions. Consequently, gradual ascent and adequate acclimatisation remain important strategies for reducing the risk of altitude-related illness (Luks et al., 2024).

Imray et al. (2010) describe the primary physiological hurdle of high-altitude environments as hypobaric hypoxia. This condition is triggered by the steady decline in barometric pressure during ascent, which subsequently reduces the partial pressure of oxygen. It is this specific environmental shift that serves as the fundamental catalyst for high-altitude illnesses, including Acute Mountain Sickness (AMS) and High-Altitude Cerebral Edema (HACE) (p. 468).

As climbers ascend to higher elevations, the air gradually becomes thinner. It is also known as a decrease in oxygen concentration in the air. The oxygen percentage in the air is constant at about 21% up to 1,000 m. Still, oxygen density decreases as atmospheric pressure decreases with altitude. Reduced atmospheric pressure at higher elevations

decreases the availability of oxygen for gas exchange in the lungs, resulting in lower arterial oxygen saturation and reduced oxygen delivery to body tissues. As can be seen from the fact that all cells, including brain cells, begin to die in less than 5 minutes without oxygen, even a slight lack of oxygen in the atmosphere affects the entire body, which is the fundamental cause of altitude sickness. It causes acute mountain sickness (AMS), high-altitude cerebral edema (HACE), and high-altitude pulmonary edema (HAPE).

Acute mountain sickness (AMS) is the most common form of acute altitude illness and is generally less severe than HAPE or HACE. Common symptoms include headache, dizziness, nausea, vomiting, loss of appetite, fatigue, and sleep disturbance, which may develop following ascent to a higher altitude (Davis & Hackett, 2017). Symptoms can improve with rest and acclimatisation, but further ascent should be avoided if symptoms persist or worsen. In more severe altitude illness, high-altitude pulmonary edema (HAPE) may cause symptoms such as breathlessness, cough, and, in advanced cases, pink or frothy sputum. Neurological symptoms such as confusion, altered mental status, and loss of consciousness are more characteristic of high-altitude cerebral edema (HACE) (Davis & Hackett, 2017; Luks et al., 2024).

Davis and Hackett (2017) define High-Altitude Pulmonary Edema (HAPE) as a non-cardiac form of edema caused by a compromise in the pulmonary blood-gas interface. This failure allows fluid to infiltrate the alveolar spaces, which significantly impairs respiratory function. The authors identify a noticeable decline in physical stamina and the onset of a persistent dry cough as the primary clinical indicators that HAPE is developing (p. 249).

High-altitude pulmonary edema (HAPE) and high-altitude cerebral edema (HACE) are severe and potentially life-threatening forms of high-altitude illness (Davis & Hackett, 2017). HAPE involves the accumulation of fluid in the lungs, which interferes with normal gas exchange and reduces the transfer of oxygen into the blood. If symptoms of HAPE develop, further ascent should be stopped and descent to a lower altitude should be undertaken as soon as safely possible. Supplemental oxygen may also be required, particularly when immediate descent is not possible (Davis & Hackett, 2017; Luks et al., 2024).

Hackett et al. (1998) describe High-Altitude Cerebral Edema (HACE) as a critical neurological syndrome characterised by the accumulation of fluid within or around brain tissue. Often considered the final, most severe stage of Acute Mountain Sickness (AMS), HACE can manifest rapidly over several hours or days. The condition is particularly lethal because the resulting increase in intracranial pressure can lead to brain herniation, often proving fatal within 24 hours if not immediately treated. Key clinical indicators include a marked decline in mental clarity, physical incoordination (ataxia), and steady neurological failure (p. 1992).

High-altitude cerebral edema is categorised by Jensen and Vincent (2020) as the terminal phase of altitude-related illness. They emphasize that while HACE occurs less frequently than other conditions, its potential for rapid deterioration makes early diagnosis vital. Mountaineers exhibiting altered mental states or significant fatigue should be treated with extreme caution, as these symptoms signal a shift toward cerebral herniation. If left unaddressed, this neurological decline can result in death in less than a day (p. 1).

As mentioned above, altitude sickness should not be taken lightly. Acute mountain sickness (AMS) is generally self-limiting when further ascent is stopped, but severe altitude illnesses, particularly high-altitude cerebral edema (HACE) and high-altitude pulmonary edema (HAPE), can be life-threatening if they are not recognised and treated appropriately (Luks et al., 2024). HACE and HAPE require immediate attention, and descent remains an important treatment when symptoms are severe or continue to worsen (Luks et al., 2024).

The most effective approach to reducing the risk of altitude illness is gradual ascent and appropriate acclimatisation. Acclimatisation involves physiological changes that allow the body to adjust progressively to reduced oxygen availability at increasing altitude. These changes include increased ventilation and other adaptations that improve oxygen delivery and tolerance to hypoxic conditions (Imray et al., 2011). Current guidelines recommend gradual increases in sleeping elevation once above approximately 3,000 m and incorporating additional acclimatisation days where possible (Luks et al., 2024).

Symptoms of AMS commonly include headache accompanied by symptoms such as dizziness, fatigue, nausea, or vomiting following recent ascent to altitude (Imray et al., 2011). More serious conditions include HACE, which can cause neurological deterioration, and HAPE, which affects pulmonary function and can become life-threatening. Climbers experiencing worsening altitude illness should stop ascending, and descent should be initiated when symptoms are severe or do not improve. Supplemental oxygen can also be used when available, particularly when descent is difficult or delayed (Luks et al., 2024). Acetazolamide (Diamox) is commonly used for the prevention and treatment of AMS. As

a carbonic anhydrase inhibitor, it promotes bicarbonate excretion and produces a metabolic acidosis that stimulates ventilation and improves acclimatisation (Luks et al., 2024).

Careful ascent planning is therefore important when travelling to high altitude. Above 3,000 m, the Wilderness Medical Society recommends that increases in sleeping elevation should generally be limited to approximately 500 m per day, with an additional acclimatisation day for every 1,000 m of elevation gained (Luks et al., 2024). Maintaining adequate hydration is also important during high-altitude activity, although excessive hydration does not prevent altitude sickness and should be avoided. Climbers should monitor themselves and other members of their group for symptoms because hypoxia and altitude illness can affect physical and cognitive performance. These strategies, together with gradual ascent and appropriate responses to developing symptoms, can reduce the risk of serious altitude-related illness.

2.2.2.2 Cold: Hypothermia and Frostbite

Moore et al. (2012) suggest that high-altitude risks are not solely due to oxygen deprivation. They argue that the simultaneous presence of freezing temperatures, intense winds, and reduced barometric pressure creates a cumulative physiological burden, significantly increasing the likelihood of cold-weather injuries such as frostbite (p. 1).

For mountaineers, those who venture into high-altitude mountains, hypothermia and frostbite are acknowledged risk factors for mountain climbing. We often hear about a climber forced to spend the night in highly exposed conditions in wind chill temperatures, and the climber died from hypothermia and frostbite.

Hypothermia occurs when core body temperature falls below 35°C because the body loses heat faster than it can produce it. Although hypothermia is commonly associated with high-altitude mountaineering and polar environments, it can also occur in moderate climates and indoor settings, showing that the risk is not limited to extreme environments (Turk, 2010, p. 106).

As they describe, hypothermia is clinically defined as a reduction in core body temperature below approximately 35°C, occurring when heat loss exceeds heat production (Turk, 2010). It occurs when the body's heat production is reduced, heat loss increases, or both occur in combination, and hypothermia can develop suddenly or gradually. When the body temperature is lower than usual, blood circulation, respiration, and nervous system function slow down.

According to Arora and McCullough (2004), hypothermia is classified into three categories based on core temperature. Hypothermia is divided into three categories according to core temperature: mild, moderate, and severe. Mild hypothermia is when the core body temperature is 33 to 35 °C, and tremors are generally prominent. A phenomenon called “chicken skin” occurs when the hair erector muscles contract. Blood vessels in the skin constrict, causing the skin to become pale and the lips to turn blue. They may become lethargic, try to sleep, or mispronounce words. They lose their balance and fall or show no reaction to external stimuli.

Turk (2010) identifies the moderate stage of hypothermia as occurring when core temperatures drop between 29°C and 34°C. This phase is marked by a significant decline in neurological function, as muscle shivering ceases and is replaced by rigidity. As the

body's metabolic processes slow, victims may experience dilated pupils and a dangerous reduction in both heart rate and respiratory frequency, eventually leading to a comatose state. Notably, cognitive disruptions such as confusion can manifest even in the milder stages, specifically at temperatures exceeding 33°C (p. 107).

Turk (2010) explains that the final cause of death in hypothermia is typically a total breakdown of cardiac function, manifested as either asystole or ventricular fibrillation. This lethal heart rhythm is often triggered by a combination of factors, including severe oxygen deprivation in the heart muscle, chemical imbalances in electrolytes, and a dangerous surge in catecholamine levels (p. 107).

Severe hypothermia occurs when core body temperature falls below 28°C and can lead to serious complications, including loss of consciousness, reduced blood pressure, abnormal heart rhythms such as ventricular fibrillation, cardiac arrest, and loss of normal reflexes (Turk, 2010).

Hypothermia is a problem, but muscles keep spasming to generate heat when body temperature drops, while peripheral blood vessels constrict to conserve heat. The problem is that cerebrovascular and coronary arteries contract by the exact mechanism as peripheral blood vessels. The energy consumed by muscle and fat cells increases, but the brain and heart do not receive blood flow. At this time, when a cerebral blood vessel is blocked, or bursts, or a narrowed coronary artery is blocked, cardiac arrest occurs immediately. Death can happen in a short period. In most cases of freezing, help from others cannot be obtained, leading to death.

While physical and mental strength remain, the human body tries to raise its temperature by contracting muscles, a phenomenon known as shivering. After that, the brainstem struggles to conserve energy by turning off metabolic functions one by one. However, if you no longer have the energy to move because your physical strength is exhausted, or if you fall asleep and let go of your mind, you will lose your ability to regulate your body temperature and eventually die before physical strength is exhausted.

Turk (2010) identifies "paradoxical undressing" as a bewildering behavioural shift occurring in the terminal phases of hypothermia. Despite dangerously low internal temperatures, individuals may experience a profound, yet erroneous, feeling of heat that leads them to discard their clothing. Interestingly, this phenomenon is documented most often in relatively moderate environmental temperatures, generally ranging from -5°C to 5°C (p. 110).

If hypothermia lasts a long time, the tremors eventually disappear, and the person may exhibit behaviours such as taking off clothes despite the cold. It is called paradoxical undressing, and the cause is not yet known, but the theory is that the brainstem is damaged by the cold and issues abnormal commands. The muscles contract, the blood vessels relax completely, and the blood flow suddenly increases. If it has come to this point, the patient has already lost any normal judgment. Climbers who have died of hypothermia are often found half-naked. And just before freezing to death, it performs an instinctive action called terminal burrowing, squeezing into a narrow space. It is a behavioural pattern observed in animals entering hibernation, and an ultimatum issued by the brainstem to the human body on the verge of death. However, because it is a phenomenon caused by low body temperature, the symptoms may persist even after the body temperature is restored to

normal. Dressing in dry clothes, moving to a warm place, raising the temperature with a stove, or drinking a warm drink if you are still conscious are also beneficial. Therefore, prevention and proper treatment knowledge for hypothermia are essential for mountaineers.

Arvin et al. (2004) identify frostbite as the most prevalent cold-related trauma among climbers operating in high-altitude or sub-zero environments. Despite this high incidence, they argue that the specific epidemiology and risk factors affecting mountaineers remain under-researched. This significant gap in the medical literature highlights a need for more focused studies into how cold-season conditions contribute to tissue damage in this specific demographic (p. 898).

According to Arvin et al. (2004), a total of 637 mountaineers recruited to the study reported 467 incidents of frostbite. These incidents are all related to a lack of training and knowledge on preventing frostbite.

Between 1984 and 1994, a tertiary hospital in northeastern Pakistan documented roughly 1,500 frostbite cases originating from the high-altitude Karakoram range. According to Bokhari et al. (1998), the patient demographics revealed a significant trend: a large majority of those suffering from cold-induced injuries were not foreign climbers but local porters and guides working on these expeditions. This data underscores the disproportionate risk faced by those providing essential support in extreme mountain environments (p. 91).

Frostbite is an important medical risk in high-altitude environments and can present a significant threat to mountaineers exposed to extreme cold conditions (Bokhari et al., 1998). Their decade-long analysis in the Karakoram range revealed that frostbite cases (n = 1,500)

occurred at a rate approximately 1.5 times higher than the cumulative total of all other conditions studied, including AMS, HAPE, and HACE combined (See Table 2.1). This underscores the physical vulnerability of individuals operating in extreme cold, as tissue damage from frostbite appears far more frequent than the systemic physiological failures usually associated with elevation (p. 91).

Table 2.1

High altitude-related problems (Frostbite: epidemiology at high altitude in the Karakoram mountains)

Problems	No. of cases
Frostbite	1500
Acute mountain sickness	469
Exhaustion	299
Hypothermia	46
Pneumonia	86
High-altitude pulmonary edema	255
High-altitude cerebral edema	95

Bokhari et al. (1998) insist that awareness and dedicated discipline regarding preventative measures for frostbite are therefore of paramount importance.

Keller et al. (2015) explain that frostbite typically targets the body's extremities, such as the digits, as a byproduct of a protective circulatory shift. When exposed to extreme cold,

the body initiates a survival mechanism that restricts blood flow to the periphery to maintain the temperature of the brain and internal organs. While this internal "triage" preserves life-sustaining functions, it leaves the fingers and toes highly vulnerable to localised tissue freezing and subsequent damage (p. 3).

Frostbite is damage to the body caused by prolonged exposure to low temperatures. Frostbite occurs when blood circulation is disrupted at low temperatures, leading to necrosis of the affected area due to oxygen deprivation. In particular, hands, feet, ears, etc. This is mainly damaged. For this reason, people can often see mountaineers who have lost their fingers and toes due to frostbite.

Reamy (1998) classifies frostbite into four distinct stages based on the depth of tissue involvement. Initial first-degree injuries are marked by localised numbness and a pale central plaque surrounded by reddened skin. As the condition advances to the second degree, clear or milky blisters typically emerge within the first day, accompanied by significant swelling (edema). Third-degree trauma is significantly more severe, indicated by blood-filled (hemorrhagic) blisters that eventually transition into a dark, rigid eschar over a fortnight. The most extreme stage, fourth-degree frostbite, results in total tissue death (necrosis) and eventual loss of the affected limb or digit (p. 36).

Reamy (1998) suggests that the onset of frostbite presents recognisable markers that serve as diagnostic indicators for the eventual degree of trauma. The process typically begins with localised sensory loss, or cold-induced numbness, which quickly transitions into a noticeable lack of motor control. This "clumsiness" in the extremities is a critical early warning sign that the cold is beginning to affect deeper physiological functions (p. 36).

The symptom of frostbite is the sudden disappearance of pain. This may be because cold spots and pain receptors do not function below a specific temperature. Therefore, high-altitude mountaineers are most afraid of losing sensation in their excruciatingly cold hands and feet and instead hope that the pain will continue. The necrotic area turns white and then rots black. If mountaineers immerse it in hot water to melt frostbite, a sudden increase in blood flow can trigger ischemia-reperfusion injury, which can worsen the damage. In the case of mild symptoms, soak the damaged area in warm or hot water for 30 to 60 minutes.

Reamy (1998) cautioned against inappropriate rewarming practices in the treatment of frostbite. Exposure to water outside the recommended temperature range may worsen tissue damage. At the same time, the application of dry heat can result in uneven warming and increase the risk of burn injury to already numb and compromised tissue (p. 38).

Overheating of frostbitten areas promotes tissue damage. Therefore, mountaineers should avoid heating a hot stove, getting close to a light bulb, or touching a hot water bottle. Once the tissue is warmed, the frostbitten area should be carefully washed, dried, and wrapped in a sterile bandage to prevent infection.

Reamy (1998) suggests that optimal recovery from frostbite involves a combination of systemic and topical treatments. Beyond the 12 mg/kg daily dose of ibuprofen, applying aloe vera topically can further soothe inflammation and enhance tissue regeneration. For field management, maintaining the integrity of blisters is vital; however, if they rupture, an antibiotic ointment should be applied immediately. Interestingly, Reamy recommends using a lightweight plastic wrap for frostbitten areas in mountain environments. This creates an occlusive barrier that mimics a natural blister, preventing wound dehydration

and guarding against infection while providing pain relief by insulating the area from frigid air (p. 39).

2.2.2.3 Avalanche Risks

Salisbury and Hawley (2007) identify avalanches as the leading cause of death in the Himalayas, accounting for a staggering 48% of total fatalities. Their research indicates that this single environmental factor is more dangerous than any other medical or physical risk. By surpassing all other causes of mortality, avalanche events define the primary safety challenge for modern Himalayan expeditions (p. 97).

McCammon (2009) and Atkins (2007) argue that while environmental variables like snowpack stability and weather are necessary conditions for an avalanche, the primary cause of accidents is typically human fallibility. They suggest that deficiencies in technical skills and situational knowledge, coupled with flawed decision-making, create a "human factor" that is more dangerous than the terrain itself. In many cases, it is the climber's inability to accurately interpret snow patterns rather than the snow itself that leads to a fatal outcome.

As outlined by Martinelli and Perla (1978), avalanches result from a shear failure where the stress of the snow mass exceeds its frictional and mechanical capacity. The slope angle and snow quality are the defining variables in this equilibrium. Triggers can be as minor as a snowball falling from a branch or as significant as rapid loading from a 30 cm storm cycle. Thermal transitions, such as warm-air inflows, further destabilize the pack by allowing meltwater to act as a lubricant between layers. Ultimately, the location and terrain

of the slope dictate the avalanche's destructive potential, often leaving climbers with little chance of survival if caught in its path (p. 66-69).

According to Reynolds and Richardson (2000) and Evans (2002), avalanches in places like the Himalayas, where snowpack amounts and fall heights differ from those in other neighbourhoods, are the scariest. In particular, what happens in alpine areas at 6-8,000 meters above sea level, such as Annapurna in the Himalayas, differs from what happens in the Alps. This kind of neighbourhood is not about pouring soft and delicate snow. In large alpine avalanches, compacted snow and ice blocks can reach substantial sizes, generating destructive kinetic forces capable of causing severe injury or death. The volume is about the size of a few apartments. A typical exposure area is tens to hundreds of meters wide and hundreds of meters to 1-2 kilometres long. Rather than pouring snow and covering it, ice masses sweep it away with kinetic energy. In addition, an avalanche, as described above, causes not only snowfall but also the movement of dirt and stones. If mountaineers get hit directly by an avalanche like this, they will be lucky if they can leave even bloodstains, let alone break through after being buried. If people do winter trekking in the Himalayas, they will sometimes pass over an avalanche that swept away a few hours or days earlier, and it is so vast that they can get lost in the powder snow. It is difficult to find the original route because all the features are buried or erased. Avalanches are not called the disaster of mountaineers for nothing.

Grissom and Radwin (2002) highlight that the porous nature of snow allows for a limited degree of gas exchange, providing a brief window for respiration while buried. However, survival is strictly time-dependent: the probability of a successful rescue is exceptionally high (92%) if the victim is extricated within 15 minutes. This likelihood drops to

approximately 30% after 35 minutes, with fatalities becoming nearly certain after two hours. Because locating a victim is the primary obstacle during this critical window, the researchers emphasize that survival systems—such as beacons, transmitters, or radar—are essential for a rapid and effective recovery (p. 144).

2.2.3 Risk Factor - The Human Factor

Human factors are an important part of understanding the risks involved in high-altitude mountaineering. While weather, terrain, and altitude create significant external hazards, the way climbers think, respond, and make decisions can also influence their safety. At high altitude, physical and mental changes can affect judgement, awareness, concentration, and the ability to respond appropriately to changing conditions. This section examines these human factors and how they may influence climbers' behaviour and decision-making in high-risk mountain environments.

2.2.3.1 Biological Factors: Cognitive Dysfunction

This study examines why high-altitude climbers risk death or damage to their bodies, what kind of physical and mental experiences they experience there, and what kind of cognitive changes they undergo through those experiences. Areas above 8000 m above sea level are called "Death Zones." Climbing such a high mountain is dangerous. Our bodies can react to extremes at high altitudes with low oxygen.

According to Lankford (2014), the "Death Zone" is defined as a level of barometric thinning that the human pulmonary system cannot overcome over the long term. At the summit of Everest, the 33% air pressure relative to sea level impairs neurological and sensory processing. This atmospheric deficit, paired with localised factors like extreme

wind chill and sub-zero temperatures, creates a high-risk environment where mental errors become frequent and physical output drops sharply. Unlike the "buffer zones" at lower elevations, altitudes exceeding 7,800 meters impose a rigid time limit on human presence, a concept rooted in the historical observations of Swiss physician Edouard Wyss-Dunant (p. 348).

At 8,000 m above sea level, climbers sometimes lose their sense of reality and act dangerously as if possessed by fantasy. Climbers may experience severe cognitive disturbances, including hallucinations, perceptual distortions, and impaired judgement. They lose their sense of reality and do dangerous and foolish things, such as suddenly talking nonsense or changing routes out of the blue. There are many stories of people who have lost their sense of reality while climbing such a place alone. A climber who had climbed Everest recalled that a climber named ‘Jimmy’ suddenly appeared in the dark, said ‘Hello,’ followed him, and then suddenly disappeared again. The high-altitude climbers often experienced a special form of psychosis and high-altitude deterioration. This is one of the ill effects of altitude.

Lankford (2014) argued that physiological deterioration at high altitude is closely linked to reduced atmospheric pressure. He noted that decline typically begins when atmospheric pressure falls to approximately half of sea-level values and accelerates rapidly with further ascent. Even when climbers maintain adequate warmth, hydration, and nutrition, the rate of physiological deterioration may exceed the body’s capacity to acclimatise (p. 349).

Lankford (2014) highlights a severe physiological crisis at the summit of Everest, where the maximal oxygen uptake drops to a critical level of approximately 1 L/min. This volume

is only marginally higher than the body's basal metabolic rate, creating a scenario where almost all available oxygen is consumed by involuntary life-support functions, such as thermoregulation and respiratory muscle activity. Consequently, there is virtually no "metabolic surplus" remaining for physical movement or complex cognitive processing, leading to a profound decline in both exercise capacity and mental clarity (p. 347).

Hallucinatory and other unusual perceptual experiences have been reported among climbers at very high and extreme altitudes. Brugger et al. (1999) investigated eight experienced high-altitude climbers and identified visual, auditory, and “felt-presence” hallucinations. Some climbers described sensing an imaginary companion, hearing voices or music, or experiencing unusual changes in bodily perception. These experiences were associated with the extreme physical and psychological conditions encountered at high altitude, including hypoxia, exhaustion, acute stress, and social isolation (Brugger et al., 1999).

More recent research has expanded on these early findings. Hüfner et al. (2018) analysed 83 reported episodes occurring above 3,500 m and found that psychotic symptoms could occur alongside high-altitude cerebral edema (HACE) or other changes in mental state, but could also occur independently. The authors described this latter condition as isolated high-altitude psychosis. Importantly, episodes involving psychosis were associated with an increased occurrence of accidents and near-accidents, suggesting that perceptual and cognitive disturbances at altitude may have important safety implications (Hüfner et al., 2018). More recent research has continued to document “third-person” experiences involving visual and felt-presence hallucinations in experienced climbers, while also

identifying possible contributing factors such as hypoxia, exhaustion, sleep deprivation, dehydration, isolation, and perceived danger (Garrido & Hüfner, 2023).

However, psychotic symptoms should not be assumed to occur frequently in all high-altitude climbers. A field study of organised high-altitude expeditions found that clinically diagnosed psychosis was rare, although some climbers reported less severe psychotic symptoms (Hüfner et al., 2021). These findings suggest that psychological responses to extreme altitude vary considerably between individuals. They also demonstrate that hallucinations and altered perception should not automatically be attributed to HACE or hypoxia alone, as several physiological, environmental, and psychological factors may contribute. Such disturbances remain relevant to mountaineering safety because altered perception and cognition may affect a climber's ability to recognise hazards and make appropriate decisions at extreme altitude.

Tempest et al. (2007) categorise the physiological symptoms of altitude sickness, while Krakauer's (1997) narrative account of the 1996 Everest disaster illustrates the lethal reality of these conditions. Beyond the physical threat of high-altitude pulmonary edema (HAPE)—which can claim even the most seasoned high-altitude workers—the most insidious danger is the collapse of rational decision-making. Krakauer (1997) admits to his own cognitive failures, such as misidentifying a colleague after a descent, while professional expedition leaders have been known to make fatal technical errors, such as misreading oxygen levels or incorrectly operating valve systems due to profound oxygen deprivation.

Elmes and Frame (2008) also point out that these cognitive dysfunctions and fatal wrong decision-making in the Death Zone led seven climbers to their deaths. Cognitive dysfunction such as summit fever, auditory and visual hallucinations, and mountain madness may result from hypoxia, exhaustion, cold, and wind exposure to a low-pressure hypoxic environment at extreme altitude.

There seem to be a few accidents and deaths caused by cognitive dysfunction at high altitude. Learning cognitive coping strategies is very important. Climbers should be taught how to cope when climbing to high altitudes, either on their own or with the help of a climbing partner. The results of this study will help mountaineers who climb at extreme altitudes understand the nature of this phenomenon, enabling them to recognise and cope with similar symptoms if they experience them during their climbs.

2.2.3.2 Psychological Factors: Motivation and Goal

People see high-altitude climbing as an extreme sport and a form of self-transcendence and self-conquest. Also, they believe those climbers want to climb extreme mountains as a part of social recognition and distinction. However, the most obvious goal for climbers is to stand on the summit of their dream high peaks. This goal is universal to all climbers.

Brymer and Schweitzer (2017) redefine extreme sports as activities where the margin for error is so slim that any failure typically leads to a fatal outcome. However, they argue that these pursuits are not merely a search for danger or "risk-taking." Instead, high-consequence athletes often experience a profound shift in their internal state, reporting an enhanced sense of meaningfulness and a newfound "authentic integration." For these

individuals, the activity provides a liberating escape from mundane life, facilitating a deep personal evolution that reshapes their entire worldview (p. 2).

Brymer and Schweitzer (2017) argued that participation in extreme sports inherently involves exposure to uncontrollable natural forces. Activities such as kayaking and BASE jumping are directly dependent on environmental conditions, including water levels and wind direction. Despite these evident constraints and risks, individuals continue to engage in such pursuits, highlighting the complex motivational and psychological dimensions underlying participation in extreme environments (p. 10).

Williams and Donnelly (1985, as cited in Luisa-Pereira, 2011) suggest that the presence of danger is not merely a byproduct but the fundamental allure of mountaineering; it acts as the primary catalyst for engagement while simultaneously serving as the factor that eventually forces retirement from the sport. This creates a societal disconnect, where the public often views the "contradictory behavior" of climbers—ascending dangerous peaks only to return to the start—with profound confusion. This lack of understanding frequently manifests as online criticism, labeling the pursuit as "reckless" or "irresponsible." Critics often question the lack of financial incentives, yet for over two centuries, the drive to overcome these vertical challenges has persisted despite social disapproval and the absence of material rewards (p. 44).

People regard high-altitude climbing as an extreme sport. However, climbing activities cannot be quantified and evaluated as easily as extreme sports events. The uncertainty of the ever-changing mountain stems from the fact that each climber encounters a different environment. Climbing activities that occur under the primary relationship between the

mountain and the climber are externally dynamic physical activities, but this activity aims for the inner world. As if a painter were painting a picture, the image of climbers fiercely searching for their path using the giant wall of an alpine mountain as a canvas is more like a creative act.

Legendary mountaineer Reinhold Messner (2003) emphasised the philosophical and experiential nature of climbing, describing mountaineering not as competition but as a deeply personal and creative engagement with risk, environment, and self (p. 210-212). Through it, climbers experience an irreplaceable sense of achievement and reflection. The more difficult the climb, the greater the sense of accomplishment. It is said that the driving force of human development is the challenge to nature and science, but on the other hand, isn't it the history of self-realisation of countless individuals?

Messner (2010) also emphasised that mountaineering extends beyond physical performance and competition, describing it as a deeply creative and aesthetic engagement with the mountain environment. He argued that climbing reflects an artistic process shaped by the climber's interaction with terrain, route selection, and ascent style, highlighting the experiential and reflective dimensions of mountaineering practice (p. 54-56). This perspective underscores the importance of cognitive, emotional, and perceptual engagement in mountaineering, reinforcing the view that safe and effective climbing requires not only technical competence but also situational awareness, judgement, and experiential understanding.

High-altitude climbers face the severity of a zone of death and suffer from a high-altitude illness while climbing an 8,000 m mountain, which requires physical and psychological

capabilities beyond endurance. They are apt to feel the temptation and fear of death, terrible pain, and an inability to reason during climbing activities, which helps them experience enlightenment that cannot be imagined on the ground. It was found that high-altitude climbers discovered the ego and changed their perspectives on life and the world, as well as their attitude toward life, through climbing. This strong motivation leads them to extreme high-altitude climbing.

According to Burke et al. (2011), climbers who perform in extreme environments have strong motivation despite internal obstacles such as fear of death, anxiety, and self-doubt, as well as life-threatening external barriers such as altitude sickness, avalanches, and extreme weather conditions. However, this strong motivation leads climbers to their deaths, as I mentioned earlier. Climbers who operate under extreme conditions at high altitudes often experience cognitive dysfunction. I have usually seen climbers lose their sanity, and their motives lead them to overlook dangerous conditions at high altitudes.

It will benefit all climbers if the research develops a new framework for exploring how climbers manage their motivation and risk factors in extreme conditions, thereby preventing unnecessary deaths in the mountains.

2.3 Learning Theories

While immersive technologies have gained considerable traction in the educational sector, their deployment in specialised high-consequence environments such as mountaineering remains under-researched. Contemporary literature has largely prioritised "high-volume" sectors—namely medical simulation, flight training, and defence—leaving a conspicuous absence of empirical data regarding outdoor safety and alpine education (Radianti et al.,

2020; Jensen & Konradsen, 2018). As outlined by Priest and Gass (2017), the foundation of mountain safety instruction is experiential learning, in which the physical environment serves as the primary classroom. This "hands-on" approach requires learners to cultivate both mechanical proficiency and analytical judgment through direct interaction with real-world alpine hazards. Such authentic engagement ensures that the development of safety protocols is inextricably linked to the unpredictable nature of the outdoor setting (Salmon et al., 2010). Despite the efficacy of traditional field-based learning, the practical implementation of such programs is often hindered by significant administrative and environmental hurdles. Apollo (2017) highlights that the high costs and complex logistics of mountain expeditions often exclude participants from under-resourced or geographically isolated areas (p. 34-36). Furthermore, the inherent physical risks involved in authentic mountain environments pose a substantial liability, particularly when introducing inexperienced climbers to high-consequence scenarios (Furman et al., 2010). Immersive technologies provide a robust pedagogical alternative by facilitating high-fidelity interactions with hazardous environments within a digitally regulated space. As noted by Makransky and Mayer (2022), this allows for the preservation of experiential learning principles while entirely neutralizing the physical liabilities associated with real-world training. By replicating the sensory cues of risk without the literal danger, VR creates a "psychologically authentic" laboratory for skill acquisition (Slater & Sanchez-Vives, 2016). However, the effectiveness of VR-based training depends on its pedagogical design and theoretical grounding. Learning theories such as Activity Theory, Experiential Learning Theory, and Constructivism provide essential frameworks for understanding how learners interact with tools, construct knowledge through experience, and transfer learning to real-

world contexts (Engeström, 1987, 2001; Kolb, 1984; Vygotsky, 1978). Accordingly, this literature review examines existing research on mountain safety education, relevant learning theories for high-risk training, and the potential of immersive technologies to enhance safety education and preparedness in mountaineering contexts.

2.3.1 Constructivism and Social Constructivism

A complex, rapidly changing world and new technologies influence pedagogical approaches in learning environments.

Barnett (2012) argues that the rapid acceleration of technological and educational needs requires a move toward more autonomous and self-governing learning frameworks. Traditional models, such as Behaviorism and Cognitivism, are increasingly viewed as incomplete in the face of modern complexity. Consequently, this study adopts a design-based research approach grounded in Constructivism and Heutagogy, prioritising the learner's agency and social interaction as the primary drivers of knowledge creation.

Constructivism is a modern learning theory, and heutagogy is self-determined learning that builds on Constructivism and Social Constructivism. Bednar et al. (1991) characterise learning as a constructive process where meaning is derived directly from individual experience. This theory suggests that instructional design should prioritise authentic contexts where learners can "re-invent" knowledge for themselves, rather than merely replicating pre-defined procedures. This makes it a vital framework for safety training, where the goal is to develop a deep, personalised understanding of environmental risk. Learning is more meaningful to students when they can interact with concepts in the learning process. Constructivism states that learning is an active, contextualised process of

constructing knowledge rather than acquiring it. Knowledge is built based on personal experiences and hypotheses about the environment. Constructivism utilises interactive teaching strategies to create meaningful contexts that help students construct knowledge based on their own experiences.

Ertmer and Newby (1993) argue that learning is not a passive process of importing information into the mind. Instead, individuals function as active architects of their own understanding, crafting a subjective internal model of reality through their unique history of environmental engagement. In this framework, knowledge is seen as a lived interpretation rather than a static recording of external facts (p. 63).

Constructivism differs from other learning theories. It is active in the learning process, helping to engage and motivate students by encouraging them to take a more active role. It is also reflective, allowing students to control their learning process and lead the way by reflecting on their own experiences. Also, it is collaborative and evolving in the learning process. The students collaborate to learn strategies and methods from one another. This different approach to learning is called Social Constructivism.

Social Constructivists view learning as a social process that occurs through participation in social activities. Meaningful learning occurs when individuals are engaged in social activities such as interaction and collaboration. Social Constructivism emphasises the importance of culture and context in the process of knowledge construction. According to Vygotsky (1978), knowledge is constructed through social interaction and is shared rather than an individual experience. He states that human beings create meaning from an

educational experience by learning with others. He views interaction with peers as an effective way of developing skills and strategies within the Zone of Proximal Development.

Vygotsky (1978) conceptualised the Zone of Proximal Development (ZPD) as the psychological space between what a learner can accomplish in isolation and what they can achieve when supported by a mentor. This "potential development" is unlocked through strategic guidance or cooperation with more experienced associates, allowing the student to navigate challenges that would otherwise be beyond their independent reach (p. 86).

He insists that teachers use cooperative learning exercises where less competent learners develop with help from more skilled peers.

2.3.2 Heutagogy

Heutagogy is self-determined learning that builds upon Constructivism, Social Constructivism, and Andragogy. Hase and Kenyon (2001) define Heutagogy as the framework for self-determined learning, synthesizing various pedagogical strands into a model centered on learner autonomy. This approach directly challenges traditional, instructor-led paradigms by advocating for a culture of open "knowledge sharing" instead of the restrictive "hoarding" of information common in rigid academic structures. In an era of rapid technological disruption, they argue that the meta-skill of "learning how to learn" is the most critical asset for navigating the evolving complexities of modern professional and social environments (p. 3).

Heutagogy is self-determined learning and involves a primary shift in the role of the teacher. The learners have the primary role in a heutagogical learning environment and are learner-centred rather than teacher-centred.

Hase and Kenyon (2001) observe that conventional educational models have historically prioritised instructor-led hierarchies, where the teacher dictates both the curricular substance and the instructional delivery. While the emergence of andragogy introduced a more nuanced focus on the needs of adult learners, it still functioned within a framework of guided supervision. In contrast, heutagogy is presented as a necessary evolution for the information age, empowering the student to act as a primary agent, autonomously determining their learning trajectory and objectives (p. 2).

Self-determined learning focuses on how people learn, enabling them to manage their learning environment to meet their needs. It focuses on what the learners want to know. According to Hase and Kenyon (2001), self-determined learning provides the learner empowerment, capabilities, and an open-ended learning environment. Also, reflective practice is an essential characteristic of heutagogy. Hase (2009) points out “a critical learning skill associated with knowing how to learn” (p. 49).

Schön (1983) posits that the capacity for continuous professional and personal growth is rooted in the habit of critical reflection. By engaging in "reflection-in-action," individuals transition from passive recipients of information to active, lifelong learners who can navigate the complexities of their field. This iterative process of evaluating one’s own performance allows the practitioner to bridge the gap between theoretical knowledge and the messy, unpredictable reality of lived experience.

Blaschke and Hase (2019) argue that human beings possess an innate and highly developed capacity for continuous learning that exists independently of structured educational systems. They suggest that modern technology has effectively liberated the learner from

the traditional necessity of a formal instructor. In this view, rigid, content-heavy curricula are becoming obsolete, replaced by a heutagogical model where individuals acquire knowledge based on their own readiness and the demands of their daily lives (p. 78).

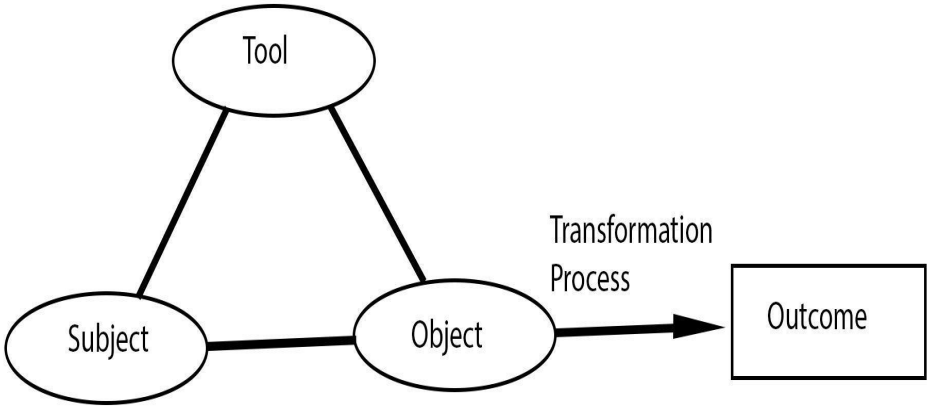
Blaschke and Hase (2019) argued that heutagogy emphasises learner involvement in program design and the creation of learning environments that mirror real-world application contexts. Drawing on the concept of state-dependent learning, they suggested that retention and transfer are enhanced when learning conditions resemble those in which skills will later be applied. Consequently, they advocated for experiential and simulation-based approaches that promote autonomy, creativity, and self-efficacy, while cautioning that teacher-centred models may foster learner dependency (p. 81).

2.3.3 Activity Theory

Part of this research is to explore the dynamics and characteristics of participants' learning experiences from the perspective of Engeström's Activity Theory (1987), which will be used in the ultimate study. The Activity Theory is a theory for analysing the activities that occur while various sociocultural and historical elements are linked and interact. The theory began in the 1920s with Vygotsky. His theory focused on mediating these three components: the subject, object, and tools or artefacts in the interaction, as indicated in Figure 2.1. Vygotsky (1978) views the relationship between the subject and objects as forming the core of activity.

Figure 2.1.

The core of an activity



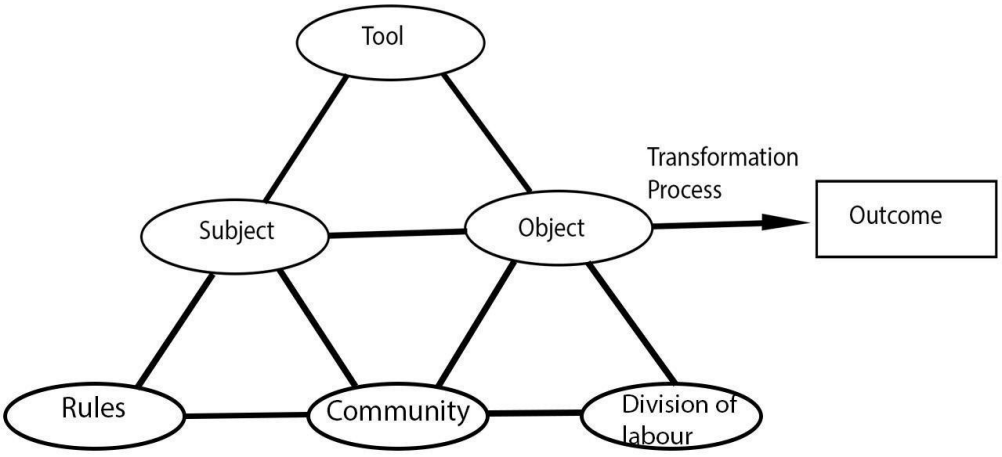
According to the conception of the triad, all activities are controlled and mediated by the use and manipulation of artefacts, tools, and objects. The subject would be a person or a group engaged in an activity, holding an object and motivating the activity. Mediation can be facilitated through various materials and mental tools, including culture, ways of thinking, and language. According to Vygotsky (1978), tool-mediated activity is essential to "the development of higher thinking." The theory, which originated in the 1920s, is currently the third-generation activity theory developed by Engeström across various fields. Engeström and Leont'ev (1978) expand Vygotsky's frameworks by introducing the concepts of activity, object of activity, and division of labour.

Engeström (1987, 2001) extends and integrates elements of Vygotsky's and Leont'ev's frameworks, and he systematises the Third-Generation Activity Theory model. It is centred on this research. Even then, the Third-Generation Activity Theory model presented by Engeström 30 years ago remains accessible. In Engeström's Activity Theory (1987), the activity system has three main components: the Subject, the object, and the community.

According to Kaptelinin and Nardi (2012), Engeström adds the ideas of community, rules, and outcomes. As articulated by Engeström (1987), human activity can be mapped through a triangular system of mediation. This model identifies the essential components—including the "subject," "object," and "mediating artifacts"—while situating them within a broader social environment defined by "rules," "community" standards, and a "division of labor." as shown in Figure 2.2 below. By viewing these elements as an integrated whole, researchers can better understand how contradictions and innovations emerge within a specific practice.

Figure 2.2

A general model of an activity system (Engeström, 1987, p 78)



The process of sociocultural development is shaped by the systemic tensions and contradictions inherent in human activity. Rather than viewing these systems as static, Engeström (2001) conceptualises them as "opening mechanisms" that facilitate institutional change. When these internal contradictions are resolved, the "object" of the

activity expands, enabling the community to transcend previous limitations and establish new professional practices (p. 137).

Crucially, Third-Generation Activity Theory shifts the focus from the individual to the collective "joint activity." Through participation, the community harmonises conflicting goals and rules to forge a new activity system. This iterative cycle, known as expansive learning (Engeström, 1987; Engeström & Sannino, 2010), uses instability as a catalyst for social transformation, embedding new practices directly into the community's shared culture.

As articulated by Grotlüschen (2010) through the lens of Holzkamp (2004), learning emerges from the tension between established routines and the "resistance" of the real world. These obstacles disrupt the flow of activity, compelling the learner to reflect on their current limitations and adapt their strategies. This transformative process ensures that learning is an active, problem-solving endeavor rather than a passive absorption of information (p. 29). Holzkamp (2004) believes that learning motivation and interest result from this process, and that it is a more efficient way of learning than defensive learning.

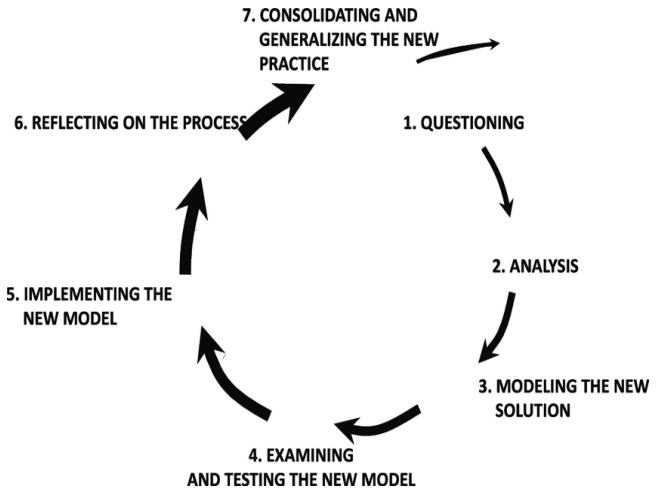
Grotlüschen (2010) distinguished between expansive and defensive learning, describing expansive learning as a process in which individuals actively engage with challenges arising from their own activity systems to broaden their possibilities for action. In contrast, defensive learning occurs when individuals engage in learning primarily to protect themselves from perceived threats to their existing practices or worldview (p. 9).

Expansive learning triggers changes in pedagogical approaches, requiring educational institutions to operate differently than they are used to in order to better understand.

Figure 2.3 below is Engeström and Sannino's (2010) cycle of expansive learning. (p 8).

Figure 2.3

The cycle of expansive learning. Engeström and Sannino (2010, p 8)



2.3.4 Authentic Learning

Herrington et al. (2010) maintained that authentic learning requires learners to engage in realistic, complex tasks that foster invention, collaboration, and meaningful problem-solving (p. 17). Lombardi (2007) described authentic learning as an approach centred on addressing complex, real-world problems through strategies such as role-play, problem-based learning, case studies, and engagement in virtual communities of practice (p. 2-4).

Herrington et al. (2010) and Lombardi (2007) argued that authentic learning moves beyond traditional, teacher-centred instructional settings by situating learning within meaningful, real-world contexts. Rather than focusing solely on the transmission of abstract concepts,

authentic learning emphasises engagement with complex tasks that align with learners' interests and intrinsic motivation. When learners perceive relevance and personal value in their learning activities, they are more likely to develop a deeper understanding and sustained engagement. In authentic learning environments, students acquire skills that are directly transferable beyond formal educational settings, supporting practical application in real-life contexts. Similarly, according to Har (2013), authentic learning is characterised by the concurrent development of knowledge and skill through active problem-solving. This pedagogical strategy immerses the student in the "real-world" dynamics of their chosen field, replacing abstract study with the lived experience of finding solutions to actual workplace challenges. Consequently, the learner gains a sophisticated understanding of how to function effectively within the specific constraints of their professional environment.

Herrington and Oliver (2000) also argue that much of the abstract knowledge students acquire in classroom-based learning environments is not retrievable in real-life situations for solving real-life problems. They insist on authentic situational learning as an alternative pedagogical framework for better outcomes. An authentic learning environment allows students to explore and construct concepts and skills through real-world problems relevant to their needs. It aligns student activities with real-world tasks as closely as possible. Authentic learning facilitates students' acquisition of knowledge, understanding of concepts, and application skills to solve real-life problems.

Lombardi (2007) noted that authentic learning environments encourage learners to persist even when they initially experience confusion or frustration, provided that the learning

activities reflect the social structures, cultural practices, and real-world relevance of the discipline (p. 2-4).

Therefore, students gain knowledge and skills for real-world issues and problems in an authentic learning environment. This learning environment leads students to the real world more effectively than traditional classroom-based learning.

In addition, advanced information and communication technologies (ICTs), as well as emerging communication, simulation, and visual technologies, enable the design and creation of truly innovative, authentic learning environments. These new technologies offer students authentic learning experiences, from experimentation to real-world problem-solving. Lombardi (2007) mentions that technological support for today's successful authentic learning environments is commonly included (p. 7).

- High-speed Internet connectivity
- Asynchronous and synchronous communication and social networking tools
- Intelligent tutoring systems, virtual laboratories, and feedback mechanisms
- Mobile devices

Lombardi (2007) also identifies eight critical factors that researchers must align on to ensure a successful authentic learning environment (p. 9).

- Goals
- Content
- Instructional design
- learner tasks
- Instructor roles

- Student roles
- Technological affordances
- Assessment

For authentic learning, teachers should prepare learning materials that mirror real-world complexities and create relevant tasks that engage students and prepare them for the real world. Herrington and Oliver (2010) guide nine critical characteristics of an authentic learning design (p. 17)

1. Authentic Context: Provide contexts that reflect how the knowledge will be used in real life.
2. Authentic Activities: Provide authentic activities.
3. Expert performances and process modelling: Provide access to both.
4. Multiple Roles and Perspectives: Offer a range of roles and perspectives.
5. Collaborative Construction of Knowledge: Support collaborative construction of knowledge.
6. Reflection: Foster reflection to facilitate the formation of abstractions.
7. Articulation: Promote articulation to make tacit knowledge explicit.
8. Coaching and Scaffolding: The teacher provides coaching and scaffolding at critical times.
9. Authentic Assessment: Provide an authentic assessment of learning within the tasks.

In summary, according to the researchers above, authentic learning with emerging technologies boosts motivation and improves student learning outcomes. It also prepares students for future careers and blends theories with practice.

2.3.5 Simulation-Based Learning

Simulation-based learning has been used in education and professional training for many years, particularly in healthcare, where learners need opportunities to develop practical skills in a safe and controlled environment. The need for alternative approaches to clinical education has been influenced by factors such as limited access to clinical sites, shortages of appropriately prepared clinical faculty, and the increasing need to prepare healthcare students for professional practice. Simulation provides an alternative way for learners to practise clinical skills and experience situations that may be difficult to reproduce safely in real clinical environments.

The use of simulation to replicate aspects of clinical practice has become an important educational approach in healthcare. Advances in technology have also expanded the range of simulation methods available, including human patient simulators and virtual scenarios. Simulation-based learning can provide learners with an interactive environment where they can practise skills, respond to realistic situations, make decisions, and learn through problem-solving without placing real patients at risk. These characteristics make simulation particularly relevant to education and training in situations where direct real-world practice may involve practical, ethical, or safety limitations.

According to Cant and Cooper (2010), the advantages of simulation-based learning can be summarised as educational effects and various uses, including high-risk training, cost efficiency, ease of use, and realistic implementation possibilities. In other words, if simulation-based learning is applied to nursing, the clinical field can be recreated in a safe setting without patient harm, and the necessary practice skills can be standardised and

practised repeatedly. In addition, learners' critical skills can be improved through such learning related to clinical practice. They can immediately experience the results of the chosen intervention and share and review practical experiences with other learners through debriefing.

As articulated by Curran and Rhodes (2005) and supported by subsequent studies (Jarzemaski & McGrath, 2008; Cant & Cooper, 2010), the interactive nature of simulation is its greatest educational asset. These scholars argue that by replacing static lectures with dynamic, practical experiences, educators can foster a deeper level of mastery. This method is particularly effective at enhancing real-world performance, as it requires the learner to synthesise information and physical skill simultaneously within a controlled, responsive environment.

Simulation-based learning enables medical students to standardise and practise essential skills in real or virtual clinical situations, experience the outcomes of interventions they have selected, and correct mistakes through debriefing. The discussion provides an opportunity for consideration. In addition, it is in the limelight as a practical educational method because it enables students to share and reflect on continuous, comparable experiences with one another. Through several prior studies, problem-solving and clinical performance have improved. It is an essential requirement for medical students.

Blanchard and Frasson (2012) categorise simulation-based education into two distinct modalities: observational and experiential. In the former, the simulation acts as a visual or descriptive anchor for existing content, whereas in the latter, the learner is positioned as an active participant. In this experiential mode, the user does not merely watch a scenario

unfold but engages with the digital environment to independently synthesise new knowledge and meaning.

However, to effectively carry out simulation education, students' active participation is essential. To achieve effective simulation education through the active involvement of medical students, it is necessary first to identify the learning types of medical students in the subjects they are learning. This is because the type of learning affects how new knowledge or skills are acquired.

According to Gagné (1987), a simulation is a model of reality that reflects the real world, and he identifies the following crucial conditions for a simulation.

- A simulation represents a real situation in which operations are carried out.
- A simulation provides the user with specific controls over the problem or situation.
- A simulation omits certain distracting variables that are irrelevant or unimportant for the particular instructional goals. Simulation = (Reality) - (Task irrelevant elements)

Various authors emphasise a few conditions for successful simulation-based learning. According to Cant and Cooper (2010), it is essential to develop scenarios that can reproduce real situations and give a sense of reality. Compared to traditional lecture-based learning, simulation-based learning can produce effective results in clinical practice and achieve the learning goals of related subjects, provided an appropriate program is developed and applied.

Second, Issenberg and co-authors (2005) emphasise the need to evaluate simulation-based learning. According to a systematic review of simulation studies in the medical field from

1969 to 2003, the most critical feature of effective simulation-based learning was the provision of feedback.

Third, Cant and Cooper (2010) and Alden and Durham (2010) insist that the fidelity of simulation-based learning should be enhanced. Simulations can be characterised on a continuum of fidelity, from low to high, based on realism. Low-fidelity is mainly used for simulation learning through simple models, such as a manikin for catheter insertion practice and an arm for intramuscular injection practice. Moderate/medium-fidelity is designed to respond according to scenarios programmed into the computer, such as Vital Sim or SimMan, for auscultation of heart and lung sounds. High-fidelity systems, such as METI (Medical Education Technologies, Inc.)'s HPS, respond in real time to student manipulations or interventions (speaking, coughing, pulse changes, etc.) based on physiological responses programmed into the computer. It will be seen that the key to increasing the realism of simulation-based learning is to secure sufficient space and implement the environment as faithfully as possible in the actual clinical site.

Fourth, it is necessary to secure trained educators capable of conducting simulation education. To maximise the effect of simulation-based learning, educators should prepare scenarios suitable for the field and be thoroughly prepared, with a focus on learners. This approach helps reduce the gap between theory and practice by enabling educators to teach more efficiently. Through simulation, learners can make appropriate judgments and mediate through critical thinking while experiencing scenarios representing various situations. The main educational effects include providing a realistic training experience in teamwork, leadership, and communication; enabling sufficient repetition of learning without being limited by time or the number of learning opportunities; increasing learners'

confidence through repeated practice in a homogeneous simulated environment; and fostering autonomous participation in learning. Simulation-based learning requires considerable effort and time to prepare and implement, but it can maximise the learning effect of theory and field practice. This research will explore informal learning to identify principles of simulation-based learning.

2.3.6 Experiential Learning Theory

Experiential Learning Theory (ELT), developed by Kolb (1984), emphasises the centrality of experience as the foundation of learning and development. Kolb proposed that effective learning arises when individuals cycle through four interconnected stages:

- Concrete Experience (CE): Concrete Experience marks the starting point of Kolb's learning cycle, where knowledge emerges through active engagement with a task or event. Instead of passively absorbing information, learners are immersed in "doing," which anchors the process in lived experience. In high-risk domains such as mountaineering, this might mean navigating an avalanche, performing rope manoeuvres, or responding to sudden weather shifts. In this study, participants engaged with a VR-based mountaineering simulation using the Oculus Quest 2 headset. They encountered hazards such as acute mountain sickness, variable weather, and navigation challenges, all from a first-person perspective. This immersion offered direct, sensory experiences that would otherwise be unsafe or impractical to replicate, ensuring that learning began from a vivid and memorable foundation.

- Reflective Observation (RO): After the immersive experience, learners stepped back to reflect on their actions, noticing patterns, inconsistencies, or points of tension between expected and actual outcomes. In practice, participants reflected in post-intervention interviews, discussing challenges such as equipment use, hazard recognition, and their emotional responses under stress. This stage fostered critical self-examination, helping participants recognise both mistakes and effective strategies. By reviewing their decision-making processes—such as why they chose a route or delayed recognising altitude sickness—participants began to extract meaningful insights from the VR sessions.
- Abstract Conceptualisation (AC): Reflection then moved into abstraction, where learners connected their observations to broader concepts, models, or theories. For instance, navigation errors in VR were linked to principles of situational awareness, while failures to recognise symptoms of altitude sickness were tied to established medical guidelines. This stage ensured that participants' individual experiences were generalised into structured knowledge aligned with safety frameworks and risk management theories. In this way, raw VR experiences were transformed into transferable lessons, bridging the gap between simulation and mountaineering education.
- Active Experimentation (AE): The final stage involved applying new insights to practice. Learners tested refined strategies during subsequent VR sessions or theorised how they would respond differently in future climbs. For example, a participant who had previously delayed turning back in worsening conditions might consciously choose to retreat earlier in the next simulation. In this study, Active

Experimentation was reinforced through the iterative cycles of DBR. As the prototype was refined, participants re-engaged with updated scenarios, testing improved hazard recognition and decision-making skills. Although simulations remained bounded, this stage symbolised the transfer of learning, preparing climbers to carry newly developed strategies into real-world environments.

This cyclical process reflects a dialectic between action and reflection, and between experience and conceptualisation, ensuring that learning is iterative and adaptable. A strength of ELT lies in its recognition of different learning styles, as individuals may emphasise certain stages of the cycle more than others.

For this study, ELT provides a valuable lens for understanding how Virtual Reality (VR) environments can replicate concrete experiences that might otherwise be too dangerous, costly, or inaccessible in real life. The immersive nature of VR allows climbers to encounter simulated risks, such as avalanches and altitude sickness, in a safe environment. Reflection and debriefing sessions following VR use allow participants to evaluate their decisions (RO), connect them to theoretical safety principles (AC), and prepare for applying these strategies in real climbs (AE). In this way, VR directly supports the experiential cycle, enabling both novice and expert climbers to build decision-making and risk-assessment skills through repeated, safe exposure to hazardous scenarios.

2.4 Tools: VR and MR Technologies

Emergent technologies, including virtual reality (VR), augmented reality (AR), and mixed reality (MR), alongside contemporary learning approaches and their associated theoretical affordances, provide a strong foundation for developing innovative instructional strategies.

The researcher's professional experience as a multimedia producer has included exploring and designing emerging media technologies such as VR, AR, and MR, positioning the researcher well to undertake this investigation.

Augmented reality (AR) refers to a live, direct or indirect view of a physical, real-world environment in which elements are enhanced or supplemented by computer-generated sensory input, such as sound, video, graphics, or GPS data. In contrast, virtual reality (VR) provides a fully immersive digital environment that replaces the physical world with a computer-generated simulation, enabling users to interact within a wholly virtual space. Milgram and Kishino (1994) conceptualised mixed reality (MR) as a continuum between the real and virtual environments, describing MR as the merging of physical and digital worlds to produce new environments in which real and virtual objects coexist and interact in real time. Since Milgram and Kishino's (1994) seminal definition, the concept of MR has been further developed in the literature. Aguayo (2018), for example, characterised MR as a learning modality that integrates digital tools and affordances to support immersive and interactive educational experiences. He argued that MR provides a platform for integrated learning environments that bridge physical and digital contexts.

Augmented/mixed reality is an immersive technology that layers computer-generated enhancements onto the real world, making it more meaningful through interaction. Also, these immersive technologies offer affordances for learning. The key term for AR and MR is flexibility. According to Kesim and Ozarslan (2012), the introduction of AR into education marks an evolution from traditional 2D media to a multidimensional, social computing environment. This medium is characterized by its ability to overlay virtual data onto the physical world, offering learners unique affordances for interaction. By allowing

for implicit user control and real-time engagement with "real-life" contexts, AR increases both the effectiveness and the appeal of complex training (p. 297).

MR offers us dynamic content and affordances that combine the physical and virtual worlds. It is flexible and portable compared to the three-dimensional real physical world and provides a low-risk environment in which to explore high-risk real-world environments.

As articulated by Dünser and Kaufmann (2006), virtual reality bridges the gap between laboratory control and real-world application. It allows for the standardization of complex scenarios, ensuring that results are not skewed by uncontrolled external factors. By manipulating the virtual environment in real time, researchers can test specific hypotheses in a completely safe space, removing the ethical and logistical barriers associated with training in high-hazard locations like mountains (p. 126).

Aguayo (2018) highlighted the significant potential of augmented reality (AR), virtual reality (VR), and mixed reality (MR) technologies to enhance digital learning and teaching practices. While traditional instructional materials such as textbooks remain valuable, immersive technologies offer distinct affordances, including interactivity, flexibility, and the capacity to simulate real-world environments with greater authenticity. These features enable learners to engage more actively with content and support deeper experiential learning.

For example, the National Museum of Singapore has implemented AR technologies that allow visitors to use mobile devices to access additional digital layers of information within exhibition spaces. One exhibition, centred on 69 images from the William Farquhar collection of natural history drawings, enables visitors to explore historical narratives

through digital content linked to physical artefacts. This integration of physical and digital elements demonstrates how AR can enrich contextual understanding through layered, interactive engagement.

Similarly, AR-enhanced books extend traditional two-dimensional learning environments by incorporating three-dimensional models, animations, audio, and interactive elements. Such multimodal features support multisensory learning and may increase learner engagement and attention. Wnuk and Oleksy (2016) demonstrated, AR applications that restore lost historical contexts can transform a student's relationship with a physical site. Their findings in Poland indicate that providing a visual link between the past and present not only improves cognitive attention but also enhances the overall attractiveness of the learning experience. This results in a more motivated student body that is more likely to engage deeply with complex historical narratives.

Collectively, these examples illustrate how AR and related immersive technologies can support more interactive, contextually grounded, and engaging learning experiences compared to conventional instructional formats.

Espidol (2017) argues that integrating Augmented Reality into traditional media can significantly bolster educational outcomes by heightening student agency and engagement. By weaving together diverse multimodal cues, AR engages several sensory channels simultaneously, which facilitates more robust cognitive processing. This layered approach to information delivery moves beyond simple novelty, offering a substantive framework for advancing literacy and comprehension through interactive immersion.

According to Espidol (2017), Augmented Reality creates a strong emotional tie for young readers, making them feel attached to the book and part of the story. Vygotsky (1978) argues that learners can go beyond what they can do on their own when aided by a more experienced peer within the Zone of Proximal Development. The role of an MR App could be a virtual, more experienced peer in this case. The App will enable mountaineers to be well-prepared before their actual climbing journey.

As articulated by McKenney and Reeves (2018), design research prioritises the development of "usable knowledge" (Lagemann, 2002) that serves both the researcher and the practitioner. By conducting studies in authentic settings rather than sterile laboratories, this approach fosters insights that are immediately relevant to educational change. The resulting interventions embody a deep understanding of the learning process and are shared through both scholarly publications and the literal "spread" of the developed educational tools (p. 7).

Reeves and Amiel (2008) posit, Design-Based Research prioritises the practical utility of educational findings. By employing a rigorous, iterative research design, scholars can refine their interventions in response to environmental feedback. This dual focus—improving the specific educational product while identifying universal design strategies—ensures that the research provides both immediate value to the target community and a lasting contribution to the field of instructional design (p. 34).

While VR, AR, and MR technologies provide the technical infrastructure for building interactive and risk-free simulations, their educational effectiveness depends on how these affordances are harnessed within a pedagogical framework. Foundational studies such as

Milgram and Kishino's (1994) continuum of mixed reality highlighted the potential of blending real and virtual environments, while Aguayo (2018) later extended this line of thinking, arguing that MR serves as a learning mode integrating digital tools, affordances, and contextualised practices. Similarly, Dunser and Kaufmann (2006) emphasised the capacity of VR and AR to provide controlled, repeatable, and safe environments in which learners can explore without exposure to real-world dangers.

However, these technological affordances alone are insufficient to ensure meaningful learning. To transform VR/MR from a technological novelty into a powerful educational intervention, researchers must examine how immersive experiences engage learners cognitively, emotionally, and socially. This is where immersive learning design principles play a crucial role. Building on experiential learning theory, Makransky and Lilleholt (2018) propose a framework that identifies presence, authenticity, emotional engagement, interactivity, and cognitive load balance as the core dimensions through which immersive environments can be effectively designed for education.

Thus, the transition from VR/MR affordances to immersive learning design principles represents a conceptual shift from what the technology can do to how it should be designed and applied. The following section introduces these principles and outlines how they foster attention, motivation, and knowledge retention while ensuring learners are neither overwhelmed nor disengaged. By connecting the affordances of VR/MR technologies with evidence-based design principles, this study situates its intervention at the intersection of technological innovation and pedagogical theory, particularly within the high-risk learning context of mountaineering safety education.

2.5 Introduction to Immersive Learning Design Principles

Building on experiential frameworks, Makransky and Lilleholt (2018) advance a model of immersive learning design that emphasises the role of psychological presence and emotional engagement in shaping meaningful learning outcomes. Their research suggests that immersion is not merely a technological feature but a pedagogical mechanism that creates a sense of "being there" in the learning environment, thereby fostering greater attention, motivation, and knowledge retention.

Key principles of immersive learning design include:

- Presence and Authenticity: Learners must feel situated within a realistic, contextually relevant environment. High-quality graphics, soundscapes, and interactivity increase authenticity and engagement. Presence refers to the psychological sense of "being there" in the virtual environment, a critical factor in immersive learning (Slater & Sanchez-Vives, 2016). Authenticity, meanwhile, ensures that the virtual environment mirrors the contextual and sensory qualities of real-world scenarios. High-fidelity graphics, realistic weather effects, spatialised soundscapes (wind, snow crunching, avalanches), and responsive interactivity contribute to this sense of realism. In mountaineering VR, authenticity is vital: climbers must perceive the environment as sufficiently credible to trigger genuine risk awareness and decision-making. Without authenticity, learners may disengage or fail to transfer lessons into real-world contexts. Thus, design must balance visual fidelity, environmental dynamics, and cultural relevance (e.g., reflecting Chilean vs New Zealand mountain conditions).

- Emotional Engagement: Emotional engagement involves eliciting affective responses—curiosity, excitement, or even controlled stress—that enhance attention, memory, and decision-making. Research shows that emotionally charged experiences are more likely to be retained and recalled (Pekrun, 2014). In VR mountaineering scenarios, stress may be evoked by sudden weather changes, simulated altitude sickness, or time-limited decision prompts. Importantly, the emotional intensity should be carefully calibrated: too little engagement risks superficial learning, while excessive stress may overwhelm learners. Controlled arousal can help simulate the psychological demands of real expeditions, training climbers not just in technical skills but also in managing anxiety, maintaining focus, and making rational decisions under pressure.
- Interactivity: Interactivity transforms learners from passive observers into active participants, which strengthens cognitive processing and knowledge retention (Makransky & Lilleholt, 2018). In VR, interactivity may take the form of navigating routes, choosing equipment, assessing weather conditions, or responding to emergencies. Decision-making under authentic constraints promotes deeper learning compared to simply watching a demonstration. For novice climbers, interactivity fosters agency and confidence, while for experienced mountaineers, it can provide an opportunity to test advanced strategies and reflect on critical thinking under stress. Importantly, interactivity allows for non-linear exploration, enabling learners to experience consequences of different choices in branching scenarios—a pedagogical feature unavailable in traditional didactic training.

- Cognitive Load Balance: While immersive technologies can foster engagement, poorly designed scenarios may overwhelm learners with too much information or task complexity. Effective design, therefore, requires scaffolding, guidance, and pacing to prevent overload. While immersion can enrich learning, poorly designed VR scenarios risk cognitive overload (Sweller, Ayres, & Kalyuga, 2011). Overload occurs when working memory is taxed by excessive information, complex tasks, or unfamiliar interfaces, reducing its capacity to process and retain information. In the mountaineering VR intervention, learners faced simultaneous demands: navigating terrain, interpreting environmental cues, managing equipment, and making rapid safety decisions. For novices, this risk was amplified by language barriers or unfamiliarity with VR controls. Effective design, therefore, requires scaffolding and pacing—gradually introducing complexity, providing onboarding tutorials, and integrating clear prompts to guide attention. Striking the right balance ensures that learners are challenged but not overwhelmed, supporting optimal engagement and knowledge transfer.

In the context of mountaineering safety, these design principles support the creation of VR environments that mirror the unpredictability and intensity of real alpine conditions. Elements such as howling wind, variable weather, or equipment malfunctions can generate emotional realism, while interactive prompts and branching scenarios require learners to make high-stakes decisions under pressure. At the same time, careful calibration is essential to ensure that novices are not overwhelmed by cognitive demands, while experienced climbers are still challenged at an appropriate level.

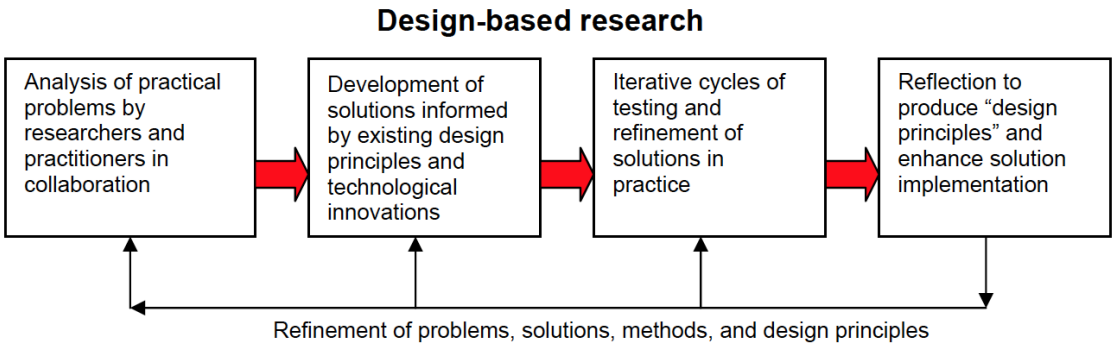
2.6 Introduction to Design-Based Research (DBR) and Expected Design Principles

As part of this critical awareness and efforts, Design-Based Research emerged as a field-oriented research method that emphasises the practical context of the school field. Design-Based Researchbegan as a reflection on educational research that was separated from the classroom context. It aims to verify the ef fectiveness of instructional interventions designed to enhance classroom learning and to generate learning theories in educational practice. According to Reeves (2006), DBR enables practitioners and researchers to identify real-world teaching-learning problems, devise a prototypical solution based on existing design principles, and test the output until everyone interested in the prototypical solution and design principles is satisfied. and requires cooperation in refining. As Brown (1992) indicates, DBR aims to present a practical intervention plan to narrow the gap between researchers and teachers as practitioners in education. Anderson & Shattuck (2012) also indicate that it has been applied to various studies in learning environment design through instructional design intervention.

According to Reeves and Amiel (2008), DBR is an iterative design process that uses analysis, creativity, testing, and reflection to explore and solve research problems - see Amiel, T. & Reeves, 2008 model below. The model, based on generic design process models, involves the identification of design principles that are then tested through the stages of design, implementation, and evaluation of prototypes using detailed feedback from users, in this instance, a VR app. Using the outcomes of the assessment, potential enhancements are theorised, which lead to changed design principles. The prototype is then iteratively redesigned and re-implemented, with further evaluation based on user feedback.

Figure 2.4

Amiel, T., & Reeves, T. (2008). Design-Based Research and Educational Technology: Rethinking Technology and the Research Agenda. Educational Technology & Society, 11(4), p34.

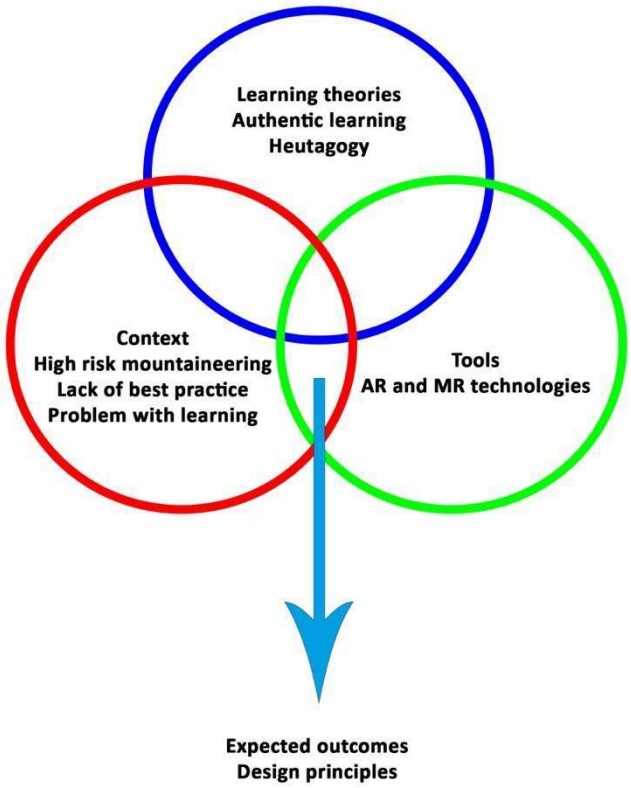


DBR has the potential not only to construct more applicable designs over time but also to generate well-supported design theories about learning and instruction. This results in a deeper understanding of complex learning environments.

Utilising Design-Based Research, the design principles will initially be developed using the three contexts mapped in Figure 2.5 below.

Figure 2.5

Expected outcomes – design principles



These three areas, along with mobile learning frameworks, are explored in the literature review below.

Herrington and her colleagues (2009) propose a comprehensive set of eleven guidelines intended to facilitate the seamless integration of mobile technologies within tertiary education. These principles emphasize that for mobile learning to be effective, it must be anchored in authentic tasks and social interactions rather than being treated as a mere delivery mechanism for content. By following this structured approach, educators can

ensure that mobile interventions support higher-order thinking and meaningful knowledge construction (p. 134).

- Real-world relevance
- Mobile contexts
- Explore
- Blended
- Whenever
- Wherever
- Whomever
- Affordances
- Personalise
- Mediation
- Produce

They concluded that design-based research focuses on real-world problems and improves learning in depth in consultation with the teachers involved. Also, according to Aguayo et al. (2017), one of the defining themes of modern mobile learning is the move toward learner-led discovery. Their research highlights how VR and MR technologies empower students to take ownership of the learning process by "generating" their own scenarios and solutions. This active involvement fosters a deeper level of cognitive investment, as the learner's own actions and decisions within the virtual space become the primary source of their instructional growth.

As articulated by Aguayo and Eames (2019), VR and MR technologies serve as powerful mediators that relocate "field-based" learning into the classroom environment. By leveraging the affordances of mobile devices, these immersive tools provide students with direct access to authentic scenarios that would otherwise be inaccessible due to logistical or safety constraints. This shift not only enhances the relevance of the coursework but also prepares learners to apply their knowledge within the specific social and physical contexts they will encounter in their future careers.

Blaschke and Hase (2015) outline several learning design principles based on Heutagogy (p. 81).

- Involve the learner as a partner in designing their learning content and process.
- Make the curriculum flexible so that new questions and understanding can be explored as new neural pathways form.
- Individualise learning as much as possible.
- Provide a flexible or negotiated assessment.
- Enable the learner to contextualise concepts, knowledge, and new understanding.
- Provide numerous resources and let the learner explore.
- Differentiate between knowledge and skill acquisition (competencies).
- Deep learning.
- Recognise the importance of informal learning and that we need only to enable it rather than control it.
- Have confidence in the learner.
- Recognise that teaching can become a block to learning.

A comparison of these three sets of Design Principles to identify overlaps relevant to this research is presented (the Digital technologies and affordances part is a more open column, as these tools are still exploring) in Table 2.2.

Table 2.2
Comparison of Design Principles for Authentic Mobile Learning and the design of Heutagogical learning environments.

Herrington and co-authors' design principles for heutagogy	**Blaschke and Hase's design principles for learning theories**	**Digital technologies and affordances (Tools)**
Real-world relevance: Use mobile learning in authentic contexts.	Involve the learner in designing their learning content and process as a partner Provide a flexible or negotiated assessment.	MR can assist a heutagogical learning approach. MR can also offer a range of experiences for diverse learners. MR can provide authentic learning experiences. MR can reinforce learning from outside the classroom and bring it into the school. MR is seen as an immersion continuum between real and digital environments. MR enhances perceptions and interactions with the real world. Learners generated learning through VR and MR. Key issues in VR and MR technologies.
Mobile contexts: Use mobile learning in contexts where learners are mobile.	Recognise the importance of informal learning and that we need only to enable it rather than control it.	
Whenever: Use mobile learning spontaneously.	Individualise learning as much as possible.	
Wherever: Use mobile learning in non-traditional learning spaces.	Make the curriculum flexible so that new questions and understanding can be explored as new neural pathways form. Have confidence in the learner.	
Affordances: Exploit the affordances of mobile technologies.	Enable the learner to contextualise concepts, knowledge and new understanding. Differentiate between	

	knowledge and skill acquisition (competencies) and deep learning.	1. Ethical and health implications of VR and MR technologies 2. Lack of interactions with educators (VR) 3. VR sickness, eye strain, dizziness and distortion
Explore: Provide time to explore mobile technologies.	Provide numerous resources and let the learner explore.	
	Recognise that teaching can become a block to learning.	

After conducting an initial literature review of both Herrington and Blaschke's design principles, I selected several principles that are particularly relevant to high-risk informal learning. These principles are learner-designed and managed, emphasising capability development in mobile learning. These principles also focus on self-reflection, double-loop learning, and non-linear learning. I believe these characteristics of mobile learning and a heutagogical environment encourage learners to be more flexible and take greater responsibility for their learning. Therefore, I would like to implement these approaches in high-risk informal learning. Initial design principles are drawn from key theoretical foundations through the literature review above, and these include:

- Involve the learner as a partner in designing their learning content and process.
- Provide a flexible or negotiated assessment.
- Recognise the importance of informal learning and that we need only to enable it rather than control it.
- Individualise learning as much as possible.

- Make the learning environment flexible so that new questions and understanding can be explored as new neural pathways form. It means that the paths become stronger with repeated use until the behaviour becomes the new normal.
- Have confidence in the learner.
- Enable the learner to contextualise concepts, knowledge, and new understanding.
- Differentiate between knowledge and skill acquisition (competencies) and deep learning.
- Provide numerous resources and let the learner explore.
- Recognise that teaching can become a block to learning.

2.7 Summary

This chapter presents a comprehensive review of the theoretical and empirical foundations underpinning the use of Virtual Reality (VR) in high-altitude mountaineering safety education, situating VR at the intersection of immersive technology, experiential learning, and risk management. High-altitude mountaineering is framed as a high-risk, decision-intensive activity requiring both technical and psychological preparedness, which traditional didactic methods often fail to address adequately. In contrast, VR offers immersive, context-rich simulations that support experiential engagement, situated learning, and safe exposure to hazardous scenarios.

The chapter draws on several key learning theories to frame the pedagogical rationale for VR integration. Constructivism and Social Constructivism, Heutagogy, or self-determined learning, inform the design of learner-centred VR experiences that foster autonomy, non-linear exploration, and decision-making under pressure. Authentic Learning theory further

justifies the use of VR by emphasising the importance of real-world relevance, problem-solving, and collaboration—features naturally embedded in immersive simulations of alpine risk scenarios.

Engeström's (2001) Third-Generation Activity Theory offers a socio-cultural lens through which VR is conceptualised as a mediating tool within broader systems of learning. This perspective highlights the dynamic interplay between tools, community, rules, and division of labour, as well as the contradictions that can generate meaningful educational change. Together, these theories provide a multidimensional framework for designing VR experiences that are pedagogically sound, culturally sensitive, and systemically integrated.

The chapter also reviews empirical studies on VR in outdoor and safety education, identifying both its pedagogical affordances—such as heightened emotional engagement and realistic scenario-based decision-making—and its limitations, including concerns about usability, realism, and equitable access. Cross-cultural considerations are addressed through literature from Chile and New Zealand, underscoring how context influences learner engagement, acceptance, and the design of VR-based instruction.

In summary, Chapter 2 lays the theoretical groundwork for the study's empirical components by articulating the educational potential of VR, highlighting relevant pedagogical frameworks, and identifying critical gaps and challenges in existing research and practice.

Chapter 3: Methodology

3.1 Introduction

This chapter outlines the methodological framework adopted for the comparative investigation of virtual reality (VR) as an educational tool in high-risk mountain safety training environments in Chile and Aotearoa New Zealand. The primary aim of this research was to explore how VR-supported learning interventions function across different sociocultural, geographical, and institutional contexts, with particular attention to the perspectives of novice climbers, experienced mountaineers, and instructional designers. Given the complex, situated nature of outdoor education and the emerging role of immersive technology in this space, a robust, theory-driven qualitative methodology was essential to capture the nuance and depth of learner experience.

The research design is underpinned by Engeström's (2001) Third-Generation Activity Theory (AT), which provides a systemic framework for analysing human activity as a culturally and historically mediated phenomenon. AT is beneficial for examining tool-mediated learning, multi-voiced communities, and contradictions within and between elements of an activity system—all of which are central to understanding the implementation and efficacy of VR in educational contexts. The focus on contradictions and expansive learning within AT enables the identification of both the affordances and constraints of VR across the two case studies.

This study employed a comparative case study methodology (Yin, 2018), allowing for in-depth exploration of two distinct yet parallel VR training implementations. The Chilean

and New Zealand contexts were selected due to their contrasting terrain, cultural traditions in mountaineering, digital infrastructure, and levels of access to immersive technologies. This comparative dimension adds analytical richness and enables the development of culturally responsive and contextually appropriate design principles.

Data collection employed a mixed-methods qualitative approach, including semi-structured interviews, pre- and post-intervention surveys, field observation notes, and document analysis. This multi-source triangulation supports the credibility and trustworthiness of the findings (Creswell & Poth, 2018; Merriam & Tisdell, 2016). Participants included learners from diverse backgrounds and levels of mountaineering experience, as well as VR developers, instructors, and educational stakeholders.

Ethical considerations were central to the research design, including informed consent, data anonymity, cultural sensitivity, and safety protocols in both field and virtual environments. The cross-national nature of the study also required attention to ethical review processes in both Chile and New Zealand.

Analytically, the study adopted thematic analysis (Braun & Clarke, 2006) to code and interpret qualitative data, with findings subsequently mapped onto the components of the AT model. Particular attention was given to identifying systemic contradictions—points of tension that may signal opportunities for learning, innovation, or redesign.

By detailing the research design, data collection strategies, ethical procedures, and analytical techniques, this chapter establishes the foundation for interpreting the thematic findings and Activity Theory analysis presented in subsequent chapters. Ultimately, this methodological approach aims not only to evaluate VR's pedagogical potential but also to

generate evidence-informed design principles that are adaptable to the diverse needs of learners and educational systems in high-risk outdoor contexts.

3.2 Research Questions

Even experienced mountain climbers can underestimate key dangers and make poor decisions in stressful, high-risk situations, leading to injury or death. My experience suggests that effective education plays a crucial role in managing these risks and enhancing the decision-making of experienced climbers. However, current educational approaches for climbers are generally limited to textbooks and 'on the mountain' learning. It is vital, therefore, that new techniques and methods be developed to enhance education.

Even experienced mountain climbers can underestimate key dangers and make poor decisions in stressful, high-risk situations, leading to injury or death (McCammon, 2004; Faerber & Kreutz, 2008). My experience suggests that effective education plays a crucial role in managing these risks and enhancing the decision-making of experienced climbers. However, current educational approaches for climbers are generally limited to textbooks and 'on the mountain' learning (Collins & Collins, 2016). It is therefore vital that new approaches and methods be developed to enhance learning.

The researcher's own experience and emergent case studies indicate that augmented reality (AR), virtual reality (VR), and mixed reality (MR) technologies offer affordances that can support new forms of experiential learning (Radianti et al., 2020; Fowler, 2015). These immersive technologies are already used in domains such as classroom learning, firefighting, and military education to simulate risk-based scenarios in safe environments (Huang et al., 2010; Bower et al., 2017). However, an initial review of the literature

suggests that there are very few rigorous studies on the design and application of VR for authentic high-risk education, especially in extreme environments such as mountaineering (Makransky & Mayer, 2022). There is a significant gap in the evaluation of learning outcomes and in theorising about how learning is transformed in these immersive contexts. Therefore, this research addresses four guiding questions to explore how the design of VR applications in authentic mountain safety education environments shapes new learning outcomes and theoretical models.

The four main research questions are:

- RQ 1 - What are the key design principles for developing a VR application for high-risk educational environments?
- RQ 2 - How can a VR application be most effectively utilised and evaluated to enhance learning in high-risk outdoor situations?
- RQ 3 - How can a VR application influence climbers' learning experience compared to when they are in a real environment?
- RQ 4 - How do climbers' responses to risk factors in extreme outdoor situations change after using a VR application design?

3.3 Research Paradigm

This research was positioned within a constructivist paradigm, which recognises that knowledge and meaning are constructed through individuals' experiences and interactions with their social and learning environments (Guba & Lincoln, 1994). Constructivism was appropriate for this study because the research focused on how participants experienced, interpreted, and responded to a VR learning environment rather than assuming that all

participants would experience the intervention in the same way. Participants from Chile and New Zealand brought different mountaineering experiences, knowledge, cultural backgrounds, and previous experiences with technology, which could influence how they engaged with and interpreted the VR scenarios.

From an ontological perspective, the study recognised that reality can be experienced and understood differently by individuals. Participants could interact with the same VR scenario but interpret the risks, environmental conditions, and required decisions differently depending on their previous knowledge and experience. This was particularly relevant to the research because participants had different levels of mountaineering experience and came from two different geographical and cultural contexts. A constructivist position therefore allowed these different experiences and interpretations to be recognised rather than assuming that there was one single experience of the VR intervention (Guba & Lincoln, 1994).

From an epistemological perspective, knowledge was developed through participants' experiences and their interactions with the VR intervention and the research process. The researcher sought to understand how participants perceived the simulated situations, how they made decisions, and how they reflected on their experiences. Questionnaires, interviews, observations, and participant reflections were used to explore these different perspectives. The use of multiple sources of data provided a broader understanding of the learning experience and supported the iterative nature of the research.

The axiological position of the study recognised that the researcher's values, knowledge, and previous experiences could influence the research process. The researcher brought

experience in mountaineering, educational technology, and learning design to the development and evaluation of the VR intervention. Rather than treating this experience as separate from the research, it was acknowledged as part of the research context. Researcher reflection and the use of multiple sources of data were used throughout the study to consider different perspectives and reduce reliance on the researcher's interpretation alone.

From a methodological perspective, the constructivist position aligned with the use of Design-Based Research (DBR)**.** DBR involves investigating educational problems in real contexts and developing, testing, evaluating, and refining educational interventions through iterative cycles (Wang & Hannafin, 2005). This approach was suitable for the current research because the VR intervention was progressively developed and evaluated with participants rather than being treated as a finished product. Participant experiences and feedback contributed to the ongoing refinement of both the intervention and its associated design principles.

The constructivist paradigm therefore provided an appropriate philosophical foundation for understanding participants' experiences, while DBR provided the methodological structure for designing and evaluating the VR intervention. Together, they supported an iterative research process that connected educational theory, participant experience, and practical design. The DBR methodology and its application to this study are discussed further in Section 3.3.

3.4 Research Methodology

Despite growing interest in immersive technologies, there remains limited application of learning theories and frameworks to guide how virtual reality (VR) can be effectively utilised in authentic educational environments, particularly within Design-Based Research (DBR) methodologies (Reeves & Amiel, 2008). However, some studies have begun to identify principles for designing pedagogically sound VR interventions (Bower & Sturman, 2015; Jong et al., 2020). There are also opportunities to explore pedagogical approaches such as heutagogy and self-determined learning in VR environments, as discussed in Chapter 2.

This research used Design-Based Research (DBR), informed by Reeves and Amiel (2008), to develop and evaluate initial design principles based on key learning theories relevant to learning in extreme and high-risk environments. Underpinned by a constructivist paradigm, the initial theoretical frameworks included Authentic Learning and Heutagogy (student-determined learning). For example, Herrington and Blaschke (2009) recommended 11 design principles for incorporating mobile learning into higher education, while Blaschke and Hase (2015) recommended 10 principles for designing learning for heutagogy. Other theories and frameworks considered included Constructivist Learning, Vygotsky's (1978) concept of the Zone of Proximal Development (ZPD), design for mobile mixed reality (MR) learning, and user-centred design. Engeström's (1987, 2001) Third-Generation Activity Theory was also used to support data analysis.

The initial design principles were evaluated through the implementation and testing of a Virtual Reality (VR) prototype educational application. The VR application simulated

high-altitude environments and presented mountaineers with risks such as altitude sickness, crevasses, ice cliffs, and frostbite within a safe, simulated setting. The prototype was iteratively redesigned based on evaluation and feedback from participant groups. Data were collected through participant interviews, researcher observations and reflections, and supplementary physiological data. This iterative process was used to examine and refine the initial design principles and explore their potential relevance to learning involving preparation, decision-making, and knowledge in high-risk contexts.

Design-Based Research was proposed by Brown and Collins (1992) as an approach to investigating learning and educational interventions within authentic settings. DBR provides a way to examine how educational technologies and learning designs operate in practice through iterative cycles of design, implementation, evaluation, and refinement. This approach was therefore considered appropriate for investigating the development and use of VR within the high-risk learning context examined in this research.

3.3.1 Application of Design-Based Research in This Study

Design-Based Research (DBR) serves two overarching purposes: first, to develop and evaluate educational interventions through iterative cycles of design, implementation, and refinement in authentic settings; and second, to generate theoretical insights and practical models that inform the design of future educational programmes. While DBR shares similarities with formative research, particularly in its emphasis on iterative improvement, it is distinguished by its dual commitment to advancing both practice and theory. Formative evaluation plays a key role in DBR, but unlike formative research, which focuses primarily

on improving instructional practice, DBR seeks to develop design principles and refine theoretical frameworks.

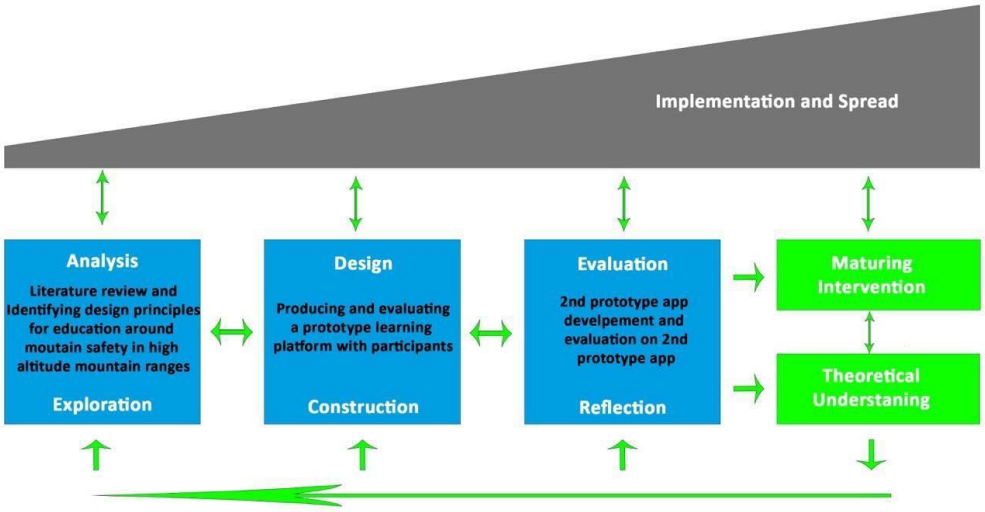
A DBR approach was adopted in this study to facilitate the iterative development of a VR safety intervention for high-altitude environments. DBR is particularly useful in settings where there is a gap between theory and real-world practice and where an iterative approach to instructional design is required (Anderson & Shattuck, 2012; Wang & Hannafin, 2005). The research was grounded in pedagogical theories, including Heutagogy, Authentic Learning, and Activity Theory, and drew on empirical data from participants in Chile and New Zealand. Through iterative design cycles, the study aimed to develop both a functional educational intervention and theoretically informed design principles for immersive learning in high-risk environments.

The DBR approach used in this study was informed by the Educational Design Research framework described by McKenney and Reeves (2012). As explained earlier in this chapter, DBR is used as the primary methodological term in this thesis, while EDR is used when referring specifically to the framework described by McKenney and Reeves. The use of EDR in this context does not indicate a change in the methodology adopted for the study.

Using this framework, the research was undertaken through four phases: Analysis and Exploration, Design and Construction, Evaluation and Reflection, and Maturing Intervention and Theoretical Understanding.

Figure 3.1

Jin Hong (2019). Conducting educational design research for mountain safety (adapted from McKenney, S., & Reeves, T, 2012)



Phase 1: Analysis and Exploration

The study commenced with an investigation of the limitations of traditional high-altitude mountaineering instruction by engaging with subject-matter experts, instructors, and climbers from New Zealand and Chile. This phase involved interviews, surveys, document analysis, and a literature review to identify educational needs, safety concerns, and pedagogical gaps in existing training approaches. The literature review covered educational theory, mountain safety and risk management in high-altitude environments, and existing AR/MR design frameworks. Preliminary feasibility interviews with experienced climbers from the Chilean and New Zealand mountaineering communities also contributed to the development of the initial design principles for the VR intervention.

Phase 2: Design and Construction

In response to the identified needs, a VR-based prototype was developed drawing on key educational theories, including Engeström's Activity Theory (1987, 2001), Heutagogy (Hase & Kenyon, 2000), and Authentic Learning (Herrington & Oliver, 2000). These theoretical frameworks guided the development of immersive, contextually relevant, and learner-centred experiences for high-risk mountaineering environments.

The Design and Construction phase focused on the iterative design and production of the prototype VR learning application. Participants engaged with the VR application using head-mounted displays and interacted with simulated high-altitude scenarios. Ethical and confidentiality protocols were followed, and informed consent was obtained from all participants in accordance with the approved research ethics requirements.

The VR learning application focused on four critical mountaineering scenarios:

- identifying and interpreting weather conditions;
- selecting and using essential mountaineering tools;
- enhancing avalanche awareness and response; and
- recognising symptoms of mountain sickness and making appropriate decisions.

An early conceptual mock-up of the VR learning application is unavailable due to licensing restrictions and the discontinuation of the software used in its development.

Phase 3: Evaluation and Reflection

The Evaluation and Reflection phase focused on assessing the more refined version of the VR learning application. This phase evaluated the application's pedagogical and technical performance while supporting further theorisation and iterative refinement. Participants interacted with the simulated scenarios in Chile and New Zealand, allowing the intervention to be examined in two different mountaineering contexts.

Data were collected through pre- and post-intervention questionnaires, interviews, researcher observations, field notes, video recordings, and supplementary physiological data. Qualitative data were analysed thematically to identify patterns across participants' experiences. The different data sources were used to inform the iterative evaluation and refinement of the intervention.

Phase 4: Maturing Intervention and Theoretical Understanding

The final phase, Maturing Intervention and Theoretical Understanding, focused on bringing together evidence from the preceding phases to refine the intervention and develop design principles for VR-based risk education. The purpose of this stage was to consider both the practical application of the intervention in mountaineering education and its contribution to theoretical understanding of immersive learning and educational technology design.

Engeström's Activity Theory (1987, 2001) was used as an analytical framework to examine how immersive technologies mediated learning within different cultural and institutional

settings. Particular attention was given to contradictions and tensions that emerged within the activity systems and how these could inform the ongoing refinement of the intervention.

The design principles were refined through iterative cycles of consultation, implementation, and evaluation. Each iteration of the prototype was considered in relation to participant feedback, usability, and learning needs. This recursive process supported the alignment of the theoretical frameworks, technological design, and practical learning needs of the intervention.

3.5 Methods

This section describes the research methodologies used in the study, including four distinct methods: questionnaires, observations, interviews, and biometrics. These methods were chosen to address the research inquiries. This section also explains how the research methodology is structured and how each method was implemented throughout the study. Research methodologies are commonly categorised into two broad approaches: quantitative and qualitative inquiry. Quantitative research focuses on numerical data and statistical analysis, whereas qualitative research emphasises participants' interpretations, meanings, and contextual experiences. Quantitative methods revolve around numerical data and statistics. Researchers collect structured data using surveys, experiments, and observations. According to Guba and Lincoln (1994), given the historical emphasis on quantification in fields like Mathematics and Physics, quantitative methods are typically associated with positivistic traditions. Positivist traditions emphasise objectivity, measurement, and empirical evidence. Conversely, qualitative methods prioritise participants' subjective interpretations of situations and focus on words and meanings.

Researchers collect data through interviews, observations, and content analysis. Cohen et al. (2007) insist that qualitative approaches can effectively interpret, explain, and contextualise various data sources. The focus lies in understanding context, culture, and individual perspectives.

This research methodology incorporates questionnaires, observations, interviews, and biometrics. The research employs a mixed-methods approach to address the research questions or objectives. It combines qualitative (interviews and observations) and quantitative (questionnaires and biometrics) elements.

Thomas and O'Cathain (2006) posit that a mixed-methods framework allows for the strategic integration of both qualitative and quantitative elements within a unified study. By merging these two paradigms, researchers can move beyond the limitations of a single data source, creating a more holistic and nuanced understanding of the research problem. This approach is particularly effective for capturing both the measurable outcomes and the underlying human experiences that define complex educational phenomena (p. 102). Researchers increasingly recognise the value of combining quantitative and qualitative methods. Integrating data types enhances research quality by compensating for each method's limitations.

This approach enables the researcher to understand the phenomenon under study comprehensively. Also, integrating qualitative and quantitative data in an evaluation can enhance its quality by leveraging the strengths of each data type to compensate for the other's limitations. For this research, qualitative methods such as interviews and observation address how interventions operate, and qualitative insights guide intervention

design, adaptation, and practical delivery. Quantitative methods, such as questionnaires and biometrics, are better suited to assessing the effectiveness of these interventions and validating outcomes. Additionally, qualitative research methods can be crucial at various stages of developing and evaluating the intervention. By gaining insights into how interventions function and enhancing their practical delivery during the initial research phases, qualitative methods also contribute to refining these intervention strategies. The choice between quantitative and qualitative methods depends on research goals, context, and the questions being explored. By embracing both approaches, researchers gain a more holistic understanding of complex phenomena. Therefore, the researcher combines these methods to address this research inquiry comprehensively.

3.5.1 Questionnaire

A questionnaire was used as one of the main data collection methods in this study to collect information from participants in New Zealand and Chile. Questionnaires provide an efficient way of collecting consistent information from participants and are particularly useful for examining behaviours, experiences, attitudes, and opinions (Rowley, 2014). Using the same questionnaire structure across the two participant groups also provided a consistent approach to data collection.

The questionnaire included a combination of closed and open-ended questions. Closed questions provided structured responses that could be compared across participants, while open-ended questions allowed participants to describe their experiences and perspectives in their own words. Combining these question types supported the collection of both

quantitative and qualitative data and provided a broader understanding of participants' experiences.

The pre-intervention questionnaire consisted of 18 items (see Appendix G) and included multiple-choice, Likert-scale, and open-ended questions. It was designed to gather baseline information about participants before they engaged with the VR intervention. The questionnaire covered five main areas: demographic information; climbing experience and self-assessed skill level; mountaineering training and professional qualifications; accident history and perceptions of risk; and familiarity with and attitudes towards VR technology in mountain safety education.

These areas were selected to provide a clearer understanding of participants' backgrounds, previous mountaineering experience, training, exposure to mountain-related risks, and familiarity with VR. Demographic and mountaineering experience questions provided context for interpreting differences between participants in New Zealand and Chile. Questions about training and qualifications helped identify participants' previous formal and informal preparation for mountaineering. Accident history and risk-related questions explored participants' previous exposure to hazardous mountain situations, while the VR questions examined their previous experience with the technology and their attitudes towards its potential use for mountain safety education.

The different areas of the questionnaire were also connected to the research questions. Questions relating to participants' experiences and perceptions of VR contributed to the development and evaluation of the design principles (RQ1) and the investigation of how VR could support learning in high-risk outdoor situations (RQ2). Questions relating to

participants' previous mountain experiences and their perceptions of the simulated environment contributed to examining VR learning in relation to real mountain environments (RQ3). Questions concerning risk awareness and responses to hazardous situations contributed to examining changes in participants' responses to risk factors (RQ4).

Quantitative responses were analysed using descriptive statistics to identify patterns in the data, while qualitative responses were examined for recurring themes and concerns. The combination of quantitative and qualitative information provided a broader understanding of participants' backgrounds, experiences, and responses (Creswell & Plano Clark, 2018).

The questionnaire was administered to participants in both New Zealand and Chile as part of the data collection process. The complete pre-intervention questionnaire is provided in Appendix G.

3.5.2 Observation

Observation is a methodological approach in which researchers systematically document behaviours, interactions, and phenomena as they occur within real-world environments. (Merriam & Tisdell, 2016). Unlike structured environments such as research labs or focus groups, observational data capture real-world behaviours and contextual nuances, shedding light on intervention implementation. According to Cohen et al. (2007) and Lincoln & Guba (1985), the principal benefit of observational methods lies in the profound insight that can be attained in authentic environments. This approach facilitates an in-depth comprehension of behaviours and interactions as they unfold organically, providing a valuable perspective often unattainable through other research techniques.

Also, observation is a valuable research method that provides researchers with insights into program operations by uncovering details that participants or staff might overlook in interviews or focus groups. The researcher describes to participants the physical or virtual environments where observations will occur and the observation protocol, explaining what the researcher will observe and any specific behaviours or interactions of interest.

This session shows how observations will be conducted, specifying the setting, duration, and focus. This method describes observational research, which involves gathering data by observing people, events, or physical characteristics in their natural settings. Additionally, it outlines the procedures for recording observational data, including note-taking and video recordings. It also describes how the researcher maintains objectivity and minimises observer bias during data collection and analysis.

In their 2018 study, Boström et al. (2018) discuss three main types of observation used in research and, to some degree, combined: participant observation, nonparticipant (or onlooker) observation, and indirect observation. Each observation method has distinct characteristics and can be applied in various ways, sometimes even in combination. Participant observation involves the researcher actively participating in the group's activities, whereas nonparticipant or onlooker observation involves observing without direct involvement in the activities under study. In indirect observation, the researcher relies on observations done by others. This research conducts non-participant observation. This observational methodology entails the researcher systematically examining the group’s activities and interactions without direct involvement. The researcher serves as an external observer, methodically documenting behaviours, events, and interactions in their natural context. Nonparticipant observation is characterised by its non-intrusive nature,

which fosters a more objective and impartial perspective of the subject under study. This approach significantly reduces the likelihood that the observer's presence will alter the group's dynamics. The researcher aims to blend into the background during observations to avoid influencing participants' behaviour. The researcher delays note-taking to minimise disruption and promote natural interactions.

The observational data would encompass details such as the duration of the process and the nature of interactions. While observations provide snapshots of behaviour and activities, they may not capture the whole picture. To enhance understanding, the researcher triangulates observational findings with post-observation interview data, ensuring a comprehensive analysis of the environment under study.

3.5.2.1 Field Notes

In the context of qualitative inquiry, field notes function as a foundational record that encompasses more than a simple chronological account of events. According to Coffey (1996), Emerson et al. (2011), and Patton (2015), these notes are vital for capturing the researcher's own reflections and the subtle nuances of participant interactions. By documenting environmental variables and behavioural patterns as they occur, the researcher creates a dense, contextualised dataset that facilitates a more profound interpretive analysis during the later stages of the project. Unlike qualitative interviews, which focus on gathering participants' perspectives and beliefs, field notes document participants' actions and behaviours within their social context.

Coffey (1996) observes that field notes encapsulate the author's personal conscience, insights, and interpretative analyses. The fieldworker transcends the role of a mere observer,

embodying the multifaceted roles of an actor within the field, a chronicler of events, a narrator of experiences, and a scribe of the observed world. Coffey (1996) emphasised that field notes function as a critical source of qualitative data, providing detailed accounts of research settings and participant interactions. By capturing contextual nuances that might otherwise be overlooked, field notes enable researchers to systematically revisit observations and develop informed interpretations grounded in participants' lived experiences.

Coffey (1996) sees field notes as more than just objective records of events and observations; they reflect the researcher's personal engagement and interpretive process. The researcher's subjective experiences, thoughts, and feelings are integral to the documentation, shaping how events and interactions are perceived and recorded. This personalised approach enriches the data with deeper layers of meaning and context. As a chronicler of events, the researcher meticulously records the sequence and details of occurrences, ensuring that the data captures the temporal flow and contextual specifics of the field setting. This role emphasises the importance of precision and attentiveness in capturing the subjects' lived reality.

In field notes, researchers capture a broad range of information that reflects their sensory and intellectual experiences during research activities. These notes include descriptions of what was seen, heard, felt, and thought, documenting people, actions, interactions, and the researcher's thoughts, questions, and ideas prompted by observations. Visual materials, such as sketches or diagrams, may also be included to enrich the record of the research setting.

As a narrator of experiences, the researcher provides a narrative structure to the field notes, weaving together observations with reflective insights. This narrative aspect helps make sense of the raw data, highlighting significant themes and patterns that emerge from the fieldwork. Finally, as a scribe of the observed world, the researcher documents the tangible and intangible elements of the field setting, from physical surroundings to social interactions. This comprehensive documentation serves as a valuable resource for analysis and interpretation.

3.5.2.2 Video Recording

Caldwell & Atwal (2005) indicate that video recording should be used for data collection, guided by the study's purpose and objectives, as well as the specific behaviours being measured. Video recording is an important method of data collection, enabling researchers to capture behaviours and interactions as they occur and analyse their relationships over time (Caldwell & Atwal, 2005; Derry et al., 2010). According to Caldwell & Atwal (2005), video recording offers high reproducibility when measuring observations. Unlike real-time data collection, video recordings can be replayed multiple times.

However, it requires more complex preparation compared to field note-taking. The researcher should prepare a video recording procedure. It describes the process for capturing video recordings, including equipment used, recording protocols, and storage methods. The most important thing is to address any ethical considerations related to video recording, such as obtaining consent and protecting participants' privacy.

When combined with observational tools, video recording allows researchers to systematically analyse and code various aspects of behaviour. These tools help researchers

apply standardised procedures and decision rules to assign codes to non-verbal behaviours, verbal expressions, or vocal utterances. Researchers can gain valuable insights into human interactions and behaviour patterns.

3.5.3 Interview

Interviews were used in this study to gain a deeper understanding of participants' experiences, perceptions, and responses to the VR intervention. Interviews are useful in qualitative research because they allow researchers to explore participants' perspectives and experiences that may not be directly observable or fully captured through questionnaires (Gill et al., 2008; Patton, 2002). They also provide opportunities to ask follow-up questions and clarify participants' responses, which can produce more detailed information about individual experiences.

Research interviews can generally be structured, semi-structured, or unstructured, depending on the purpose of the research and the level of flexibility required (Robson, 1995). The main characteristics of these approaches are summarised in Table 3.1.

Table 3.1

The main types of interviews

Structured Interviews	These have predetermined questions in a set order, often closed-ended (yes/no or multiple-choice). They provide quantitative data and allow for easy comparisons between participants.
Semi-structured Interviews	A blend of structured and unstructured interviews. Questions follow a thematic framework but allow flexibility. Considered "the best of both worlds" due to order and openness.

Unstructured Interviews	Open-ended and free-flowing, allowing participants to express their thoughts. Interviewers present a problem or topic and enable respondents to raise related issues, allowing the conversation to develop naturally around it. This approach is less structured but rich in qualitative data.

This research used semi-structured interviews because they provided a balance between consistency and flexibility. The same main areas could be explored with participants in New Zealand and Chile, while follow-up questions allowed participants to explain their individual experiences in more detail. This was particularly useful for exploring participants' experiences of the VR environment, where individual reactions, perceptions, and previous mountaineering experience could vary considerably. Semi-structured interviews also allowed the researcher to clarify responses and explore unexpected issues that emerged during the discussion (Alshenqeeti, 2014; Robson, 1995).

The interview questions were organised around several areas that reflected the aims and research questions of the study. These included participants' overall experience of the VR environment, perceptions of realism and immersion, responses to simulated high-altitude risks, learning experiences, decision-making, and views about how the VR intervention could be improved. Participants were also encouraged to compare aspects of the simulated experience with their previous experiences in real mountain environments. The complete semi-structured interview questions are provided in Appendix H.

The different areas of questioning were connected to the research questions. Questions concerning participants' views of the VR design and suggestions for improvement contributed to the development and refinement of the design principles (RQ1). Questions

about how participants interacted with and experienced the VR environment supported the evaluation of VR as a learning approach for high-risk outdoor situations (RQ2). Questions asking participants to reflect on realism, immersion, and their previous real-world mountain experiences contributed to understanding the relationship between VR learning and learning in real environments (RQ3). Questions concerning risk recognition, responses to simulated hazards, and decision-making contributed to examining participants' responses to risk factors following the VR experience (RQ4).

The interviews complemented the questionnaire by allowing participants to explain the reasons behind their responses in greater depth. While the questionnaire provided structured information that could be compared across participants, the interviews provided additional context about individual experiences, perceptions, and decision-making. Using the two methods together therefore provided a broader understanding of how participants experienced and responded to the VR intervention.

Face-to-face interviewing was used because it allowed the researcher to communicate directly with participants, ask follow-up questions, clarify responses, and discuss participants' experiences in detail. Face-to-face interviews can also provide access to verbal and non-verbal information that may not be available through other interview formats (Opdenakker, 2006). These characteristics were useful in this study because participants were asked to reflect on their experiences immediately following their interaction with the VR environment.

3.5.4 Biometric Feedback

Biometric feedback involves measuring and analysing physiological signals to assess a person's physical or emotional state. According to Chow (2017), biometric signals are the manifest results of the body's instinctive reactions to neurological or environmental triggers. These physiological outputs serve as a direct link between a person's internal state and the external world, capturing the subtle bodily changes that occur during a specific experience. This automated feedback loop provides researchers with a quantifiable way to observe human responses to diverse stimuli. The expansion of wearable technology enables the unobtrusive collection of various biometrics. This process uses biometric feedback devices to collect and interpret data such as heart rate, blood pressure, skin conductance, brainwave patterns, and muscle tension. For example, according to Michels et al. (2013), heart rate stands out as a particularly revealing physiological marker, providing critical data on the intensity of a person's stress response. By analysing cardiac shifts, researchers can gain valuable perspectives on the level of arousal experienced during specific activities. This makes HR track a foundational component of any study aimed at measuring the impact of high-pressure situations on human performance and health. Research suggests a correlation between heart rate and stress, with studies indicating that heightened heart rates coincide with increased salivary cortisol levels, a known stress marker. These measurements offer insights into physiological or emotional arousal levels, stress, attention, and other aspects of well-being. This feedback is typically obtained through wearable devices, sensors, or specialised equipment that accurately measure and interpret physiological signals. These devices are versatile and can be used for a variety of purposes. In fields like healthcare, sports performance, psychology, and human-computer interaction,

biometric feedback helps individuals gain self-awareness, monitor and manage stress, enhance performance, and track progress towards specific goals.

3.5.4.1 Applications of Biometric Feedback

Biometric feedback has gained increasing attention across a range of disciplines due to its ability to provide real-time physiological data that can inform and personalise interventions. In this study, biometric data—such as heart rate variability—were used to assess emotional and cognitive responses during immersive VR training. However, the application of biometric feedback extends far beyond educational settings. Table 3.2 outlines key areas of benefit where biometric feedback is utilised, spanning healthcare, sports science, psychology, and human-computer interaction. These examples demonstrate the versatility of biometric feedback as a tool for enhancing performance, monitoring well-being, supporting clinical treatment, and informing adaptive system design.

Table 3.2

The benefit of biometric feedback

Applications	**Benefit areas**	**Benefit**
Healthcare	Stress and anxiety management	Biometric feedback can help monitor and manage stress and anxiety levels by providing real-time data on physiological responses.
	Rehabilitation	In physical therapy, biometrics can monitor muscle activity and guide patients through exercises, ensuring they perform movements correctly and safely.
	Chronic disease management	For conditions like hypertension or diabetes, biometric feedback can help patients and healthcare providers monitor vital signs and adjust treatments accordingly.
Sports performance	Performance	Athletes can use biometric feedback to

	optimisation	monitor their physiological responses during training, allowing them to optimise their workouts and improve performance.
	Injury prevention	By tracking muscle activity and movement patterns, biometric feedback can help identify potential injury risks and adjust training regimens to prevent injuries.
Psychology	Cognitive behavioural therapy (CBT)	In CBT, biometric feedback can help individuals become more aware of their physiological responses to stress and anxiety, aiding the development of coping strategies.
	Behavioural research	Psychologists use biometric feedback to study the physiological aspects of behaviours and emotions, providing a deeper understanding of human psychology.
Human-computer interaction (HCI)	User Experience (UX) Research	In HCI, biometric feedback can assess user engagement, stress, and satisfaction while interacting with technology. This data can inform the design of more user-friendly interfaces.
	Adaptive systems	Systems can be designed to adapt to the user's physiological state in real time, for example, by adjusting task difficulty based on the user's stress or attention levels.

3.5.4.2 Methods of Biometric Feedback

Biometric feedback encompasses a range of physiological measurement techniques that enable researchers and practitioners to assess internal states such as stress, attention, and cognitive workload. These methods are increasingly used in educational, clinical, sports, and human-computer interaction (HCI) contexts to inform personalised interventions and adaptive system design. In the context of immersive learning environments—such as virtual reality (VR) applications for high-risk training—biometric feedback offers valuable insights into how learners physiologically respond to simulated stress or cognitive demands.

Table 3.3 summarises commonly used biometric devices, the physiological signals they measure, and their typical applications. These tools form a critical component of the data collection strategy used in this study to evaluate participant engagement, emotional arousal, and learning outcomes.

Table 3.3

The methods of biometric feedback

	Devices	Measurement	Applications
Heart rate monitor	Wearable fitness trackers, heart rate monitors	Beats per minute (BPM)	Stress management, fitness tracking
Electroencephalography (EEG)	EEG headsets	Brainwave patterns	Neurofeedback, attention training
Electromyography (EMG)	EMG sensors	Muscle activity	Rehabilitation, sport performance
Skin conductance	GSR sensors	Electrical conductance of the skin	Stress detection, emotional arousal monitoring, lie detection
Blood pressure monitoring	Blood pressure cuffs, wearable blood pressure monitors	Systolic and diastolic pressure	Hypertension management, cardiovascular health monitoring
Respiration rate monitoring	Respiratory belts	Breath per minute	Stress management, respiratory health
Temperature monitoring	Wearable temperature sensors	Body temperature	Stress management, biofeedback therapy
Eye tracking	Eye-tracking glasses, cameras	Eye movement patterns	Human-computer interaction, attention and focus training

3.5.4.3 Biometric Devices and Technologies

Biometric feedback can be obtained using various devices. These technologies enable accurate measurement and interpretation of physiological signals, facilitating the application of biometric feedback across diverse fields. These technologies enable precise measurement and interpretation of physiological signals, facilitating the application of biometric feedback across diverse fields.

Table 3.4

Biometric devices and technologies

Wearable devices	Smartwatches, fitness trackers, specialised health monitors
Sensors	GSR sensors, EEG headsets, EMG sensors
Specialised equipment	Medical-grade monitoring devices used in clinical settings

Note: GSR: Galvanic Skin Response, EEG: Electroencephalography and EMG: Electromyography.

Researchers aim to develop wearable, programmable, waterproof devices and systems that accurately sense and conspicuously display biometric optical outputs, including heart rate, in real time for wearers actively engaged in exercise and sport. The devices/systems will be augmented to provide real-time data views to additional persons, including but not limited to coaches, instructors, and physicians, who will assist wearers in achieving personalised fitness, health, and performance goals. Biometric feedback can help monitor participants' reactions to a VR prototype app. During Biometric feedback, participants are connected to electrical sensors, including a Suunto watch, which allows researchers to gather information about participants' physiological responses via a VR prototype app that uses heart variability biofeedback (measuring pulse and heart rate).

The heart-rate measurements were used as supplementary data only. The Suunto device was a commercially available device rather than medical-grade equipment; therefore, the measurements were non-clinical and non-diagnostic and were not intended to diagnose stress, anxiety, or any medical condition.

When participants use a VR app, researchers can find that their chronic stress can dramatically affect their bodies. This may include elevated blood pressure, increased body temperature, and disruption of brain function. Participants wear a Sunnto wearable electrical sensor watch during the VR experience section. The Sunnto sensor measures one or more signs of stress. This can include heart rate, muscle tension, or body temperature. The measurements provide feedback about how their bodies respond to a VR app.

These changes in heart rate are interpreted as indications of physiological arousal rather than evidence of a specific emotional or medical state.

In addition to the educational program, participants in the biometric feedback group received information about their physiological metrics. The rise of wearable technology has broadened the scope of detecting and monitoring various disease-related functions due to advancements in manufacturing and technology. Virtual Reality (VR) technology immerses users in simulated environments, offering sensory experiences like sight, sound, smell, and touch. VR has applications in gaming, sports training, military simulations, space exploration, and surgical training. This study aims to develop an integrated system that combines physiotherapy, biometric feedback from physiological sensors, physical motion, and virtual reality, utilising Oculus Quest 2.

3.6 Research Design

3.6.1 Participants

Participants are relatively experienced mountain climbers with more than five years of experience in high-altitude mountains. They included NZAC (New Zealand Alpine Club), mountain guides from Wanaka and Queenstown, NZ Mountain Safety Council, DOC (Department of Conservation), expedition groups, and local guides from the Andes range in Chile. The eligible experts should work in organisations related to the climbing industry and mountain-guide communities in high-altitude regions. The research recruited 20 participants (n=20) using the app.

The researcher sought to advertise to expert climbers in the mountain communities of New Zealand and Chile. The researcher then formally invited those interested in participating in the focus groups and interviews. Contact details were identified through selected guide companies, climbing communities (such as mountaineering groups), and the primary researcher's networks. Selected participants ranged from novice climbers to experienced or professional mountaineers, including those who were professionally guided into high-risk situations. Participants were recruited via advertisements, emails, and personal climbing networks in New Zealand and Chile. Participation in this research is voluntary. They can withdraw from the study at any time. Suppose they choose to withdraw from the study. In that case, they were offered the choice between having any data identifiable as belonging to them removed or allowing it to continue to be used. However, removing participants' data may not be possible once the findings have been produced.

Participants didn't feel discomfort or embarrassment during the pre-intervention or interviews. However, some participants experienced discomfort, such as dizziness, when using the app.

3.6.1.1 Anticipated and Possible Challenges

One of the key challenges was getting people to respond through the app evaluation/feedback process. Finding participants was challenging, as many potential participants live in remote areas. Video conferencing for remote focus group participants was considered. Also, although the researcher has extensive knowledge and experience in digital media production, it was challenging to explore and develop VR and MR apps, as these are new areas. Additionally, understanding different cultural aspects and learning and teaching methodologies in Chile was challenging.

3.6.2 Location

These locations were strategically selected based on both research relevance and practical feasibility. New Zealand was chosen as one of the primary sites because the researcher was based at the Auckland University of Technology (AUT) and had strong connections with the New Zealand Alpine Club (NZAC), which enabled efficient recruitment and access to an active community of experienced and emerging mountaineers. The local alpine environment, particularly in the Southern Alps, provides diverse high-altitude climbing conditions that closely align with the risk scenarios simulated in the VR intervention.

Chile was selected as the second research site due to its rich mountaineering culture, extremely high-altitude environments in the Andes, and its relevance for testing the VR intervention in a culturally and geographically distinct context. The researcher's

supervisory team included a Chilean academic with direct professional and mountaineering contacts in the region, which facilitated participant recruitment, local partnerships, and cultural adaptation of the training content. Furthermore, Chile's varied alpine conditions enabled exploration of how VR training could be adapted to different environmental and safety demands.

The selection of these sites was also supported by the award of the Prime Minister's Scholarship for Latin America (PMSLA), which enabled the researcher to conduct fieldwork in Chile. This funding not only provided financial resources but also institutional recognition, reinforcing the value of cross-cultural research in advancing innovative safety training solutions for high-risk outdoor environments.

By situating the study in both New Zealand and Chile, the research could examine the transferability and adaptability of VR-based safety education across two distinct mountaineering contexts—one rooted in a temperate maritime alpine climate and the other in high-altitude Andean terrain—thereby enhancing the external validity and cultural responsiveness of the design principles developed.

3.6.2.1 Chile

Participants were novice or experienced mountain climbers in Chile. Data collection was carried out on the campus of the University of Viña del Mar, Viña del Mar, Chile, between December 2023 and February 2024. Participants are from various areas, including expedition groups, local climbers, and local guides from the Andes range in Chile. The eligible experts should work in organisations related to the climbing industry and mountain-guide communities in high-altitude regions. The research is anticipated to

involve up to 10 participants (n=10) using the app (10 per stage). Their age is between 25 and 60.

3.6.2.2 New Zealand

This research involved mountaineers from the New Zealand Alpine Club (NZAC) at the City Campus of Auckland University of Technology, Auckland, New Zealand. Participants were invited to take part in the study, and a total of 10 New Zealand participants were recruited. The research involved up to ten participants (n = 10) using the VR application in each stage. Participants' ages ranged from 25 to 60 years.

3.7 Research Analysis

The data are mainly qualitative and involve a small number of participants, so the researcher is unlikely to need qualitative analysis software to identify key themes. The researcher can categorise participant feedback via thematic coding of emerging themes and creating graphical charts of responses to the survey questions (both quantitative and qualitative). The quantitative data from the biometrics can be analysed via Excel spreadsheets. The researcher will collect biometric data, including heart rate, to triangulate subjective feedback from participants through pre- and post-surveys, interviews, and their interactions with the app prototype. The research uses a Suunto watch to detect Heart Rate Variability (HRV). When participants' HRV increases while using the app, they are in a tense, stressful environment similar to the real one. It reflects that the virtual environment successfully simulates the real environment in safe locations.

As noted, the research employs multiple methods to gather data, including surveys, interviews, researcher observations/reflections, and biometric feedback during the user

testing of the VR prototype. Engeström's (1987, 2001) Third-Generation Activity theory is used to make sense of socio-cultural factors and is utilised in the analysis. Activity theory helps researchers analyse data and prepare interview questions. It also helps to identify and analyse the cultural differences between the New Zealand and Chilean mountaineer cohorts.

Activity Theory will be utilised in the analysis. Activity theory will help me learn to analyse data and prepare interview questions. It also helps to identify and analyse different cultural aspects between New Zealand and Chilean mountaineers.

Also, this session describes thematic, descriptive analysis and biometric statistical analysis as part of the research analysis methods.

Thematic and descriptive analyses are qualitative research methods used for analysing textual data. According to Braun and Clarke (2006), thematic analysis is a qualitative analytical approach used to identify recurring patterns and meaningful themes within a dataset. By systematically coding and organising qualitative material, researchers can interpret how participants construct meaning around particular experiences or phenomena. It aims to uncover the underlying meanings, concepts, and perspectives present in the dataset. The process includes coding and categorising the data into themes, which are then organised and analysed to gain insights into the research question or topic. The thematic analysis focuses on capturing the richness and nuances of the data and understanding the participants' experiences, beliefs, or perspectives.

On the other hand, descriptive analysis involves organising and summarising data to provide a clear overview of its key characteristics and patterns (Sandelowski, 2000; Tracy, 2013). It involves providing a detailed and comprehensive data account without extensive

interpretation or explanation of underlying meanings. Descriptive analysis often involves organising the data, summarising information, identifying patterns or trends, and presenting it in a structured manner.

Both thematic and descriptive analyses are valuable qualitative research methods for gaining insights from textual data. Thematic analysis allows for a deeper exploration of the underlying meanings and perspectives, while descriptive analysis provides a clear and straightforward representation of the data. The choice between these approaches depends on the research objectives, the nature of the data, and the desired level of interpretation and description in the research study.

3.7.1 Activity Theory

This research adopted Engeström's (2001) Third-Generation Activity Theory as both a methodological framework and an analytical tool to examine the design, implementation, and evaluation of a VR-based mountaineering safety training intervention within two distinct socio-cultural contexts—Chile and New Zealand. Activity Theory (AT) offers a systemic perspective that extends analysis beyond individual learner outcomes to the broader educational, cultural, and institutional settings in which the intervention was situated. For this research, Activity Theory (expansive learning) provides frameworks for interpreting findings from various data collection methods, such as surveys, VR app experiences, interviews, and biometric feedback. According to Hasan and Kazlauskas (2014), Activity Theory centres on the systematic study of human activities, characterised by the intentional relationship between a subject and their intended outcome. Grounded in the work of Vygotsky (1978), this perspective views activity as a unified whole where the

"purpose" of an action is inseparable from the "actor." Within intricate research settings, these activities are often viewed as a "system of activities," where various moving parts interact to influence the overall learning or work process (p. 11).

Activity Theory has four principles: object-orientedness, internalisation/externalisation, mediation, and development. These four principles are considered an integrated system and are associated with this research's data collection and analysis process. In this study:

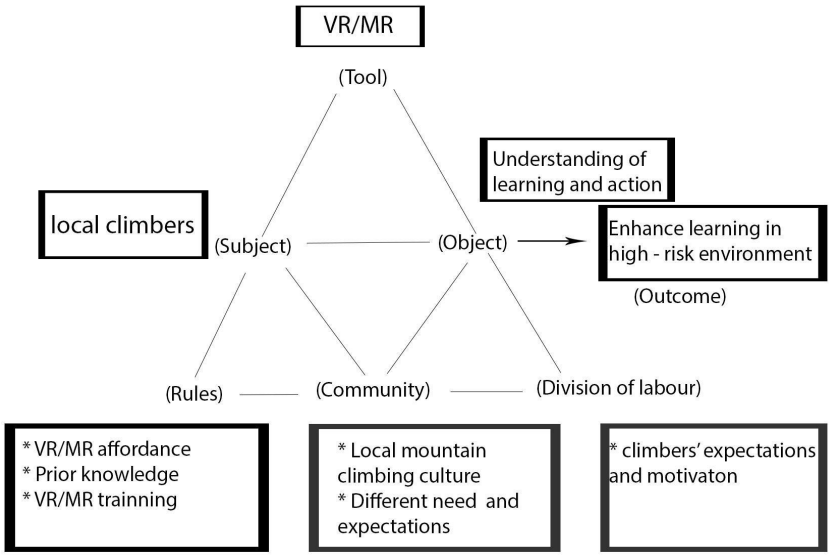
- Object-orientedness involved aligning the intervention with the core goal of enhancing safety skills, decision-making, and situational awareness in high-risk mountaineering environments.
- Internalisation/externalisation was reflected in participants' ability to trial complex decision-making and safety strategies in a simulated VR environment without engaging in real-world climbing risks.
- Mediation was achieved through the VR app and biometric sensors, which served as tools to facilitate and observe learning processes.
- Development occurred as the VR prototype evolved through iterative DBR cycles, shaped by ongoing data collection, participant feedback, and refinement of design principles.

Activity Theory (Engeström, 1987, 2001) informed the methodological design of this study by providing a systemic framework for understanding the VR-based mountaineering safety training intervention within its socio-cultural context. Methodologically, Activity Theory informed research design, data collection and iterative redesign (DBR cycles).

Research Design – The research design involved mapping the entire activity system for each national context—New Zealand and Chile—encompassing the subject (learners), object (safety competence), tools (VR app, biometric sensors), community (mountaineers, trainers, institutions), rules (safety protocols, cultural norms), and division of labour (roles of climbers, trainers, and researchers)—to ensure that all design decisions were contextually grounded. This mapping process ensured that all design decisions were grounded in the realities of each context, recognising the influence of cultural, institutional, and technological factors on learning.

Figure 3.2

Activity Theory was adopted for this research.



- Subject: Local mountaineers in New Zealand and Chile.
- Object: Understanding of learning and action in high-risk environments.
- Rules: VR/MR affordance, Prior knowledge, VR/MR training.

- Community: Local mountain climbing culture, different needs, and expectations in NZ and Chile.
- Division of labour: Climbers' expectations and motivations.
- Outcome: Enhance learning in high-risk environments.

- Data Collection – Data collection was then structured to capture how these elements interacted in practice, using multiple methods, including interviews, observations, biometric feedback, and video recordings. This multi-layered approach enabled the identification of both enabling factors and systemic barriers to effective learning.
- Iterative Redesign (DBR cycles) – The iterative redesign process, embedded within the DBR cycles, was guided by the identification of systemic contradictions. Examples included tensions between learner autonomy and institutional safety requirements, and between immersive realism and technological limitations. These contradictions provided valuable insights that informed successive refinements of the VR prototype, ensuring that it remained responsive to both pedagogical goals and contextual constraints.

Analytically, Activity Theory enabled a multi-layered interpretation of learning experiences by:

- Mapping activity systems for Chile and New Zealand to highlight contextual differences in community structures, cultural safety attitudes, and resource availability.
- Identifying contradictions across four levels:

- Primary – Within elements (e.g., VR realism vs usability issues).
- Secondary – Between elements (e.g., institutional rules vs experiential learning needs).
- Tertiary – Introducing VR as a challenge to traditional training models.
- Quaternary – Tensions between VR-based training and adjacent activities, such as on-mountain practice.

- The impact on learning was interpreted by linking biometric, observational, and interview data to the components of Activity Theory, revealing how the VR intervention mediated emotional engagement and influenced decision-making under simulated stress.
- Theorising systemic change involved explaining how immersive technology can be sustainably integrated into high-risk outdoor education, while recognising and addressing the institutional and cultural constraints that influence its adoption and effectiveness.

By embedding Activity Theory into both the methodology and the analysis, the study ensured that the VR intervention was examined as part of a dynamic socio-cultural system rather than as an isolated tool. This approach enabled a theory-driven, iterative design process that identified and addressed systemic tensions, producing contextually relevant design principles for VR-based mountaineering safety training and contributing to both practical innovation and theoretical advancement.

3.7.2 Thematic and Descriptive Analysis

Thematic and descriptive analysis are two qualitative research methods used to analyse textual data such as interview transcripts, survey responses, or written documents. Both approaches aim to identify and interpret patterns or themes within the data but do so in different ways and with different focuses. Thematic and descriptive analyses are two common approaches used in qualitative research to analyse and make sense of data.

According to Braun and Clarke (2006), thematic analysis is a method for identifying, analysing, and reporting patterns within data. Thematic analysis involves identifying and analysing patterns and themes within qualitative data. It aims to uncover the data set's underlying meanings, patterns, and concepts. The process involves systematically coding and categorising the data into themes or patterns, which are then interpreted and analysed to gain insights into the research question or topic. The thematic analysis focuses on capturing and understanding participants' perspectives and experiences in a study.

Braun and Clarke (2006) argue that thematic analysis can highlight the social, cultural, and structural contexts that shape individual experiences. This approach enables the development of knowledge that emerges from interactions between the researcher and participants, uncovering socially constructed meanings.

Joffe (2011) proposes that thematic analysis is well-suited for constructivism because it can demonstrate how specific social constructs evolve by analysing diverse data sets. In this approach, constructivist thematic analysis aims to uncover latent, deeper themes within the data, illustrating the development of social constructs.

According to Kiger and Varpio (2020), thematic analysis is executed through a series of rigorous, overlapping phases designed to identify and refine patterns within a dataset. This systematic approach allows the researcher to move from a basic familiarity with the data to a sophisticated conceptualisation of the underlying themes. By following this established sequence, the researcher ensures that the final analysis is both transparent and grounded in the authentic responses of the participants.

1. Familiarisation with the data: Researchers read and re-read the data to become familiar with it.
2. Generating initial codes: Researchers systematically code exciting features of the data across the entire dataset.
3. Searching for themes: Codes are collated into potential themes, and all data relevant to each theme is gathered.
4. Reviewing themes: Themes about the coded extracts and the entire dataset are checked to ensure they form a coherent pattern.
5. Defining and naming themes: Themes are refined for clarity and understanding, and each is clearly defined and named.
6. Producing the report: A final analysis usually involves selecting vivid, compelling examples, analysing the selected extracts, relating the study to the research question and literature, and producing a scholarly report.

Thematic analysis is flexible and can be applied to various research questions and data types. It is beneficial for exploring patterns of meaning across a dataset, allowing researchers in this study to make sense of collective or shared experiences.

ASTM (1992), Gacula (1997), Murray et al. (2001), and Kemp et al. (2009) describe descriptive analysis as summarising and describing the characteristics, features, or properties of a data set. It focuses on providing a detailed, comprehensive account of the data without necessarily interpreting or explaining its underlying meanings. Descriptive analysis often includes summarising event frequencies, describing qualitative data in a structured manner, or providing numerical summaries of quantitative data. This approach is beneficial when the researcher aims to present a clear and straightforward representation of the data without extensive interpretation. This method is less interpretive than thematic analysis and seeks to provide a straightforward account of the data. Critical aspects of descriptive analysis include data collection, data organisation, summary and description and contextual understanding. For summary and description, it provides a comprehensive data summary, often using descriptive statistics in quantitative research or detailed textual descriptions in qualitative research. Descriptive analysis helps provide a clear, detailed understanding of the dataset by identifying key features and basic patterns without necessarily delving into deeper underlying meanings or interpretations. It often serves as a precursor to more complex analyses, providing a foundational understanding upon which further analysis can be built. The table below shows the difference between thematic and descriptive analysis.

Table 3.5

The difference between thematic and descriptive analysis

	Thematic analysis	Descriptive analysis
Focus	Patterns and themes	Clear and detailed data
Depth of analysis	Understand meanings and patterns	Summarising what is present in the data
Flexibility	Flexible and can be adapted to various research questions	More structured and straightforward

Tracy (2013) discusses descriptive analysis in qualitative research and emphasises its role in providing clear, straightforward data summaries that are accessible and meaningful to various stakeholders. Also, Sandelowski (2000) highlights that descriptive qualitative studies aim to describe phenomena rather than explain them, making them particularly useful for gaining insights into poorly understood areas. These sources provide valuable insights into how descriptive analysis can be effectively used in qualitative research to produce comprehensive, accessible data summaries.

Both methods are valuable in qualitative research, with thematic analysis particularly useful for exploring complex patterns and meanings and descriptive analysis essential for providing a clear and comprehensive overview of the data. The choice of approach depends on the research objectives, the nature of the data, and the desired level of interpretation and description in the research study. This research uses both methods to describe its data and explore its deeper meanings.

3.7.3 Biometrics Statistical Analysis

Biometric statistical analysis refers to the use of statistical methods to analyse and interpret data generated by biometric systems that measure unique physiological or behavioural characteristics for identification and authentication (Jain et al., 2011). This analysis is essential in biometrics, providing quantitative measures, evaluating performance, and making statistical inferences from the collected data. Participants wear a smartwatch (or similar wearable device) during the VR simulation to assess stress by recording heart rate data via a smartwatch application. This indicates alignment between the cognitive and emotional impacts of VR/MR learning experiences and learner outcomes within an enhanced simulation (Aguayo et al., 2018).

Some key aspects of biometric statistical analysis include:

- Performance Evaluation: Statistical analysis assesses the performance of biometric systems by measuring metrics such as identification accuracy, false acceptance rate, false rejection rate, and receiver operating characteristic (ROC) curves. These metrics help determine the system's effectiveness and reliability.
- Template Matching: Biometric systems compare captured biometric samples with pre-registered templates. Statistical techniques such as similarity scoring, probability density estimation, or matching algorithms are used to evaluate the similarity or dissimilarity between the samples and templates.
- Error Analysis: Statistical analysis identifies and examines errors and variations in biometric data. It involves understanding the sources of errors, quantifying

measurement uncertainties, and assessing the impacts of noise, artefacts, or environmental factors on the system's accuracy.

- Population Modelling: Statistical models that analyse population characteristics and variations in biometric data. It includes analysing population distributions and demographic effects, as well as developing statistical models to capture variability in biometric characteristics across individuals or groups.

Overall, biometric statistical analysis provides insights into the performance, accuracy, and variability of biometric systems. It helps optimise system designs, improve identification/authentication algorithms, and ensure the reliability and security of biometric-based applications.

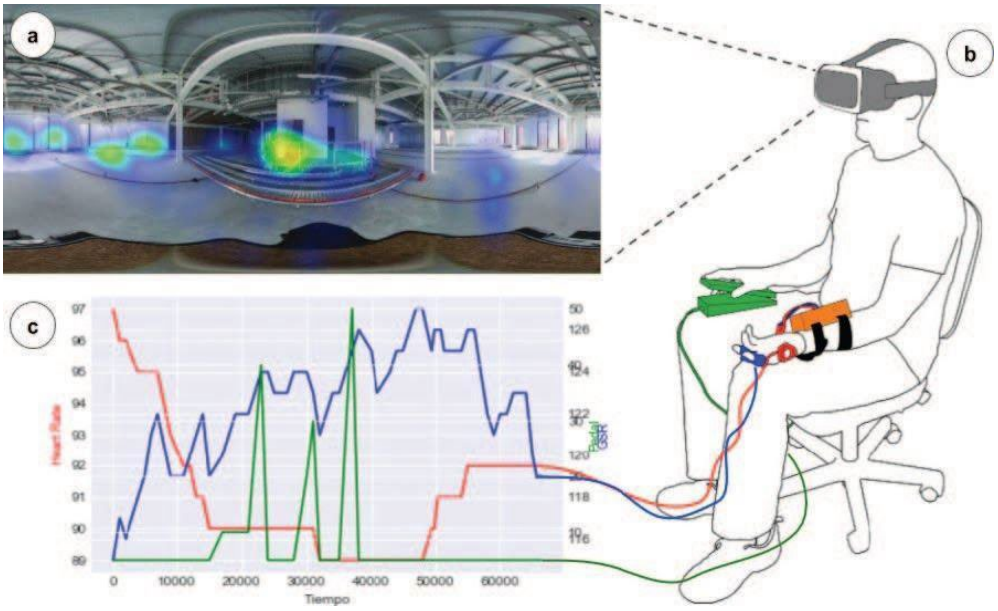
To aid analysis, the researcher categorises participant feedback into emerging themes and creates graphical charts of responses to the survey questions (quantitative and qualitative). The quantitative biometrics data are analysed using open-source plotting software. The biometric measurement method is anticipated to be very similar to Aguayo and Cochrane's approach (Cochrane, Cook, et al., 2018).

The chosen 360-degree online visualisation platform, SeekBeak, allowed for the background recording of the viewing of the hidden points of interests in the form of a 'hotspot heat map' (Figure 2a). To record a hotspot in the heat map, students had to stare at a given potential hazard for more than 2 s. Students were also connected to an embodied reports unit that recorded first-person data via a self-reporting pedal and third-person data via HR and GSR sensors (Figure 2b). Students were presented with the 360-degree scenario for a minute and were asked to increasingly press the

pedal when they felt emotionally engaged with the scene. Note that all participants from the pilot study (n = 10) reported not being distracted by the task of pressing the pedal while visualising the 360-degree scenario. However, we acknowledge that such a task may alter the biofeedback response, which calls for future methodological improvements to eliminate and/or isolate this potential issue. Finally, the embodied reports data were processed and plotted against time for a global representation of first- and third-person data sets in relation to the duration of the experience (Figure 2c; for details see Cochrane et al. 2018).

Figure 3.3

Experimental piloting set-up using an embodied reports unit to record first- and third-person data during a paramedicine virtual reality scenario: (a) hotspot heat map representing the immersive experience of a participant; (b) experimental set-up including the subjective feedback via subjective self-reporting pedal (green) and HR and GSR sensors (blue and red, respectively); and (c) analytical representation of embodied reports data sets against time of the virtual reality experience (Cochrane, Cook, et al., 2018)



Building on the prototype VR/MR learning environment design (Cochrane, Cook, et al., 2018), the researcher triangulated subjective feedback and responses from participants across pre- and post-interviews, biometric feedback, and researcher observations/reflections.

In this study, biometric feedback was used as part of a mixed-methods data collection strategy to capture participants' physiological responses during their engagement with the VR-based mountaineering safety training app. These physiological measures provided objective indicators of cognitive and emotional reactions—such as stress, focus, and arousal—that complemented qualitative data obtained through interviews, observations, and video recordings.

During the intervention sessions, participants wore a Suunto wearable watch to monitor their HRV and track real-time physiological changes. This device was selected for its portability, ease of use, and ability to provide continuous feedback without interrupting the immersive experience. The researcher monitored data from these sensors and later analysed them to identify patterns in emotional engagement, decision-making stress, and learning behaviours.

Measurements focused on key biometric signals using a Suunto watch.

- Heart Rate Variability (HRV) – to assess physiological arousal and stress during VR exposure.

This measurement was integrated with pre- and post-intervention questionnaires and thematic analysis to support triangulation and reinforce the validity of the study's data. The figure below illustrates the actual data collection setup used during the intervention. The

image shows a participant wearing a VR headset and a biometric sensor, a Suunto watch. At the same time, the researcher monitors the session via a connected device, and another device captures video and audio feedback for analysis.

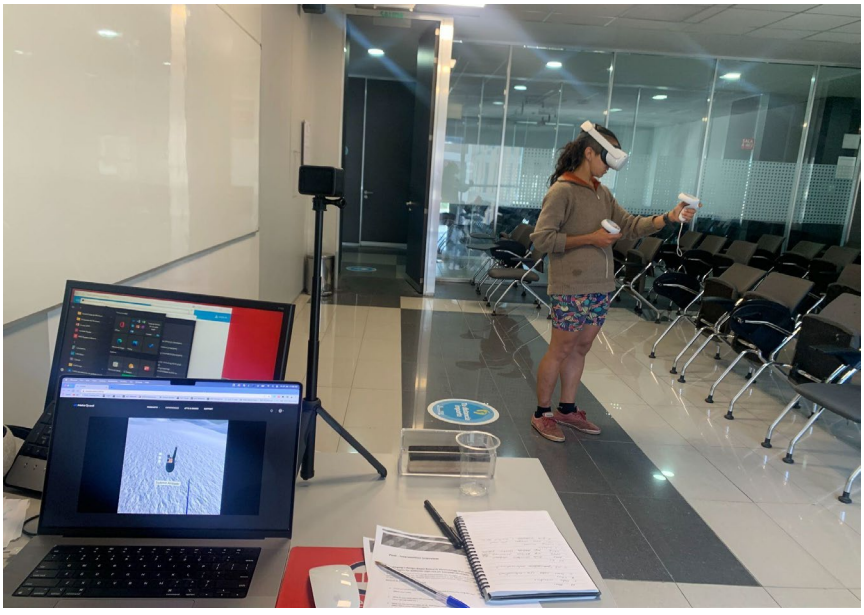
Figure 3.4

Data Collection Setup for VR Intervention with Biometric Feedback



Figure 3.5

Data Collection Setup for VR Intervention with Biometric Feedback



3.8 Data Collection

As noted, data are gathered through interviews and biometric feedback from end-user use of the prototype app at different stages of development. Researcher observations/reflections are also used as data. In the interviews, participants are asked to describe how various aspects of learning were enhanced (or not) compared to other types of learning they have encountered. Biometric feedback is obtained using a virtual reality (VR) head-mounted display (HMD), an Oculus Quest 2, and Suunto 9 wearable biometric measurement equipment to detect the user's heart rate during app use.

Heart rate was recorded using a Suunto 9 watch (Suunto Oy, Finland; model OW183), running software version 2.23.24 and PPG version 7253. The device uses photoplethysmography (PPG), an optical method that detects changes in blood volume at the wrist rather than measuring the electrical activity of the heart through electrocardiography (ECG). Therefore, the readings obtained from the watch are more accurately described as PPG-derived heart-rate estimates based on the peripheral pulse signal. Although pulse rate and heart rate generally correspond under normal conditions, they are physiologically different measures (Bent et al., 2020). No ECG, chest-strap reference measurement, or blood-pressure assessment was undertaken to validate the readings or confirm that pulse rate corresponded directly with heart rate for individual participants. For this reason, the Suunto readings were treated as supplementary, non-clinical and non-diagnostic data.

The Suunto 9 also provided temperature readings; however, these were not measurements of internal or core body temperature. Readings taken while the watch is worn on the wrist

may be influenced by both the wearer and the surrounding environment and were therefore not treated as medically validated measures of body temperature. Consequently, the temperature data were not used to determine whether changes in PPG-derived pulse readings were caused by body temperature, environmental conditions, or other physiological factors.

The same standard adjustable Suunto 9 wristband was used for all participants. Before each measurement, the researcher adjusted the strap to fit the participant's wrist and checked that the watch was positioned securely against the skin without being excessively tight. The watch was positioned above the wrist bone so that the optical sensor maintained direct contact with the skin without restricting blood circulation, following Suunto's recommendations for wrist-based heart-rate measurement (Suunto, 2023). No participants had a wrist size that prevented the standard adjustable band from being fitted appropriately.

Despite these limitations, the Suunto 9 provided a practical and accessible method of collecting supplementary data in remote mountaineering environments. The wrist-worn device was lightweight, portable, and relatively easy to use without additional chest straps or medical equipment, making it suitable for field-based outdoor research. Its purpose in this study was not to provide clinical or diagnostic measurements, but to observe general changes in PPG-derived pulse readings during the VR experience. These data were interpreted cautiously and considered alongside questionnaires, interviews, and observations rather than as an independent measure of participants' physiological or emotional state.

Methodological triangulation is utilised to evaluate users' overall learning behaviours and outcomes from that data. Using the evaluation, the researcher redesigns the 1st prototype app for further development. Methodological triangulation is used to evaluate learning outcomes and theorise. Methodological triangulation enables researchers to use several methods to have multiple perspectives on a specific research problem.

Bell and co-authors (2009) note that triangulation, which involves using multiple investigations or approaches to examine a specific research problem, combines multiple perspectives on an event or phenomenon. It means that researchers can get closer to understanding the essence of events and phenomena. This technique differs from the mixed research method, which combines quantitative and qualitative approaches. The critical point is that it is more reasonable to view it as an approach that reflects the belief that a diversified approach to the subject and its study can yield a broader and deeper understanding. Triangulation can be defined as the use of one or more research tools or methods to add breadth and depth to data and their analysis. Pritha (2022) also insists that triangulation approaches enable researchers to achieve a more holistic perspective on a specific research question and enhance credibility and validity.

According to Johanson and Williams (2017), these triangulation techniques take four forms. The first is data triangulation, which collects the study data from various cases, categories, and samples. For example, varying the place, provider, and time of data collection, or related information, helps yield meaningful results by examining consistency or differences across research findings. Second, multimethod triangulation uses multiple research methods within a single study. For example, assuming that 'research on classroom learners' perception of reading textbooks' is conducted, various research tools or techniques,

such as questionnaires, interviews, and videotaping, are used with the same group of research participants. Doing so can increase the validity and reliability of the study. Thirdly, other researchers, such as interviewers or performance observers, conduct the same study. Denzin (1978) calls this investigator triangulation to secure the validity and reliability of the study. This can have a significant meaning in providing various perspectives on a single study. Finally, it is a triangulation technique in which a researcher uses multiple theories and perspectives throughout the research process to understand and interpret data. It enables broad and deep understanding and interpretation. This study uses the second form of triangulation, methodological triangulation.

According to Pritha (2022), there are several benefits to using methodological triangulation, including the following.

- Cross-check evidence/Credibility: Data from multiple sources.
- Complete understanding of a research problem.
- Capture the complexity of real-world phenomena.
- Enhance validity.

Therefore, this study uses methodological triangulation to enhance the credibility and validity of the research questions. The overall goal is to develop transferable design principles applicable to other educational design knowledge contexts (e.g., VR educational apps across different contexts).

Table 3.6

Procedure of data collection

Research Phase	Data Gathering	Data Processing
1	Advertising	The researcher advertises in mountain communities (NZ Alpine Club magazine and NZ Alpine Club Facebook) in New Zealand and Chile, through a research coordinator in Chile, to solicit expressions of interest from participants.
2	Invitation	The researcher invites those interested in participating in the research via advertisements and email.
3	Initial contact participants	Participants are informed of the project details, consent process, and the data collection process by the researcher.
4	Data analysis fieldwork	User testing of the VR learner app is conducted at AUT in NZ and at Universidad de la Frontera and Universidad Andrés Bello in Chile.
	Note: The researcher conducts data analysis in NZ. The data collection is only for the 1st stage.	

5	Interview/questionnaire before they use the VR app (30 mins)	Asking about their experience in mountaineering at high altitudes and training, etc.
6	Biometric feedback (30 minutes)	Each stage of developing a prototype VR learning app takes around an hour per participant.
7	Interview post-intervention (30 minutes)	Participants discuss their experience after using a prototype VR learning app.

The research involves designing, producing, and evaluating a prototype VR learning app with invited participants. The researcher gathers data through questionnaires, observations, and the use of the prototype app and conducts feasibility interviews with climbers from climbing communities in New Zealand and Chile. Participants are informed of the project details, consent process, and the data collection process by the researcher. As mentioned above, the research employs methodological triangulation to measure learning outcomes, using multiple methods to gather data, including interviews, questionnaires, and biometric feedback.

The researcher interviews participants for around half an hour each, pre- and post-use of the VR app. If the researcher is unable to conduct interviews in person due to COVID-19, they will be conducted online via Teams or Zoom. Biometric feedback takes around 30 minutes per participant at each stage of developing a prototype VR learning app. Participants wear a Suunto watch to measure HRV. As part of biometric feedback, participants' heart rates are monitored before and after using the VR app, as heart rate is a

significant indicator of stress. When stress levels increase, heart rate increases Before conducting the research, all participants are informed about how biometric feedback is collected. Participants wear a virtual reality (VR) Head Mounted Display (HMD) headset, an Oculus Quest 2.

Regarding the side effects of VR headset use, there is a potential for nausea or discomfort. If any participant reports discomfort or nausea, the researcher will remove that participant from the study and provide medical support.

The research follows safety and confidentiality protocols to protect participants and researchers. For biometric feedback, participants will be informed in advance. The research will use a Suunto watch to detect heart rate. Qualitative data from pre- and post-app interviews will be triangulated with biometric responses collected before, during, and after app use, as well as interview feedback. Participants receive the questionnaire documents and the prototype app either during the first meeting or by email. This Virtual Reality (VR) environment is captured from authentically staged contexts using a 360° camera, such as a GoPro Max, with interactivity added via platforms such as Unity for viewing on a virtual reality (VR) Head Mounted Display (HMD), an Oculus Quest 2.

The development of the mobile VR intervention is guided by the design framework proposed by Cochrane (2016) and Cochrane, Narayan, and Antonczak (2016). This model emphasises a shift from content-centred delivery to a student-centred, social-constructivist approach, providing a structured pathway for integrating immersive technologies into the curriculum. By adhering to this framework, the researcher ensures that the VR experience

is not merely a technical add-on, but a pedagogically scaffolded tool designed to foster deep engagement and collaborative learning.

Table 3.7

Pre-intervention, intervention, and post-intervention description

Intervention process	Description
Location	A room in the WU Building, Level 3 at the AppLab, Auckland University of Technology in Auckland, New Zealand. A studio at Universidad Andrés Bello, Viña del Mar, in Chile. A researcher, a research assistant, and one participant are in the room per session. Each session runs for approximately 90 minutes and includes the following stages:
Biometric set-up	The research involves setting up a biometric data collection device (e.g., a smartwatch or Suunto) with a biometric recording feature to capture heartbeat data (60-90 min max). The biometric device is set up on the participant's wrist. Biometric data collection runs throughout the intervention (i.e., the pre-intervention survey and the VR app testing).
Pre-intervention Survey (30 min)	The survey covers demographic questions, prior experience with high-altitude mountaineering, and educational experience with high-altitude mountaineering. The survey is available as a Google Form. The participant has access to a laptop to respond to the survey.
The user testing of the VR app Intervention (20-30 min)	The intervention includes using a VR app prototype for high-altitude mountaineering education. An Oculus Quest 2 VR headset is available for participants to experience the VR app prototype. Participants will use this equipment during the intervention. Participants use the prototype VR app for 20-30 minutes. The intervention (the user testing of the VR app) includes: *Video recording:* A researcher sets up two video cameras on tripods on the left and right sides of the room to avoid interrupting the intervention. The researcher informs participants when to start and stop recording.

	• *Step 1*: Ensure the participant is comfortable in the VR environment, that the VR app is running, and that biometric data collection is recorded. • *Step 2*: The participant uses the start of the VR app. • *Step 3*: At the end of VR app testing, the researcher will stop the test and remove the biometric device.
Post-intervention Interview (30 min)	Participants are interviewed immediately after using the VR app to discuss their user experience and the potential of immersive learning technologies for high-altitude mountaineering.

The intervention uses a VR app prototype for high-altitude mountaineering education. A VR headset (Oculus Quest 2) allows participants to experience the VR app prototype. Participants use this equipment during the intervention.

The researcher provides participants with introductory information on how to use the VR headset before conducting the intervention. After a 5–10-minute introduction, participants wear the VR headset and use the prototype VR app for 20 minutes in a dedicated room. The participants follow navigation in the prototype VR app and learn each lesson. For example, the participants see the following screens in the prototype VR app:

The screen below, Figure 3.6, displays the various learning lessons available (Only Mountain Sickness will be available in this prototype version).

Figure 3.6

HAMS app main Menu page



Figure 3.7 shows the Mountain Sickness lesson's first page.

Figure 3.7

Mountain Sickness main page

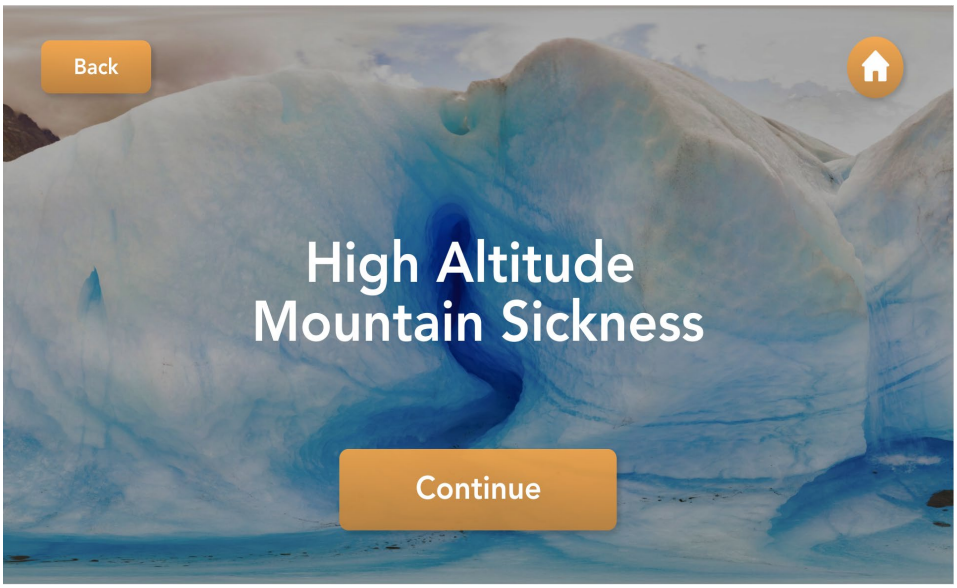
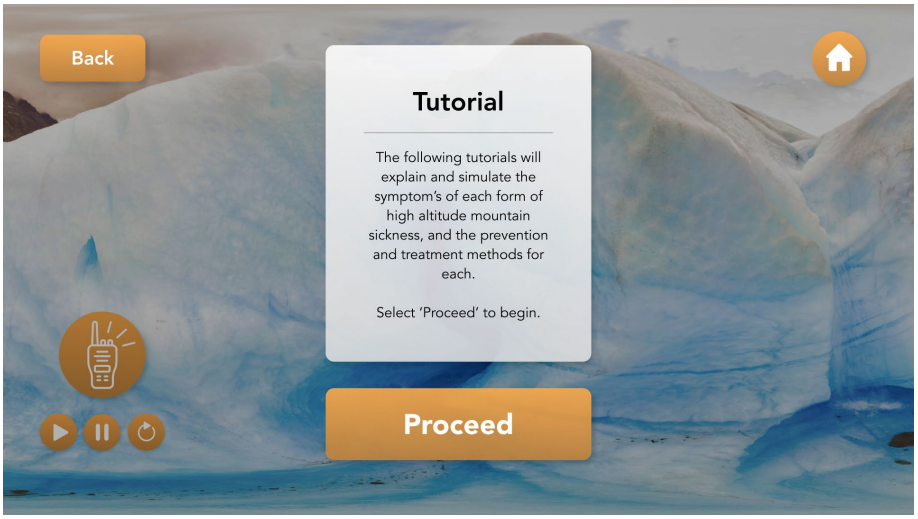


Figure 3.8 explains to participants how to use the app.

Figure 3.8

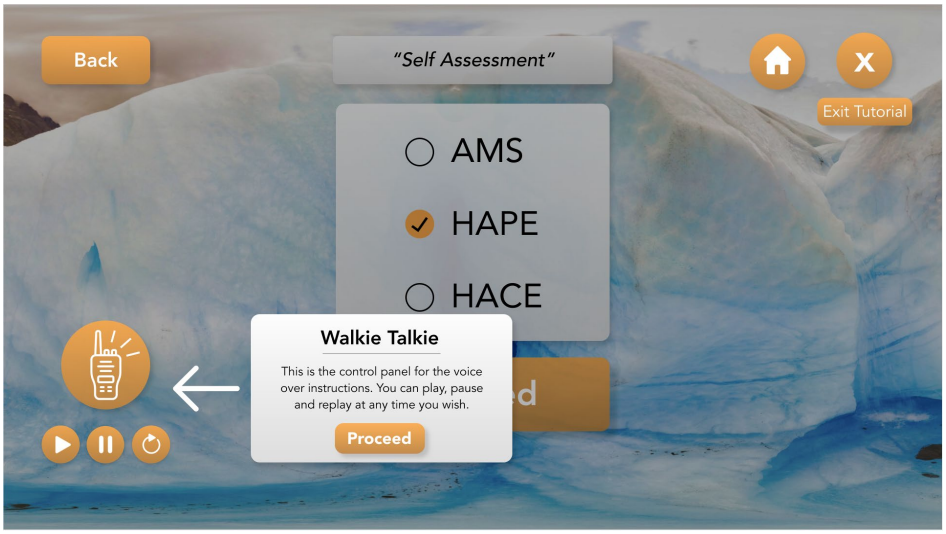
Tutorial page



As shown in Figure 3.9, a virtual instructor explains how to use the app through Walkie-Talkie prompts. In addition, the researcher verbally complements the app's instructions.

Figure 3.9

Self-Assessment page



An instructor explains how to use the app through Walkie-Talkie prompts. For example, it says: “Please select the appropriate answer from the multiple-choice options on the screen.” Participants must answer each question.

3.9 Data Validity

Ensuring data validity is a critical aspect of rigorous qualitative and mixed-methods research, particularly within the iterative framework of Design-Based Research (DBR). In this study, data validity was approached through multiple strategies to ensure that the findings are trustworthy, credible, and transferable across the contexts in which the VR intervention was implemented.

- Triangulation

To enhance the internal validity of the findings, data triangulation was employed by collecting information from multiple sources and methods. These included pre- and post-intervention questionnaires, semi-structured interviews, biometric feedback (e.g., heart rate variability), video recordings of VR engagement, and field observations. This methodological triangulation enabled cross-verification of data, reducing the risk of bias or overreliance on a single data stream.

- Theoretical Triangulation

The study also engaged in theoretical triangulation by interpreting findings through multiple learning theories—Kolb’s Experiential Learning Theory, Engeström’s Activity Theory, Heutagogy, and Authentic Learning. Applying different theoretical lenses enabled

a more comprehensive understanding of participant behaviours, cognitive engagement, and learning outcomes in response to the VR experience.

- Iterative Refinement and Member Checking

As a key feature of DBR, iterative refinement contributed to data validity by enabling the researcher to re-evaluate design elements while continuously considering emerging data. Insights from initial cycles were validated and further refined in subsequent iterations. Additionally, member checking was used during interviews and feedback sessions, allowing participants to clarify and confirm their responses, thereby ensuring that the data accurately reflected their intentions and experiences.

- Contextual and Cultural Validity

Given the bicultural nature of the study (New Zealand and Chile), attention was given to contextual validity. Instruments were reviewed and, where necessary, adapted to suit cultural and linguistic contexts. Stakeholder consultations and local expertise helped ensure that the questions, scenarios, and terminology were culturally appropriate and accurately understood by participants in both countries.

- Ethical Considerations and Researcher Reflexivity

To safeguard the ethical integrity and authenticity of the data, all participants provided informed consent, and ethical protocols were followed throughout the study. The researcher also engaged in ongoing reflexivity, maintaining a research journal to document assumptions, positionality, and potential influences on data collection and interpretation. This self-awareness strengthened the credibility and transparency of the research process.

- Transferability and Trustworthiness

Although the findings are specific to high-altitude mountaineering contexts, a thick description of the settings, participant demographics, and learning environments has been provided to support transferability. It allows other researchers or practitioners in similar high-risk training domains to evaluate the applicability of the design principles and findings to their contexts.

4.0 Ethical Consideration

Ethics approval for this research was obtained from Auckland University of Technology (AUT) Ethics Committee before any data collection commenced. The approved ethics application covered both research locations, allowing the study to be conducted in New Zealand and Chile under the same research protocol. The approval included participant recruitment, informed consent, data collection procedures, and the secure management of research data across both locations. Although the study was undertaken in two countries, the same ethical principles, participant information sheets, consent forms, and data management procedures were applied consistently throughout the research. Conducting the research in both New Zealand and Chile enabled the findings to be compared across different geographic and cultural contexts while maintaining the same ethical standards.

This proposed research was conducted with participants from NZAC (New Zealand Alpine Club), mountain guides in Wanaka and Queenstown, NZ Mountain Safety Council, DOC (Department of Conservation), expedition groups, and local guides from the Patagonia range (Chile). Experienced climbers were recruited from organisations in the climbing industry and mountain guide communities in high-altitude regions. Selected participants

had more than five years of experience in high-altitude mountaineering. The researcher advertised in mountain communities in New Zealand and Chile for expressions of interest from participants. The researcher then invited those interested in participating in the research via advertisements and email. Participants only helped the primary researcher collect data and didn't influence the study's outcome or process. Participants benefited from the research in mountain safety and risk management in high mountain ranges.

User testing of the VR learning app took place at AUT or at other more convenient locations for participants. Interviews were conducted in a safe and comfortable environment. The research followed safety protocols and confidentiality protocols to protect the privacy of participants and researchers. As the primary researcher was also an experienced mountaineer, they understand the participants' social and cultural context in mountain communities.

The written information document about the research was sent to participants before conducting user testing and interviews. The researcher sent participants the research consent in writing before the study. All information participants provide was confidential and wasn't revealed under any circumstances. The researcher followed confidentiality protocols. For example, hard copies of interview and focus group transcripts, consent forms, and video recordings will be stored in a locked cabinet in the primary supervisor's office on AUT's City campus, accessible only to the researcher. All data will be stored until the end of the PhD study, and no sooner than five years from the publication of the thesis; all transcripts and field notes will be shredded, and computer files deleted.

User testing took around 30 minutes, and interviews took. up to 1 hour. Participants didn't experience any discomfort or embarrassment during interviews. Participants were unlikely to experience risk or pain due to cultural, employment, or financial pressures. There was no conflict of interest or coercive influence between the researcher and participants.

4.1 Summary

This chapter has established the methodological foundation of the study, detailing how a Design-Based Research (DBR) approach was used to design, implement, and evaluate a Virtual Reality (VR) training intervention for high-altitude mountaineering safety education. The chapter has shown how each phase of the DBR cycle was informed by theoretical grounding, empirical evidence, and iterative refinement, ensuring a strong alignment between educational needs, technological development, and desired learning outcomes.

A mixed-methods strategy—combining interviews, biometric data, questionnaires, and thematic analysis—was employed to capture both the experiential and pedagogical dimensions of the intervention. The design was informed by Heutagogy, Authentic Learning, and Engeström's Third-Generation Activity Theory, which ensured that the VR intervention was not only technically innovative but also pedagogically robust and culturally responsive. Conducted in both Chilean and New Zealand contexts, the research addressed systemic challenges in outdoor safety education. It offered insights into how immersive technologies can facilitate learning in culturally diverse, high-risk environments.

Chapter 4: Intervention Development

4.1 Introduction

This chapter outlines the intervention phase of the study and details the development of a virtual reality (VR) application, drawing on the first two phases of Design-Based Research (DBR). It begins by situating the intervention within the socio-geographic contexts of New Zealand and Chile, explaining the rationale for selecting these sites and how they offer contrasting yet complementary perspectives on VR's potential in high-risk education.

Design-Based Research (DBR) was adopted as the methodological approach for this study. The terms Design-Based Research (DBR) and Educational Design Research (EDR) are used in the literature to describe closely related approaches that share an iterative process of designing, implementing, evaluating, and refining educational interventions in real-world settings (McKenney & Reeves, 2012). In this thesis, DBR is used as the primary term to describe the research methodology. EDR is used specifically when referring to the broader educational design research framework described by McKenney and Reeves (2012). The use of EDR in this context does not indicate a change in the methodology adopted for this study.

The DBR approach used in this study was informed by the Educational Design Research framework articulated by McKenney and Reeves (2012), which emphasises iterative design cycles, collaboration between researchers and practitioners, and the development of

practical solutions grounded in theory. Following the model introduced in Chapter 3 (see Figure 3.1), this chapter describes two sequential phases: analysis and exploration, and design and implementation.

In the analysis and exploration phase, the study undertook a comprehensive needs assessment in both countries. The analysis phase included situational analysis, SWOT evaluation, feasibility interviews with experienced climbers, and a review of literature related to mountain safety and immersive learning design. (Helms & Nixon, 2010). These processes refined the problem statement and informed the initial set of design principles underpinning the intervention.

The design and implementation phase focused on translating these insights into a prototype VR learning application. The prototype, which initially took the form of mock-ups and low-fidelity demonstrations, was iteratively refined through engagement with mountaineers and stakeholders in Chile and New Zealand. Two key training scenarios were prioritised: recognising dangerous weather conditions and identifying symptoms of altitude sickness. These scenarios were chosen for their high relevance to safety and their suitability for immersive simulation. An early prototype demonstration was developed and shared via Adobe Spark, showcasing the direction of the intervention.

Participants in both countries engaged with the VR prototype and provided feedback, which, alongside biometric data and observational analysis, informed further iterations. This process highlighted not only the usability and pedagogical potential of the VR tool

but also its limitations and the contextual adaptations required for cultural and geographic relevance.

In summary, this chapter documents the design, development, and initial deployment of the VR application during Phases 1 and 2 of the DBR process. It shows how theory, practitioner input, and empirical data combine to shape early intervention, setting the stage for the evaluation of outcomes and the refinement of design principles discussed in later chapters (see Chapter 8).

By combining theoretical grounding, situational analysis, and iterative design, the first two phases of the DBR framework established a robust foundation for the intervention. These phases ensured that the VR prototype was not developed in isolation but was shaped by the specific cultural, environmental, and pedagogical needs of New Zealand and Chile. Having introduced the rationale, methods, and early stages of prototype development, the next section (4.2) turns to the pre-intervention context, presenting the socio-cultural and geographic factors that informed both the design of the VR tool and participants' engagement with it. This contextualisation is critical for understanding how the intervention unfolded in practice and why the findings later diverged between the two cohorts.

4.2 Socio-Geographic Context of the Intervention: Chile and New Zealand

4.2.1 Socio-Geographic Context of the Intervention: Chile

According to the Chilean mountaineering guide company Adventure Alternative (Adventure Alternative 2023). Mountaineering in Chile: Guide and safety information. Chile is an excellent destination for mountaineering, offering diverse, challenging environments for mountaineers of all levels and a range of climbing options. Chile boasts a diverse range of mountain ranges, including the Andes, the world's longest continental mountain range, which offers numerous mountaineering opportunities. Nagy et al. (2023) and Clapperton (1994) point out that notable peaks include Ojos del Salado, at 6,893 m, the highest active volcano in the world, and Aconcagua, at 6,961 m, the highest peak outside of Asia. The country offers a range of climates and terrains, from the arid Atacama Desert, including Ojos del Salado in the north, to the icy glaciers of Patagonia, such as Torres del Paine, known for its stunning granite towers. According to Neate (1994), this area in Patagonia offers challenging climbs and is also renowned for its trekking circuits in the south. This diversity allows mountaineers to experience different climbing environments within the same country. Also, Chile's numerous active and dormant volcanoes, such as Villarrica and Osorno, offer unique climbing experiences.

Figure 4.1

The Andes. (Copyright www.chile.travel)



Figure 4.2

Aconcagua. (Copyright 2022 https://peakvisor.com)



Figure 4.3

Ojos del Salado. (Copyright 2019 https://www.adventurepeaks.com)



Figure 4.4

Torres del Paine, Patagonia (Copyright 2019 by Jin Hong)



In addition, Butorovic et al. (2003) note that diverse climatic conditions in Chile's mountainous regions make it an ideal place for studying weather patterns and their impact on mountain climbing. It includes research on how extreme weather conditions affect climbers and the associated risks of mountaineering. The varied ecosystems and biodiversity in Chile's mountains also offer opportunities to study the environmental impacts of mountain climbing and to support conservation efforts. Researchers can investigate how climbing activities affect local flora and fauna.

In addition, Chile has a well-established infrastructure to support mountaineering, including guided expeditions that facilitate the logistical aspects of conducting research in remote and challenging areas. Organisations like Chile Montaña offer specialised climbing tours and support for high-altitude expeditions. Chile has a rich history and culture of mountain climbing, with numerous local climbers and mountaineering communities, including the Federación de Andinismo de Chile (FEACH) and the Centro de Estudio en Montaña (CEM). This provides a wealth of knowledge and experience that can be invaluable for research.

Therefore, Chile is an excellent location for mountaineering research. Its varied geography—which encompasses high-altitude deserts, glaciers, and extensive mountain ranges—offers ample opportunities for studying mountaineering and related fields such as geology, climate science, and high-altitude physiology. The country's unique environmental conditions provide a natural laboratory for exploring the effects of altitude on the human body, the impacts of climate change on glaciers, and geological phenomena.

The accessibility of high-altitude areas and the diversity of terrain make Chile an ideal setting for both applied and theoretical investigations.

Equally important, Chile's mountaineering community represents a rich social and cultural base for this type of research. Organisations such as the Federación de Andinismo de Chile (FEACH), local climbing clubs, and newer academic centres like the Centro de Estudios de Montaña (CEM) play a key role in fostering training, mentorship, and cultural traditions around climbing. Many Chilean climbers participate in club-based training systems that blend experiential, community-led instruction with formalised courses. It creates a multi-voiced, collaborative culture of practice that aligns closely with the participatory ethos of Activity Theory. Engaging with this community ensures that VR interventions can be tested and refined across a broad spectrum of learners—from recreational novices in urban clubs to highly experienced alpinists with international expedition experience. Thus, Chile offers not only the geographic conditions but also the human capital necessary for meaningful, contextually grounded research in mountaineering education.

4.2.2 Socio-Geographic Context of the Intervention: New Zealand

New Zealand is renowned for its dramatic alpine landscapes, well-developed infrastructure, and rich mountaineering traditions, making it an exceptional location for both climbing and mountaineering research. The Southern Alps, which span the length of the South Island, are particularly significant. This range includes Aoraki/Mount Cook (3724 m)—the nation's highest peak—along with glaciers such as the Tasman, which provide unique

opportunities for technical ice climbing, glaciological study, and research on the effects of climate change (Heather, 2018; Booth & Cullen, 2001). New Zealand's mountains are also known for their rapidly changing weather conditions, creating a natural laboratory for investigating climbers' adaptive strategies, forecasting, and safety protocols.

Figure 4.5

The Southern Alps in New Zealand (Copyright https://www.virtualoceania.net)



Figure 4.6

Mt Aoraki/Cook. (Copyright 2019 by Jin Hong)



Equally important to the geography is the country's vibrant mountaineering community, which provides a rich pool of participants for educational research. Organisations such as the New Zealand Alpine Club (NZAC) and the Mountain Safety Council (MSC) play central roles in shaping training pathways and safety practices. This community fosters mentorship, volunteerism, and collaborative learning, ensuring that climbers of all levels—from beginners to advanced alpinists—engage in ongoing skill development. Such cultural features make New Zealand socially well-suited for VR-based interventions, as the technology can be trialed across diverse learner profiles, from novices seeking foundational awareness to experienced climbers refining advanced decision-making under stress.

The technical and cultural innovation fostered by these conditions is also notable. Challenging terrain and volatile weather have historically driven the development of specialised climbing techniques and equipment, providing a valuable context for studying safety and efficiency in high-risk environments. Mountaineering schools, clubs, and training programmes offer structured instruction, while the MSC provides accessible resources and courses focused on hazards such as avalanches, falls, and equipment misuse. These institutions not only support climbers but also create a framework within which immersive technologies can be aligned to existing safety curricula and educational practices.

Beyond mountaineering practice, New Zealand's alpine ecosystems add further research value. Fragile habitats in the Southern Alps support rare and endemic species, making them sensitive to human activity. Climbing in these regions raises important questions about environmental impact, including soil erosion, vegetation disturbance, and wildlife interactions. Researchers and outdoor organisations are increasingly linking mountaineering with conservation through initiatives such as invasive species control, habitat restoration, and Leave No Trace campaigns. It opens pathways for VR training to extend beyond technical safety by embedding environmental stewardship and ecological awareness into climbers' preparation.

Finally, New Zealand's infrastructure—including extensive hut networks, marked alpine routes, and accessible national parks such as Aoraki/Mount Cook and Fiordland—facilitates both climbing practice and academic research. These conditions make the country an ideal site for comprehensive studies that integrate physical, environmental,

cultural, and technical aspects of mountaineering. Taken together, New Zealand provides a rich, multi-layered context where VR-based training can be meaningfully developed, tested, and evaluated, bridging the domains of safety education, outdoor pedagogy, and conservation practice.

4.3 Pre-Research Workshop and Consultation in Chile and New Zealand

In April 2019, the researcher conducted an informal workshop in Chile with the local mountain guide community. Initially, the mountain guides were sceptical about using a prototype VR app for mountain training, believing that face-to-face training was the best method and doubting its benefits. To address these concerns, as part of a fieldwork research trip to Chile, the researcher and his supervisor organised and conducted a consultation workshop in Puerto Natales, Patagonia, to explain the purpose and potential advantages of the VR app for training (see Figures 4.8, 4.9).

During the informal workshop, the mountain guides were allowed to experience a prototype 360 VR app firsthand, showing alpine conditions along with overlayed information (see Figure 4.7 below). Following their interaction with the VR app, a discussion was held to gather their feedback. The response from the mountain guides was overwhelmingly positive. Many had never used a VR app for mountain training before, and they recognised that using a learning VR app could add significant value to their training regimen for various reasons.

This experience highlighted the potential for VR technology to complement traditional mountain training methods. The researcher gathered participants' suggestions and recommendations during the informal workshop in Chile. This evaluation and feedback on the prototype 360 VR app played a crucial role in conceptualising, designing and refining the VR application. The insights from the mountain guides significantly contributed to the development of the second stage of the VR app, ensuring it better met users' needs and expectations.

Figure 4.7

The 360 *VR Prototype app was used in the pre-research consultation workshop in April of 2019 in Puerto Natales, Chile. (Copyright 2019 by Jin Hong)*



Note: An early conceptual mock-up of the VR learning application is unavailable due to licensing restrictions and the discontinuation of the software used in its development.

Following the fieldwork in Patagonia in April of 2019, the researcher engaged in casual conversations with Peter Campbell, the former president of the New Zealand Alpine Club, a highly experienced mountain climber and a qualified mountaineering instructor. Peter expressed interest in the VR training app and wanted to participate in its development.

However, due to the onset of the pandemic and his circumstances, the conversation was halted. During rock climbing sessions, the researcher also had casual discussions with members of the NZ Alpine Club about the VR app. Through these conversations, the researcher gathered recommendations and suggestions, which were then used to further develop the prototype app. The feedback collected during these sessions was instrumental in refining and enhancing the VR training application.

Figure 4.8

View of the researcher while conducting an informal workshop in Puerto Natales in Chile with the local mountain guide community. (Copyright 2019 by Jin Hong)



Figure 4.9

A researcher conducted an informal workshop in Chile with the local mountain guide community. (Copyright 2019 by Jin Hong)



4.4 Development of VR as a Possible Solution

After conducting an informal pre-search consultation workshop with Chilean mountaineers in 2019, my intuition was confirmed that implementing a VR prototype educational app could simulate high-altitude environments in ways that traditional classroom or field-based instruction alone could not. These early conversations revealed both enthusiasm and scepticism: participants recognised VR's potential for training but also raised concerns about cultural relevance, usability, and the absence of physical stressors. Their feedback validated the premise that VR could be a valuable tool in mountaineering education if developed iteratively and in close collaboration with end users.

According to Radianti et al., (2020), the VR prototype application was designed to allow climbers to experience and respond to hazardous mountain conditions within a controlled simulated environment, enabling risk-free rehearsal of decision-making processes before entering real alpine settings. By exposing learners to simulated risk scenarios, the application aimed to strengthen decision-making skills and support cognitive and emotional preparedness before real-world expeditions. (Gaba, 2004).

The app was developed in collaboration with AUT's AppLab, following iterative cycles of prototyping, testing, and refinement. Early versions were rudimentary mock-ups designed to test feasibility and usability. Subsequent versions incorporated feedback from sample cohorts of climbers in both New Zealand and Chile, allowing the prototype to evolve into a more sophisticated tool. This iterative process, consistent with the DBR approach (McKenney & Reeves, 2012), ensured that the prototype remained responsive to user needs while grounded in established theoretical design principles.

4.4.1 Creation of the Virtual Scene

The AppLab design team used Unity 5.5 to develop a virtual reality (VR) simulation that replicates a high-altitude mountain environment for the training intervention. Released in 2016, Unity 5.5 represented a pivotal version of the widely adopted cross-platform game engine, offering substantial improvements in its virtual reality development capabilities. These included enhanced native VR support, advanced physics engines, and an upgraded particle system that enabled more realistic environmental effects such as snow, wind, and shifting weather conditions. These features made the platform particularly well-suited for

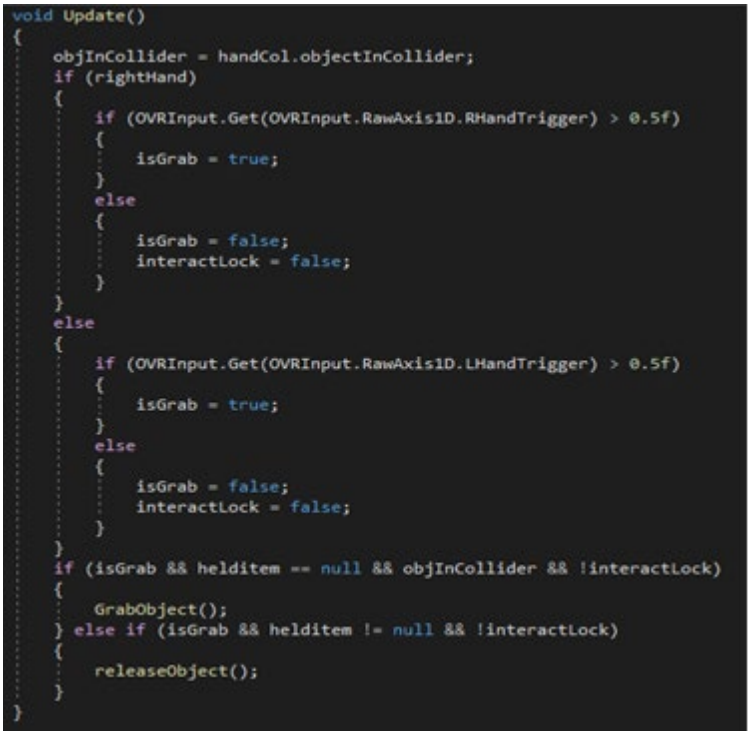
creating immersive and pedagogically valuable simulations in this study, where realism and interactivity were critical to learner engagement.

Using Unity 5.5, developers from the Auckland University of Technology's AppLab built the initial virtual mountain scenario, which simulated the challenges of high-altitude environments and integrated decision-making prompts relevant to mountaineering safety. Importantly, the simulation was not static; it was iteratively refined based on participant feedback. For example, during the Chilean intervention, participants identified audio-related limitations, such as environmental sounds that did not align with visual cues. In response, the development team incorporated adjustments to the audio design, synchronising environmental soundscapes more effectively with the visual simulation. This refinement not only improved realism, as noted by participants' accounts from the New Zealand cohort (see Chapter 7, Section 7.3.1 for details), but also enhanced the sense of presence—a key factor in immersive learning design.

By leveraging AppLab's technical capabilities alongside iterative user-informed adjustments, the study achieved a balance between technological sophistication and learner-centred responsiveness. This iterative process underscores how VR prototypes in educational research can evolve in alignment with participant insights, ensuring the simulation functions not only as a technical artefact but as a user-centred pedagogical tool capable of mediating authentic cognitive and emotional engagement with high-risk scenarios. The images below (Figure 4.11) illustrate a portion of the script developed to program a basic radio interaction, which was used to construct and simulate a virtual high-altitude mountain environment within the VR prototype.

Figure 4.11

The script for the basic radio interaction



```
void Update()
{
    objInCollider = handCol.objectInCollider;
    if (rightHand)
    {
        if (OVRInput.Get(OVRInput.RawAxis1D.RHandTrigger) > 0.5f)
        {
            isGrab = true;
        }
        else
        {
            isGrab = false;
            interactLock = false;
        }
    }
    else
    {
        if (OVRInput.Get(OVRInput.RawAxis1D.LHandTrigger) > 0.5f)
        {
            isGrab = true;
        }
        else
        {
            isGrab = false;
            interactLock = false;
        }
    }
    if (isGrab && helditem == null && objInCollider && !interactLock)
    {
        GrabObject();
    } else if (isGrab && helditem != null && !interactLock)
    {
        releaseObject();
    }
}
```

This Unity C# script (See Figure 4.11) demonstrates the logic for enabling hand-based interaction with virtual objects, such as a radio, within the VR mountaineering training environment. The script detects whether the right- or left-hand trigger on the Oculus Quest 2 controllers is pressed beyond a threshold (0.5f). When pressed, the variable isGrab is set to true, allowing the participant to grasp and interact with an object. If released, the script resets isGrab and unlocks interaction. The code also manages the conditions under which an object can be grabbed (GrabObject()) or released (releaseObject()), based on whether the user's hand collider overlaps with the object collider (objInCollider) and whether an item is already being held (heldItem). This basic interaction framework

underpinned participants' ability to manipulate objects in the simulation, supporting immersive, hands-on engagement with safety-critical equipment and scenarios.

Figure 4.12

Unity Editor screenshots - the basic radio interaction



The image above (Figure 4.12) shows the Unity development interface during the prototyping phase of the VR intervention. The 3D alpine environment, featuring snow-covered terrain and mountainous backdrops, is rendered in the Scene view.

Figure 4.13

Unity Editor screenshots - pre-climb scene 2



Figure 4.13 shows the Unity development environment used to create the Pre-Climb Scene 2 of the VR mountaineering safety training prototype. The scene depicts a simulated alpine environment with snow-covered terrain, distant mountain ranges, and an orange tent as a key focal point. The Unity interface illustrates the placement of objects and environmental assets within the 3D space, including directional lighting, fog effects, and camera positioning.

Figures 4.14 and 4.15 show the entry screen of the prototype VR educational app designed for mountaineering safety training. The main interface invites users to begin the High-Altitude Mountain Sickness (HAMS) test by selecting Proceed. The app introduces learners to different simulated scenarios of altitude-related illness and asks them to identify symptoms and recommend appropriate treatments. Key navigational elements

are positioned around the interface: a Back button for returning to the previous screen, home and information icons (top-right) for navigation and guidance, and a large Proceed button (bottom centre) to launch the test. Additional controls at the bottom left include communication tools (radio icon), playback, pause, and restart options. A real-time biometric feedback indicator is visible in the bottom-right corner, displaying a heart rate of 104 BPM, integrated to enhance immersion and user self-awareness. The background features a panoramic alpine environment, reflecting the real-world mountaineering contexts simulated in the app. This interface was iteratively refined during the design-based research process to ensure usability, clarity, and pedagogical alignment with the training objectives.

Figure 4. 14

The interface of a prototype App - main page

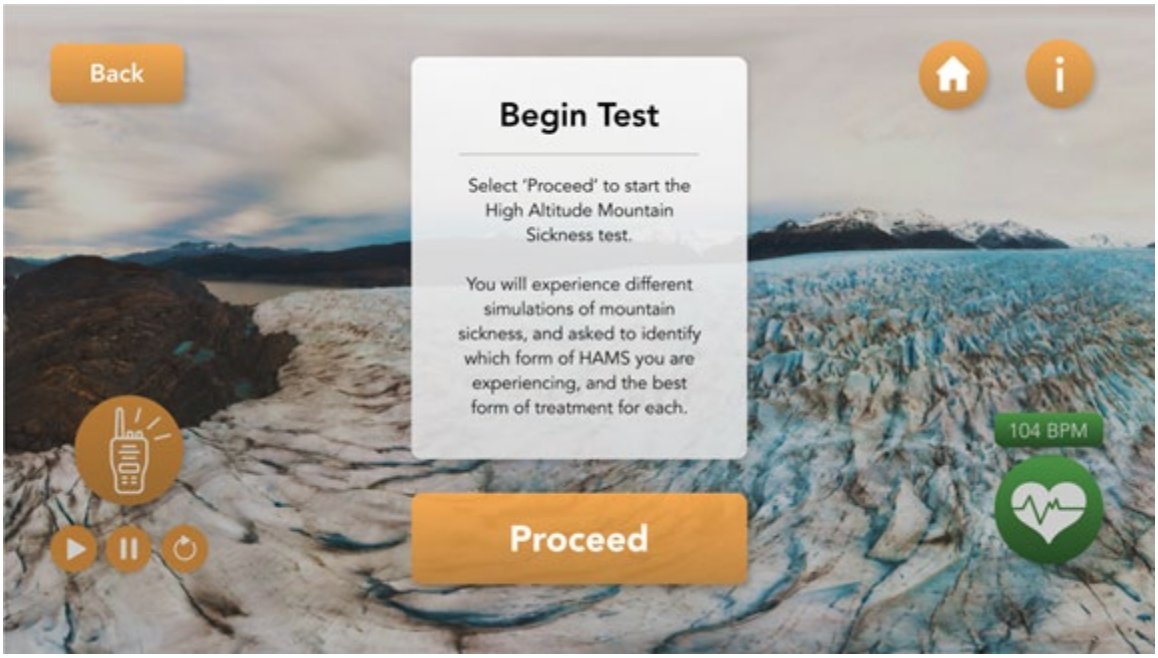
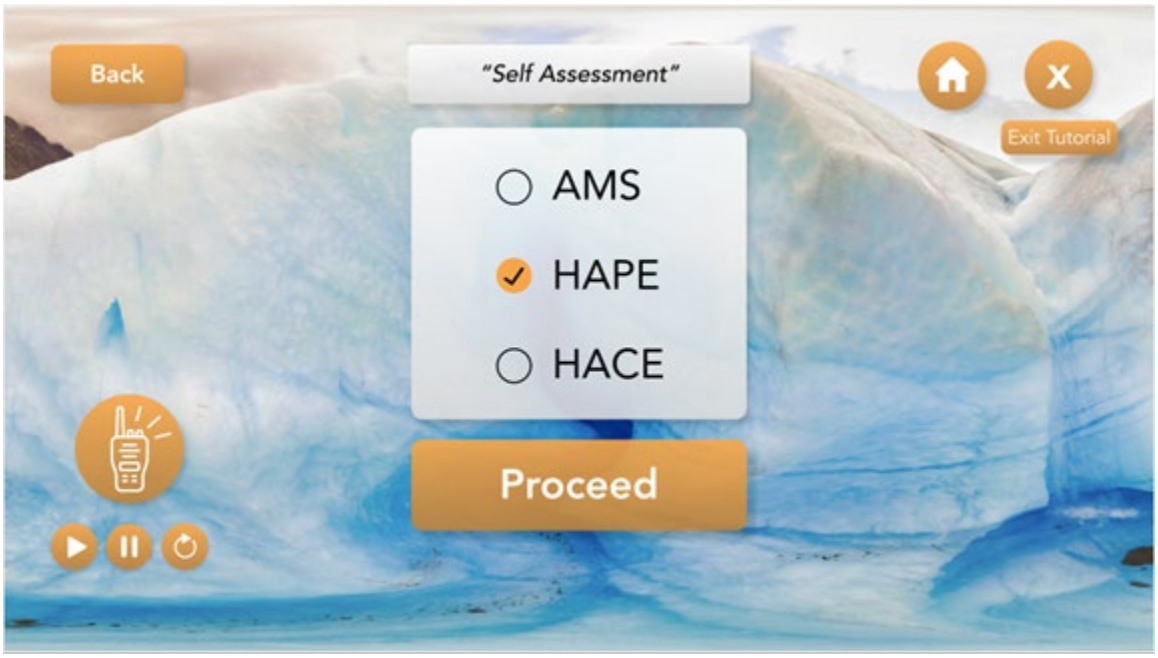


Figure 4. 15

The interface of a prototype App - questions



4.4.1.1 Visualisation of the VR Prototype and Intended User Experience

The images presented above illustrate key stages in the development of the VR prototype, offering insight into both the technical implementation and the educational intentions that guided its design. The screenshots taken from the Unity Editor (Figures 4.11–4.13) demonstrate how mountaineering scenarios were gradually modelled and refined to simulate realistic alpine environments. These environments include pre-climb camp scenes, mountain ridges, and interactive elements such as radio communication devices. Together, they formed the basis for immersive learning tasks that positioned the user not as a passive viewer but as an active decision-maker.

From a user experience (UX) perspective, the VR system was designed to promote presence and engagement by recreating common but high-risk scenarios encountered in mountaineering. Participants were expected to interact with virtual artefacts (e.g., radios, environmental cues, biometric feedback) to make critical decisions, such as identifying symptoms of altitude sickness or assessing the impact of sudden changes in weather. By situating learners in contexts that demanded judgment under pressure, the VR application sought to strengthen both cognitive rehearsal and emotional preparedness—dimensions that traditional classroom instruction alone cannot fully address.

4.4.1.2 Informing the Interface Design

The interface design shown in Figure 4.14, the Begin Test screen, reflects an iterative co-design process informed by literature on immersive learning, pre-study workshops in Chile and New Zealand, and early user feedback sessions. The clean and minimalist layout was chosen to reduce cognitive load while foregrounding the central learning task. Key navigation elements (Back, Home, Information) were positioned for accessibility, while large, high-contrast buttons supported ease of use, even for novice VR participants. The integration of real-time biometric feedback (heart rate monitoring) was based on evidence that physiological awareness can enhance emotional immersion and self-regulation (Makransky & Lilleholt, 2018). The decision to embed this data visually in the interface enabled learners to monitor their stress levels while engaging with demanding scenarios, thereby reinforcing the link between physical and cognitive states.

4.4.1.3 Simulation Content and Contextual Choices

The simulation environments shown in these images depict generic alpine landscapes rather than specific mountains. This decision was deliberate: while realism was important for immersion, the prototype prioritised creating adaptable environments that could resonate with participants in both Chile and New Zealand. Using generic representations avoided privileging one national or geographic context over another, while still embedding recognisable features such as glaciers, snowfields, and alpine camps. This design choice reflects the principle of cultural neutrality with contextual flexibility, allowing the VR tool to be adapted for multiple regions without requiring a complete redesign.

At the same time, certain modules incorporated region-specific cues during later iterations (e.g., avalanche warnings for New Zealand, rockfall risks in Chile), ensuring that the learning remained authentic to each mountaineering community's experiences. The overarching aim of these simulations was not to perfectly replicate physical conditions such as altitude or cold, but to model the decision-making environments that climbers encounter—balancing risk awareness, teamwork, and ethical judgment in moments of stress.

Together, these images and interfaces demonstrate how the VR prototype evolved from conceptual sketches into a functional, immersive training tool capable of addressing core challenges in mountaineering education. They highlight the way design principles, cultural context, and user feedback were woven into the development process. The following

section now turns to the implementation of this prototype in intervention studies across Chile and New Zealand, examining how climbers engaged with the system in practice and how their feedback further shaped the refinement of design principles.

4.4.2 Virtual Reality Devices

For the VR prototype, the study used the Oculus Quest 2 (see Figure 4.16) to deliver the VR intervention sessions in both Chile and New Zealand. As a standalone, all-in-one virtual reality system, the device eliminated the need for external sensors or a tethered computer, making it highly portable and well-suited for deployment across multiple venues. However, this advantage comes with trade-offs: standalone headsets typically offer lower graphical fidelity, reduced resolution, lower refresh rates, and limited processing power, which can lead to less crisp visuals or reduced environmental detail. Some users reported that textures appeared more blurred or that lighting effects were less realistic than in PC-tethered systems. Such technical limitations may reduce perceived realism and the sense of presence, both of which have been identified as important factors influencing engagement and learning outcomes in immersive virtual environments. (Makransky & Lilleholt, 2018; Radianti et al., 2020).

In both countries, the headset enabled participants to experience the virtual high-altitude environment with freedom of movement, supported by advanced motion tracking that allowed the simulations to adapt responsively to user actions (See Chapters 6 and 7). The integrated high-quality spatial audio further enhanced immersion by providing environmental soundscapes, such as wind and snow, that aligned with visual and

interactive cues. This combination of mobility, accessibility, and sensory realism made the Oculus Quest 2 an effective tool for introducing VR-based mountain safety training to diverse cohorts in Chile and New Zealand, ensuring consistency in user experience despite geographical and institutional differences.

Figure 4.16

VR device used during the intervention. - Oculus Quest 2



4.5 A Room Set-Up

The intervention study was conducted in a controlled indoor environment that allowed for both immersive engagement with the VR application and systematic observation of participant behaviour. To capture multimodal data, the room's physical setup was carefully designed and standardised across sessions.

A digital video camera mounted on a tripod was positioned on either the left or right side of the room, depending on available space and lighting conditions. It ensured that the participant's body language, physical movements, and interactions with the VR equipment could be recorded for later observational analysis (see Section 3.4.2 for a detailed description of the observation protocol). The placement of the camera (GoPro camera) was intentionally chosen to minimise distraction for participants while maintaining a clear field of view of the headset, handheld controllers, and overall posture.

Each intervention session involved three individuals: the participant, the researcher, and a research assistant. The participant engaged directly with the VR simulation, while the researcher facilitated the session, provided instructions, and monitored safety. The research assistant was primarily responsible for technical oversight, including managing recording equipment, monitoring biometric data, and assisting with troubleshooting. This triadic arrangement ensured smooth session flow while allowing the researcher to focus on participant engagement and observation. Figure 4.17 (below) illustrates this room configuration.

The gear set-up within the intervention space included three main components:

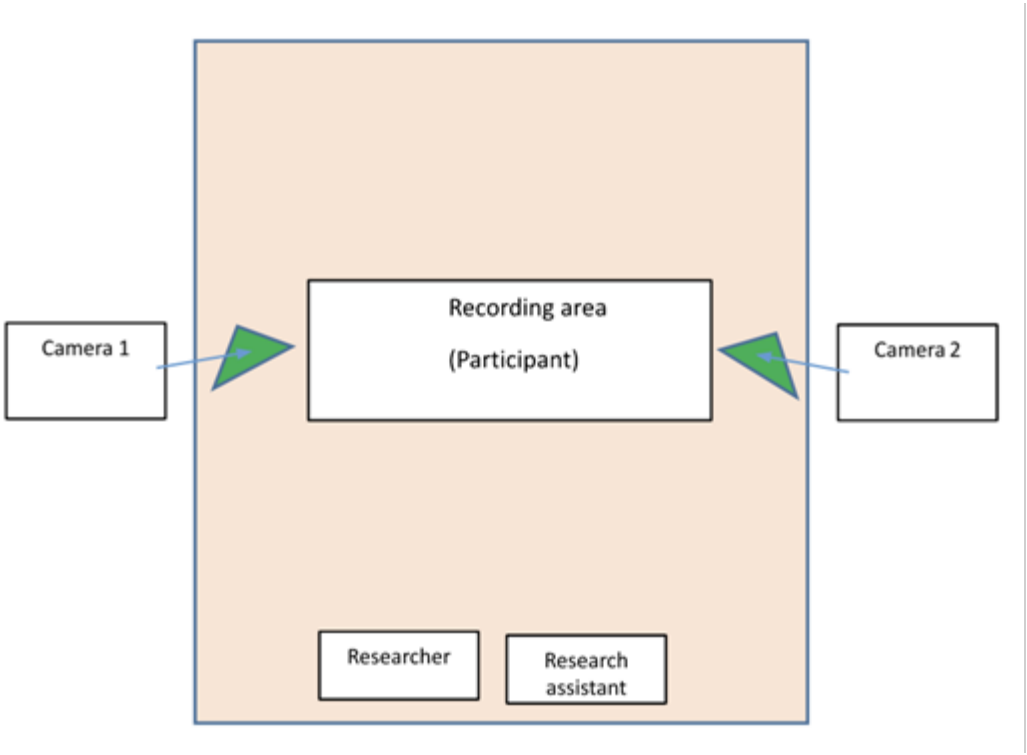
- VR Hardware: The Oculus Quest 2 headset was used as the primary VR device. It provided immersive visual and auditory input, allowing participants to experience the designed mountain safety training scenarios. The headset's portability and ease of use made it well-suited for use across multiple research sites (New Zealand and Chile).

- Video Recording System: A fixed-position video camera on a tripod captured each session. This recording served as an observational tool to track participant behaviour, gestures, and signs of immersion or discomfort.
- Biometric Data Collection: A Suunto watch was made available to participants to collect biometric measures such as heart rate. It allowed the study to assess physiological responses to stressful or high-stakes scenarios within the VR environment.

During each session, participants simultaneously wore the VR headset and the biometric watch. This dual setup enabled the study to capture both subjective user experiences (via post-session interviews and questionnaires) and objective physiological data. Together with the observational video, these instruments created a multimodal dataset that triangulated cognitive, emotional, and behavioural engagement.

Figure 4.17

A VR app prototype setup



4.6 The VR Intervention Procedure

The intervention process was designed to introduce participants to a controlled yet immersive high-altitude mountaineering simulation of acute mountain sickness (AMS) via virtual reality (VR). The sequence of activities unfolded in several stages to ensure consistency, participant safety, and reliable data collection across both the Chilean and New Zealand cohorts, as follows:

1. Orientation and onboarding
2. Pre-Intervention data collection

3. Intervention - Immersive VR exposure
4. Observation and monitoring
5. Post-Intervention data collection
6. Interview: Feedback and reflection

1. Orientation and Onboarding

Participants began the intervention with a structured introduction to the VR equipment and procedures. The researcher outlined the purpose of the simulation, explained the safety protocols, and provided detailed instructions on how to operate the Oculus Quest 2 headset and handheld controllers for 15 minutes. A short tutorial session was included to familiarise participants with basic navigation within the virtual environment, as illustrated in Figures 4.18 and 4.19 below. In Chile, some participants experienced difficulties as all onboarding and VR instructions were provided in English. To address this challenge, a local researcher assisted by interpreting key information during the orientation. Several participants also recommended that future versions of the application include a Spanish-language option to enhance accessibility and usability.

Figure 4.18

A local researcher assisting a participant during the onboarding process in Chile. (Copyright 2023 by Jin Hong)



Figure 4.19

A researcher assisting a participant during the onboarding process in NZ. (Copyright 2023 by Jin Hong)



2. Pre-Intervention Data Collection

Before participants entered the simulation, two preparatory steps were undertaken. For the first, the pre-intervention survey, participants completed a short questionnaire designed to establish baseline measures of their demographic background, climbing experience, prior training, familiarity with VR technologies, and self-perceived confidence in responding to mountain safety challenges. This survey provided important contextual data, enabling comparisons across user groups (e.g., novices vs experienced climbers; Chilean vs New Zealand participants). It also captured attitudinal dimensions, such as perceptions of VR's usefulness for safety training, which later informed the analysis of post-intervention reflections. It took around 5 - 10 minutes.

Following the survey, biometric data were recorded using a Suunto wearable watch (see Figure 4.20). Each participant's resting heart rate (HR) was measured in a calm, seated state before donning the VR headset. It took around 2 - 3 minutes. This step established a physiological baseline against which post-intervention responses could be compared. By combining survey and biometric baselines, the study sought to integrate both subjective (self-report) and objective (physiological) measures of engagement and learning preparedness.

Figure 4.20

A research assistant fitting a participant with a Suunto watch for biometric feedback in NZ. (Copyright 2023 by Jin Hong)



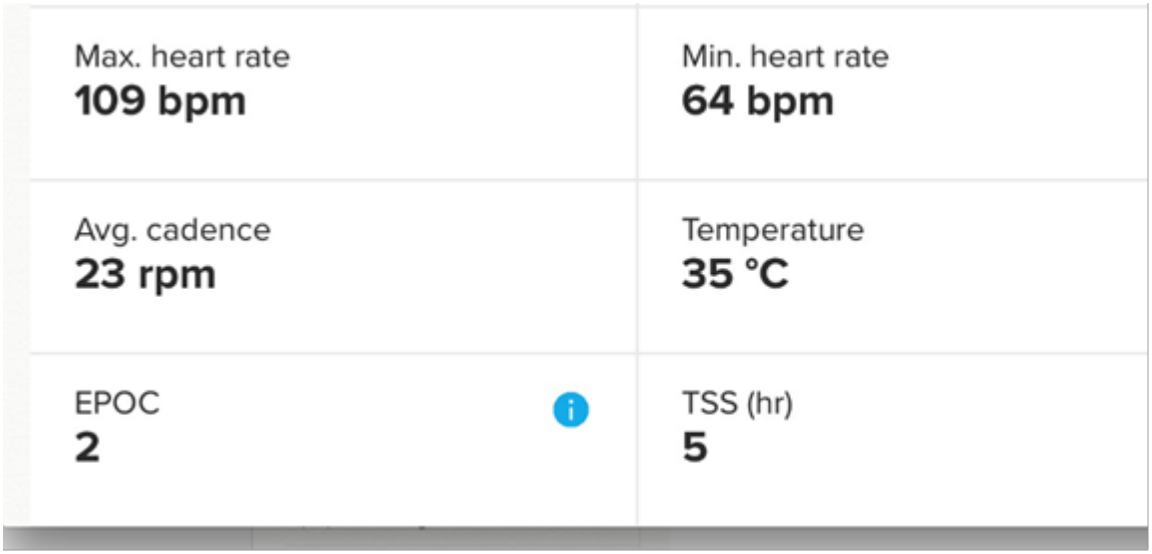
As part of the VR session, heart rate was measured to assess physiological changes. The majority of participants exhibited elevated HR during the VR session, suggesting increased arousal or stress associated with the immersive experience. Figure 4.21 below shows biometric data recorded during the intervention phase using a Suunto wearable device. Key metrics include maximum heart rate (109 bpm), minimum heart rate (64 bpm), average cadence (23 rpm), body temperature (35°C), excess post-exercise oxygen consumption (EPOC = 2), and training stress score (TSS = 5 hr. equivalent).

This data illustrates how participants' physiological responses were monitored during their engagement with the VR simulation. For example, the increase from a resting heart rate baseline (64 bpm) to a maximum of 109 bpm indicates heightened arousal and engagement during the virtual experience. Although the VR simulation does not involve physical

exertion comparable to real-world climbing, the increase in heart rate suggests that the immersive simulation elicited measurable physiological arousal, commonly associated with emotional engagement and perceived realism in simulated training environments. (Meehan et al., 2002). The cadence and temperature values are contextual artefacts of the wearable system. While cadence (23 rpm) is not directly meaningful in the VR context, the metric was generated by the device's default sports-training mode. Body temperature, however, provides a stable physiological baseline, confirming that changes in heart rate were not attributable to overheating or external conditions.

Figure 4.21

Interface of the Suunto application displaying a participant's heartbeat during the VR intervention in Chile



3. Immersive VR Exposure

Participants then engaged with the VR prototype, which simulated a high-altitude mountain environment. Built in the Unity 5.5 development environment, the simulation incorporated audiovisual elements such as wind, environmental noise, and interactive decision-making prompts. The core scenario focused on acute mountain sickness (AMS), chosen as the sole high-risk case for this prototypical version of the application. During the simulation, participants navigated through decision-making tasks and risk-assessment prompts designed to mirror the cognitive and emotional pressures of real mountaineering, as illustrated in Figure 4.22 below.

Figure 4.22

A participant engaging with the VR application during the intervention in New Zealand. (Copyright 2023 by Jin Hong).



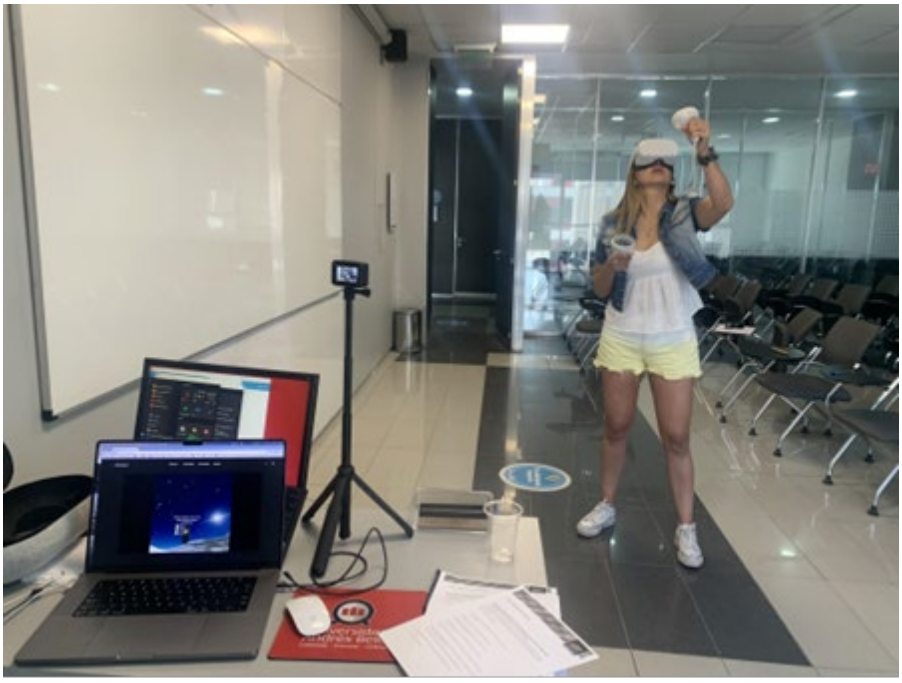
The image above (Figure 4.22) shows a participant actively using the VR training application during the intervention study conducted in New Zealand. The participant was wearing a Meta Quest 2 headset and holding motion controllers, which enable interaction with the simulated alpine environment. On the projection screen, the VR interface was mirrored, showing the mountain terrain and the instructional overlays that guide users through the training sequence. This mirroring allowed both researchers and observers to monitor the participant's progress and engagement in real time.

4. Observation and Monitoring

Throughout the VR sessions, the researcher carefully observed participant behaviour and responses, documenting the process. Observational data were supported through video recordings and written field notes, enabling the researcher to document behavioural responses and contextual interactions during the intervention. (Creswell & Poth, 2018). These observations provided complementary qualitative data to contextualise physiological responses. Figure 4.23 below shows the observation and monitoring of a participant during the VR intervention in Chile.

Figure 4.23

Observation and monitoring of a participant during the VR intervention in Chile. (Copyright 2023 by Jin Hong)



5. Post-Intervention Data Collection

Immediately after the VR simulation concluded and the Meta Quest 2 headset was removed, a secondary phase of data collection was conducted to capture the immediate physiological and psychological effects of the immersion. First, the researcher recorded the participant's post-intervention heart rate using the Suunto wearable device. This measurement was taken while the participant remained seated to ensure that any increase in HR could be attributed to the "cognitive and emotional stress" of the AMS scenario rather than to physical movement. As noted in Figure 4.20, comparing these terminal metrics against the resting baselines established in Stage 2 allowed the researcher to quantify the level of psychological fidelity achieved by the simulation.

6. Interview: Feedback and Reflection

Following the intervention, participants engaged in a post-intervention interview. This step captured their subjective impressions of the VR experience, including perceived realism, usability, strengths, and limitations. Chilean participants tended to provide detailed, experience-driven critiques focused on environmental realism and decision-making fidelity, while New Zealand participants emphasised accessibility, safety, and the simulation's introductory learning value. These findings are discussed further in Chapters 6 and 7.

4.7 Summary

Chapter 4 outlines the systematic development of a virtual reality (VR) intervention for high-altitude mountain safety education, utilising a Design-Based Research (DBR) framework. This framework draws on the model proposed by McKenney and Reeves (2012). The chapter begins by justifying the selection of two socio-geographically distinct contexts—Chile and New Zealand, both of which offer diverse alpine environments and established mountaineering cultures. These locations provided contrasting yet complementary settings for exploring how immersive learning technologies can be applied in high-risk, outdoor educational environments.

The intervention followed two iterative DBR phases: Analysis and Exploration, and Design and Implementation. In the first phase, the researcher conducted stakeholder consultations with experienced mountaineers and training organisations in both countries (e.g., NZAC, FEACH). Informal workshops and interviews revealed varying levels of technological readiness and cultural perceptions of risk, which directly informed

the initial design of the VR. Feedback from these sessions helped identify critical learning scenarios, such as recognising weather patterns and symptoms of altitude sickness.

The second phase focused on prototyping and testing the VR app. In both Chile and New Zealand, the app was introduced to key participants using Oculus Quest 2 headsets in controlled environments. The intervention incorporated immersive VR scenes created in Unity, biometric feedback collection, and observational data. This phase was crucial for evaluating both the usability and pedagogical effectiveness of the prototype. Participants engaged in guided scenarios that replicated high-risk mountaineering conditions, and their feedback guided iterative improvements to the application.

The Chilean intervention involved structured user sessions, technical testing, and preliminary cognitive-behavioural immersion procedures. Meanwhile, the New Zealand intervention similarly emphasised technical validation and user feedback but faced delays due to the COVID-19 pandemic, which interrupted collaboration with local stakeholders. Throughout the chapter, the research highlights how emerging insights from participant interactions informed the continuous refinement of the VR intervention, in line with DBR principles of iterative solution testing. The process revealed practical challenges—such as interface usability, headset discomfort, and context-specific needs—and validated the VR app's educational potential.

Ultimately, Chapter 4 establishes a foundation for linking theoretical design principles with empirical feedback, setting the stage for the deeper thematic analysis presented in Chapters 5 to 7. The chapter underscores the importance of culturally responsive design,

iterative testing, and stakeholder co-creation in developing immersive learning tools for high-risk outdoor education.

Chapter 5: Pre-Intervention Findings

5.1 Introduction

I chose the Educational Design Research framework because it supports the iterative development and evaluation of educational interventions while generating both practical solutions and theoretical knowledge. Its three phases—Analysis and Exploration, Design and Construction, and Evaluation and Reflection—aligned well with my goal of designing, refining, and evaluating a VR learning environment, ultimately leading to evidence-based design principles for mountain safety education.

The pre-intervention phase of this study is meticulously aligned with the "analysis and exploration" stage of the McKenney and Reeves (2012) EDR model. The analysis and exploration phase establishes a detailed understanding of the problem context before any prototype intervention is designed or implemented. Drawing on the EDR model developed by McKenney and Reeves (2012) (see Figure 3 in Chapter 3), this chapter presents the 1st phase, analysis and exploration, thoroughly examining the problems to be addressed in Chile and New Zealand pre-intervention. This model typically involves an iterative process with key phases: analysis and exploration, design and construction, and evaluation and reflection. EDR is an iterative methodology that uniquely blends rigorous scientific inquiry with the systematic development of practical solutions to complex educational challenges.

Educational Design Research emphasises the simultaneous development of theoretical understanding and practical solutions to real-world educational problems (McKenney &

Reeves, 2012). It is often achieved through close collaboration between researchers and practitioners in authentic, real-world settings. This dual objective ensures that the research outcomes are not only methodologically sound but also highly relevant and impactful for educational practice. The EDR process is characterised by continuous iterative cycles. The iterative nature of EDR enables researchers to refine interventions continuously while ensuring their relevance and effectiveness in authentic educational contexts. This approach implicitly acknowledges the dynamic and complex nature of educational environments, where a "one-size-fits-all" solution is rarely optimal. The iterative cycles facilitate continuous feedback loops, enabling researchers to revise aspects that may not be conducive to learning and ensure the solution is contextually sensitive and robust, thereby increasing its likelihood of adoption and sustained use in practice. It offers a significant advantage over linear research models that might produce theoretically elegant but practically unworkable solutions, ultimately enhancing the long-term impact and relevance of the research findings.

This chapter addresses the 'analysis and exploration' phase, as it directly relates to the pre-intervention activities described. The pre-intervention phase is especially important because it provides a baseline of participants' knowledge, attitudes, or behaviours before any changes are introduced—allowing researchers to accurately measure the impact of the intervention by comparing before-and-after results. The intervention phase introduces the core experimental element—the VR application—while the post-intervention phase focuses on measuring immediate effects and gathering qualitative reflections. The very purpose of having distinct pre- and post-intervention phases is to enable a direct comparison of participant states or outcomes before and after the intervention. This

comparison is fundamental to inferring the intervention's effect. The baseline data provide the initial state against which post-intervention changes are measured, thereby supporting the evaluation of effectiveness by providing clear comparison points and allowing for stronger claims about the intervention's influence.

During the pre-intervention stage, the researcher aims to assess participants' initial responses to the use of VR technology in high-altitude mountaineering. This analytical approach is used to refine the problem statement, ensuring that participants and the researcher have a shared understanding of the problem before progressing to the second phase, which involves prototyping the intervention.

The pre-intervention survey primarily assesses participants' understanding of virtual reality (VR) technologies in high-risk education in Chile and New Zealand. The survey covers demographic questions, prior experience, and educational background in high-altitude mountaineering. The primary objective of the pre-intervention questionnaire was to systematically collect foundational baseline data concerning participants' mountaineering experiences, training histories, accident involvement, familiarity with virtual reality (VR) technologies, and perceptions of VR-assisted mountain safety education in Chile and New Zealand. Collecting this multidimensional data was critical for informing the design of an educational intervention that is not only evidence-based but also tailored to the specific needs, abilities, and prior experiences of the target climbing community. The research sought to maximise relevance, engagement, and potential impact by adopting a participant-centred design approach.

Before implementing the intervention, participants completed a questionnaire to assess their baseline knowledge, attitudes, and behaviours regarding VR technology in high-altitude mountain training. This data provided a foundation for understanding their initial perspectives and for identifying areas requiring targeted support for high-risk education.

As explained, the intervention in this research comprised three data-collection phases.

- The pre-intervention phase was based on a questionnaire survey.
- The intervention phase was based on participants' use of the VR app.
- The post-intervention phase consisted of an interview

conducted immediately after participants used the VR app.

To provide a clear, concise overview of the study's structure, the following table summarises the intervention phases and their associated data collection methods.

Table 5.1

Research Intervention Phases and Data Collection Methods

Phase	**Primary Activity & Method**	**Purpose**
Pre-intervention	Questionnaire Survey	Establish foundational baseline knowledge, attitudes, and perceptions.
Intervention	VR App Use and Observation	Deliver the VR-based educational intervention in high-altitude mountaineering.

Post-intervention	Interview	Evaluate immediate impact, gather qualitative insights, and assess changes in perceptions and experiences.

The pre-intervention survey was conducted in Chile in January 2023 and in New Zealand in May 2024. The total number of participants is 20, with 10 in each country.

5.2 Questionnaire Design and Methodology

As described in Section 3.4.1, the 18-item pre-intervention questionnaire (see Appendix G) collected baseline information about participants' mountaineering backgrounds, previous training and experience, exposure to mountain-related risks, and familiarity with VR technology. This section presents the questionnaire findings from participants in Chile and New Zealand.

5.3 Participant Demographics in Chile

The pre-intervention survey for the Chilean cohort was conducted between 27 January and 4 February 2023 in Vina del Mar and Santiago in Chile. A total of ten participants completed the pre-intervention questionnaire. There were no participants under 20 or over 60. The cohort is thus characterised by a relatively young-to-middle-aged adult population, typically considered to be in peak physical condition for demanding outdoor activities. The group included five males and five females with a mean age of 37.4 years.

Table 5. 2

Gender Distribution

Male	5
Female	5

Table 5.3

Age Distribution

20–30 years	5
30–40 years	4
40–50 years	1

5.3.1 Climbing Experience and Self-Assessment

The pre-intervention survey predominantly consisted of individuals with moderate to extensive climbing experience, indicating a high baseline level of engagement with mountaineering. The majority (approximately 73%) identified themselves as advanced or professional climbers, with most having more than 5 years of experience. Two participants were mountain guides and rock-climbing and mountaineering instructors.

5.3.1.1 Climbing Locations

Participants reported extensive experience across diverse terrains, including the Central Andes, Patagonia, and coastal and inland ranges in Chile and Argentina. This geographical diversity underscores broad exposure to diverse mountaineering environments.

5.3.1.2 Years of Climbing Experience

Participants' climbing experience ranged widely, with one participant being a new climber (less than 1 year), three having 1–5 years of experience, two with 5–10 years, three with 10–15 years, and one participant having 20–30 years of experience; no participants reported more than 30 years of experience.

Table 5. 4

Years of Climbing Experience

Years experience	**Participant**
New Climbers (<1 year)	1
1-5 years	3
5-10 years	2
10-15 years	3
20-30 years	1
Over 30 years	0

5.3.1.3 Self-reported Skill Level

Regarding skill level, participants reported varying levels: one as a beginner, two as intermediate, five as advanced, and two as professional climbers.

Table 5. 5

Self-reported skill level

Skill level	**Participant**
Beginner	1
Intermediate	2
Advanced	5
Professional	2

5.3.2 Training and Qualifications

Respondents with qualifications held a range of certifications, including hiking guide accreditations and professional climbing certifications. Although almost all participants had experience at high altitudes, formal training in specialised high-altitude techniques was significantly lacking, indicating a potential area of vulnerability.

5.3.2.1 Sources of Mountain Training

Some participants learned their mountaineering skills in training schools and local mountain clubs. They first learned skills from local mountain clubs and then expanded their skills and knowledge in training schools. Also, some of them learned climbing skills from their climbing partners and friends.

Table 5. 6

Sources of Mountain Training

Training sources	**Participant**
Outdoor institutions/training schools	8
Local mountain clubs	5
Climbing partners (informal mentorship)	3

5.3.2.2 Formal Mountaineering Qualifications

Eight participants reported holding formal mountaineering qualifications, while two did not.

Table 5. 7

Formal Mountaineering Qualifications

Yes	8
No	2

5.5.2.3 High-Altitude Climbing Experience (>3000m)

In terms of high-altitude experience, nine participants had climbed at elevations exceeding 3,000 meters, while one participant had not.

Table 5. 8

High-Altitude Climbing Experience (>3000m)

Yes	9
No	1

5.3.2.4 Formal High-Altitude Training

Two participants reported having received formal high-altitude training, while eight had not.

Table 5. 9

Formal High-Altitude Training

Yes	2
No	8

5.3.3 Incident History and Risk Perception

5.3.3.1 Experience of Accidents

Four participants reported experiencing a climbing-related accident, while six had not. Incidents included critical conditions such as frostbite and hypothermia, highlighting the real-world risks participants face.

Table 5. 10

Experience of Accidents

Yes	4
No	6

5.3.3.2 Perceived Primary Causes of Accidents

When asked about the perceived primary causes of climbing accidents, participants most cited mountaineers' mistakes (eleven responses), followed by natural forces (two responses); no participants identified gear failures as a primary cause. Participants emphasised human error as the dominant cause of mountain accidents. Human error was most frequently identified as the primary cause of accidents, a finding consistent with previous research on mountaineering incidents (Furrer & Nigg, 2018; McCammon, 2004).

Table 5. 11

Primary Causes of Accidents

Mountaineers' mistakes	11
Natural forces	2
Gear failures	0

5.3.3.3 Common Mistakes at High Altitude Identified

Participants identified several common mistakes at high altitude, including improper equipment use, deficient decision-making processes, inadequate acclimatisation protocols, and insufficient preparation or underestimation of natural hazards. Analysis of the pre-intervention survey data indicated that participants commonly observed the following errors occurring in high-altitude environments.

Three participants noted improper equipment use, such as incorrect setup, misuse of safety gear, or failure to carry essential items, which can compromise safety in critical situations. Two participants pointed to deficient decision-making processes, where climbers failed to assess risks effectively or chose unsafe routes under pressure. One participant highlighted inadequate acclimatisation protocols, emphasising the dangers of ascending too quickly without allowing the body to adjust to reduced oxygen levels.

The most frequently cited issue, mentioned by four participants, was insufficient preparation and underestimation of natural hazards, including a lack of thorough planning,

poor route research, and failure to anticipate environmental challenges. These findings reveal key behavioural and procedural gaps that targeted VR-based training could help address by reinforcing best practices and risk management strategies.

Table 5. 12

Common Mistakes at High Altitude Identified

Improper equipment use	3
Deficient decision-making processes	2
Inadequate acclimatisation protocols	1
Insufficient preparation and underestimation of natural hazards	4

5.3.3.4 Commonly Identified Risk Factors

Participants also highlighted key challenges encountered in high-altitude environments, including altitude-related illnesses (such as AMS, HAPE, and HACE), rapid and unpredictable weather changes, unstable and challenging terrain, and a lack of navigation skills or local knowledge. Thematic analysis of the pre-intervention survey revealed that participants identified the following common risk factors at high altitude. Three participants emphasised the dangers of altitude-related illnesses, such as Acute Mountain Sickness (AMS), High Altitude Pulmonary Edema (HAPE), and High-Altitude Cerebral Edema (HACE), noting that awareness and early recognition of symptoms are essential for safety. Four participants highlighted rapid, unpredictable weather changes as a significant hazard, underscoring the need for climbers to be prepared for sudden environmental shifts.

One participant pointed to the challenges of complex and unstable terrain, which can increase the risk of slips, falls, and equipment failure. Additionally, two participants identified a lack of navigation skills and local knowledge as a contributing factor to accidents, particularly for those unfamiliar with the specific mountain environment. Together, these insights underscore the multifaceted nature of mountaineering risks and the importance of comprehensive, scenario-based training to improve preparedness.

Table 5. 13

Commonly Identified Risk Factors

Altitude-related illnesses (e.g., AMS, HAPE, HACE)	3
Rapid and unpredictable weather changes	4
Difficult and unstable terrain	1
Lack of navigation skills and local knowledge	2

5.3.4 Familiarity with Virtual Reality (VR) Technology

The data suggest moderate overall familiarity with VR technologies, though practical engagement varied substantially across participants.

5.3.4.1 Prior VR Usage

Eight participants reported prior experience with virtual reality (VR), while three had no prior VR experience.

Table 5. 14

Prior VR Usage

Yes	8
No	3

5.3.4.2 Experience Levels with VR

Participants' experience with virtual reality varied: five reported no prior knowledge, five had between 1 and 5 years of VR use, and one reported over 20 years of experience.

Table 5. 15

Experience Levels with VR

0 years	5
1-5 years	5
20+ years	1

5.3.5 Perceptions of VR-Assisted Safety Education

5.3.5.1 Positive Perceptions

Participants viewed VR-assisted education as a promising complementary tool for mountain safety training, emphasising its potential to safely simulate realistic high-risk scenarios, enhance critical thinking and decision-making skills, and increase climbers' preparedness without physical risk. Four participants emphasised the value of VR in safely simulating realistic, high-risk scenarios, allowing them to experience challenging alpine conditions—such as severe weather events or avalanche threats—without facing the actual physical dangers of the mountains. Three participants reported that the technology enhanced their critical thinking and decision-making skills, as the simulations required them to assess evolving conditions, weigh options, and make timely choices under pressure. Similarly, three participants noted that VR increased their preparedness without exposing them to physical danger, providing an opportunity to build skills and confidence in a controlled, repeatable environment before attempting real-world climbs. Together, these perspectives suggest that VR enables learners to experience realistic scenarios while avoiding the physical dangers associated with real-world environments.

Table 5.16

Positive Perceptions

Simulating realistic, high-risk scenarios safely	4
Enhancing critical thinking and decision-making skills	3
Increasing preparedness without exposing climbers to physical danger	3

Participant C1 acknowledged the pedagogical value of the intervention, stating, “It is a good approach to this kind of topic, but it wouldn’t replace technical experience.” This comment suggests that while immersive simulation was perceived as beneficial for introducing safety concepts, it was not viewed as a substitute for direct, hands-on alpine training. Similarly, Participant C3 expressed strong support for the realism of the intervention, noting, “It could be a very good way to approach mountaineers in realistic situations.” This response highlights the perceived authenticity of the simulated scenarios and their potential relevance to real-world mountaineering contexts.

5.3.5.2 Concerns Identified

Participants identified several key concerns regarding VR-assisted education, including its inability to replicate authentic sensory experiences such as cold and fatigue; the risk of fostering overconfidence due to perceived safety in virtual environments; the high costs of developing and maintaining VR platforms; and limitations in physical conditioning and practical skills development. Five participants pointed to VR's inability to replicate authentic sensory experiences, such as the physical strain of climbing, the sensation of cold, or the onset of fatigue, which are critical aspects of real-world mountaineering. One participant noted the high costs associated with developing and maintaining VR platforms, highlighting potential barriers to widespread adoption, particularly for smaller climbing organisations or educational institutions. Additionally, four participants raised concerns about the limitations of VR in developing physical conditioning and practical skills, emphasising that while VR can effectively enhance cognitive preparedness and decision-making, it cannot replace the physical demands and muscle memory gained

through actual climbing practice. These insights underscore the importance of viewing VR as a complementary tool rather than a complete substitute for traditional mountaineering training.

Table 5.17

Concerns Identified

Inability of VR to replicate authentic sensory experiences (e.g., cold, fatigue)	5
High costs are associated with developing and maintaining VR platforms	1
Limitations in physical conditioning and practical skills development	4

Participants also expressed reservations regarding the limitations of immersive simulation. Participant C1 highlighted the distinction between virtual control and environmental unpredictability, stating, “It is a controlled situation, but nature is unpredictable.” This comment reflects an awareness that while the simulation provides structured, safe exposure to hazards, it cannot fully replicate the dynamic, uncontrollable conditions characteristic of real alpine environments. Similarly, Participant C2 raised concerns regarding the potential psychological effects of immersive training, noting, “I could tell it can be overconfidence because of the app.” This observation suggests that simulated mastery may risk fostering misplaced confidence if not accompanied by critical reflection and explicit discussion of the limitations of virtual environments. Together, these concerns underscore the importance of framing VR-based interventions as complementary tools rather than replacements for field-based experiential learning.

5.3.5.3 Recognised Benefits

Participants highlighted several perceived benefits of VR-based mountaineering training. One participant emphasised its role in enhancing situational awareness and hazard recognition, enabling climbers to better identify and assess risks in simulated environments before encountering them in real life. Two participants valued the opportunity for safe repetition and skill reinforcement, noting that VR allowed them to practise scenarios multiple times without exposure to real-world danger. Five participants considered VR a valuable preparatory tool for novice and intermediate climbers, helping to build foundational knowledge and confidence before progressing to high-altitude conditions. Additionally, two participants observed that VR increased learner engagement, with its immersive nature encouraging active participation and sustained interest throughout the training process. Collectively, these responses suggest that VR can play a meaningful role in preparing climbers—particularly those at earlier stages of their mountaineering journey—by combining safety, engagement, and targeted skill development.

Table 5.18

Recognised Benefits

Enhanced situational awareness and hazard recognition	1
Safe repetition and skill reinforcement	2
A valuable preparatory tool for novice and intermediate climbers	5
People are more involved in learning	2

5.3.6 Implications for Intervention Design

The above findings underscore that although participants possess substantial climbing experience, there are notable gaps in formal high-altitude training that may impact safety outcomes. The data indicate that participants are experienced climbers with a strong understanding of mountaineering risks; however, there's a notable gap in formal training for high-altitude climbing. Despite limited VR experience, participants demonstrated a high level of receptivity to VR-assisted educational approaches, paired with cautious optimism tempered by a critical awareness of the technology's limitations.

Accordingly, the VR intervention was carefully structured to:

- Prioritise realistic and authentic scenario development.
- Integrate structured reflection and debriefing sessions after the simulation.
- Address not only technical competencies but also psychological preparedness for unpredictable, high-risk environments.

By responding to the empirical needs identified through the pre-intervention assessment, the VR app and intervention aim to optimise learning outcomes and foster safer, more informed mountaineering practices.

5.3.7 Heart Rate Analysis: Pre- and Post-Intervention

Using a Suunto watch, resting heart rate (HR) was measured both before and immediately after a mountain safety training intervention that integrated virtual reality (VR) simulation. Further technical specifications and procedures for biometric data

collection are outlined in Chapter 3, Section 3.4.4.3 (Biometric Devices and Technologies). A total of 9 participants has completed HR data. One participant was unable to complete the biometric feedback component due to a technical malfunction in the Suunto watch, which prevented accurate data capture during the session.

5.3.7.1 Heart rate measurement

Most participants exhibited a notable increase in heart rate following the intervention, with changes ranging from +29 bpm to +64 bpm. The most significant increases were observed in participant C 3 (+64 bpm) and C 1 (+62 bpm), suggesting heightened physiological responses during the VR scenarios. Heart rate data for C 8 were unavailable and should be considered when interpreting the overall results.

Table 5. 19

Heart rate measurement

Heart rate	**Pre-intervention (bpm)**	**Post-intervention (bpm)**	**Variation (bpm)**
C 6	69	98	+29
C 7	62	98	+36
C 5	60	100	+40
C 9	64	106	+42
C 4	69	111	+42
C 10	64	109	+45
C 2	51	101	+50

C 1	50	112	+62
C 3	62	126	+64
C 8	Missing	Missing	N/A

Figure. 5.1

Heart Rate Measurements Pre- and Post-Intervention and Variation Across Participants

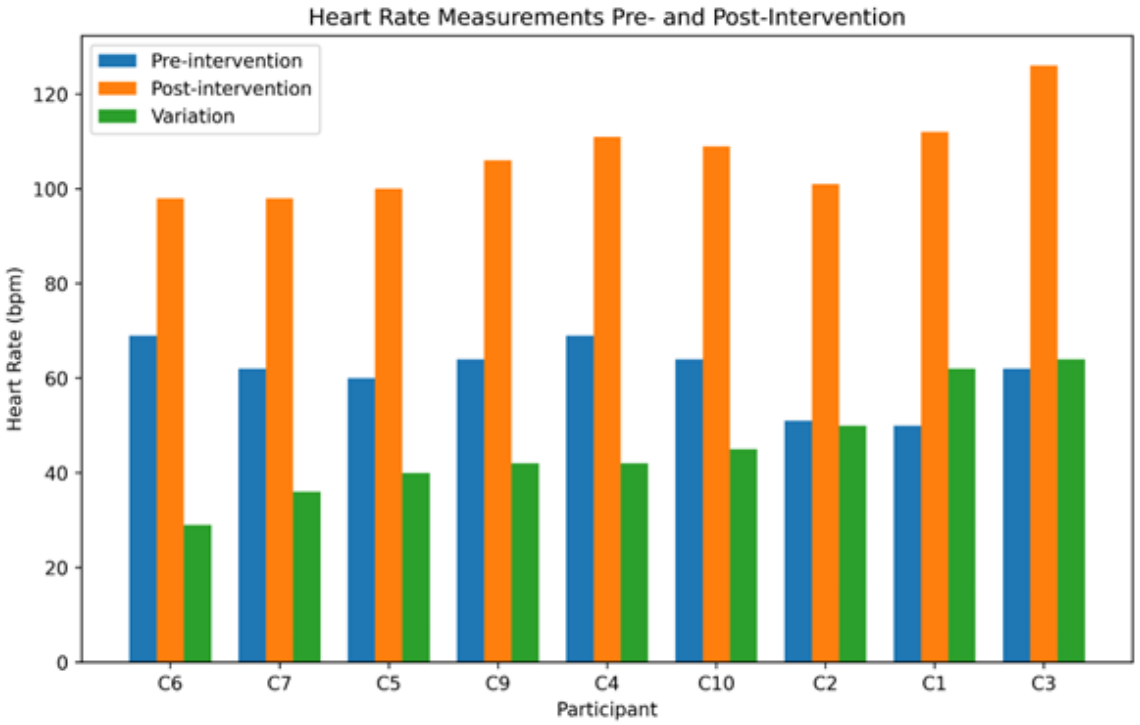


Figure 5.1 shows key findings indicating a consistent increase in heart rate for all participants with complete data following the intervention. The average heart rate rose from 61.2 bpm before the intervention to 106.8 bpm after the intervention, an increase of 45.6 bpm (approximately 74.6%). It represents a 74.6% average increase in heart rate post-intervention. This substantial rise may reflect heightened physical engagement, such as

increased movement during VR scenarios, or psychological arousal, including stress, excitement, or heightened alertness. It is important to note that heart rate data for C8 were missing both before and after the intervention, which should be considered in the analysis of averages.

5.3.7.2 Interpretation

The heart rate measurements taken before and after the VR-based mountaineering intervention revealed a consistent upward trend among most participants, indicating a notable physiological response to the simulation. Pre-intervention heart rates ranged from 50 to 69 bpm, with C 2 and C 1 recording the lowest baseline values. Following the intervention, post-intervention rates increased for all participants with valid data, peaking at 126 bpm for C 3. The largest variations were observed in C 3 (+64 bpm) and C 1 (+62 bpm), suggesting pronounced cardiovascular engagement. Moderate increases were recorded for C 6 (+29 bpm) and C 7 (+36 bpm), while C 3 (+50 bpm) and C 5 (+40 bpm) displayed above-average changes. These patterns indicate that the VR scenarios effectively elicited heightened physiological arousal, comparable to responses observed in real-world high-intensity activities. Data for one participant (C 8) was unavailable due to a device malfunction, slightly limiting cohort completeness but not altering the clear trend of elevated heart rates across participants.

The consistent increases suggest a broadly uniform physiological response among participants, likely reflecting heightened arousal, engagement, or stress during the immersive scenarios. Larger increases in certain individuals, such as C 3 and C 1,

may indicate greater sensitivity to the VR environment or deeper immersion. Differences in baseline fitness, anxiety sensitivity, or familiarity with VR may also account for the observed variability in reactivity.

Several limitations must be acknowledged. The absence of C 8's heart rate data reduces the generalisability of findings. More critically, continuous heart rate monitoring was not implemented due to technical constraints, meaning only pre- and post-intervention readings were available. This limitation prevented capturing moment-to-moment physiological fluctuations during the simulation, such as acute spikes at stressful decision points or gradual adaptation over time. Live monitoring could have provided more detailed insights into the temporal patterns of stress, engagement, and recovery throughout the high-risk virtual scenarios.

Overall, the results demonstrate that the VR-based intervention elicited measurable and consistent physiological arousal, supporting its potential to simulate high-stakes conditions and to prepare participants psychologically and cognitively for real-world mountaineering challenges.

5.3.8 Summary - Chile Pre-Intervention Findings

The Chilean pre-intervention phase, conducted in early 2023, followed the analysis and exploration stage of the Educational Design Research (EDR) model (McKenney & Reeves, 2012), aiming to establish a detailed baseline of participants' mountaineering experience, training background, accident history, familiarity with VR, and perceptions of VR-assisted

safety education. The ten participants—five males and five females, aged 20–50—were generally experienced climbers, with 73% identifying as advanced or professional, and most having more than five years of climbing experience. While many had diverse terrain experience and formal mountaineering qualifications, gaps were found in specialised high-altitude training, with only two participants having formal training above 3,000m.

Accident history revealed that 40% had experienced frostbite or hypothermia. Human error was the leading perceived cause of accidents, as evidenced by identified mistakes such as improper equipment use, poor decision-making, inadequate acclimatisation, and insufficient preparation. Commonly cited risk factors included altitude illness, rapid weather changes, unstable terrain, and lack of navigation skills.

Familiarity with VR was moderate; eight participants had prior exposure, but experience levels varied. Perceived benefits of VR included realistic hazard simulation, enhanced decision-making, safe repetition, and value for novice-to-intermediate climbers. Concerns included its inability to replicate physical conditions, limitations in developing physical conditioning, and high implementation costs.

Heart rate data from nine participants showed a consistent post-intervention increase, with an average rise of 45.6 bpm (74.6%), suggesting intense physiological arousal during VR scenarios. However, the absence of continuous, real-time HR monitoring limited the analysis of moment-by-moment stress responses. This baseline analysis informed the VR

intervention design, ensuring a focus on realistic scenarios, structured reflection, and psychological preparedness alongside technical skills.

5.4 Participant Demographics in New Zealand

A total of ten participants completed the pre-intervention questionnaire as part of the mountain safety education study. The age distribution revealed that most participants were within the 21 to 40 years range, indicating a relatively young cohort with active involvement in outdoor activities:

Table 5. 20

Gender Distribution

Male	7
Female	3

Table 5. 21

Age Distribution

21–30 years	4
31–40 years	4
41–50 years	1
51-60	1

Regarding gender distribution, 70% of participants identified as male (n = 7), and 30% identified as female (n = 3). This gender split aligns with known trends in mountaineering communities, which are often male dominated but are gradually diversifying.

5.4.1. Climbing Experience and Self-Assessment

5.4.1.1 Climbing Locations

Participants primarily engaged in climbing and mountaineering activities within New Zealand. Frequently mentioned locations included Mt Taranaki, Mt Ruapehu, various climbing gyms throughout the country, and general tramping and outdoor mountaineering areas. This range of environments indicates a contextually relevant sample with experience across both indoor and outdoor climbing settings, providing a diverse foundation for assessing mountain safety training needs.

Participants primarily engaged in climbing and mountaineering activities within New Zealand. Common locations mentioned included:

- Mt Taranaki
- Mt Ruapehu
- Various climbing gyms across New Zealand
- General tramping and outdoor mountaineering areas

5.4.1.2 Years of Climbing Experience

Participants reported a broad range of climbing experience, though the majority had relatively limited time in the sport. Specifically, one participant was a new climber (less than 1 year of experience), six had between 1 and 5 years of experience, two had between 6 and 10 years of experience, and one had between 21 and 30 years of experience. No participants reported 11–20 years or over 31 years of climbing experience.

In terms of self-assessed skill levels, four participants identified as beginners, six as intermediates, one as an advanced climber, and none as professional climbers. This distribution suggests that while most participants had some experience, the overall group skewed toward beginner and intermediate skill levels, indicating they are appropriate candidates for targeted mountain safety interventions. Participants reported a range of climbing experience levels, though most had been involved for a relatively short time. The following breakdown was observed.

Table 5. 22

Years of Climbing Experience

Years of experience	**Participant**
New climber	1
1–5 years	6
6–10 years	2
21-30	1

5.4.1.3 Self-reported Skill Level

Regarding skill level, participants reported varying levels: three identified as beginners, six as intermediates, and one as advanced.

Table 5. 23

Self-reported skill level

Beginner	3
Intermediate	6
Advanced	1
Professional	0

5.4.2 Training and Qualifications

5.4.2.1 Sources of Mountain Training

Participants reported diverse training backgrounds, including formal instruction from outdoor institutions or training schools (three participants), training through local mountain clubs (five participants), and informal training with climbing partners (five participants). Only one participant reported holding a formal mountaineering qualification, highlighting a notable gap between practical experience and official certification among the group.

Table 5. 24

Sources of Mountain Training

Training sources	**Participant**
Outdoor institutions/training schools	3
Local mountain clubs	5
Climbing partners (informal mentorship)	5
No formal training	1

5.4.2.2 Formal Mountaineering Qualifications.

One participant reported holding formal mountaineering qualifications, while nine did not.

Table 5. 25

Formal Mountaineering Qualifications

Yes	1
No	9

5.4.2.3 High-Altitude Climbing Experience (>3000m)

High-altitude exposure, defined as climbing above 3,000 meters, was limited among participants, with only one reporting such experience and nine participants without. Furthermore, none of the participants had received formal high-altitude

training. Regarding accident history, only one participant reported having experienced an accident in the mountains, specifically losing track of the route. This limited exposure to high-altitude environments and accidents may affect participants' perceptions of risk and overall preparedness.

Table 5. 26

High-Altitude Experience

Yes	1
No	9

5.4.2.4 Formal High-Altitude Training

One participant reported having received formal high-altitude training, while nine had not.

Table 5. 27

Formal High-Altitude Training

Yes	1
No	9

5.4.3 Incident History and Risk Perception

5.4.3.1 Experience of Accidents

Only one participant reported having experienced a climbing-related accident, while nine participants had not. Incident: lost track while navigating the climbing route.

Table 5. 28

Experience of Accidents

Yes	1
No	9

5.4.3.2 Perceived Primary Causes of Accidents

Eight participants identified mountaineers' mistakes as the primary contributing factor to mountain accidents, and three participants identified natural forces such as sudden weather changes. No participants reported gear failure or other causes. Commonly identified mistakes included poor decision-making, failure to turn back when faced with adverse conditions, inadequate assessment of surroundings, risk-taking behaviours, and a lack of practical knowledge and skills. Frequently mentioned risk factors encompass unpredictable weather patterns, physical limitations, avalanches and terrain hazards, as well as user error and overconfidence. These qualitative insights underscore the critical need for enhanced decision-making skills and situational awareness in high-altitude environments.

Table 5. 29

Primary Causes of Accidents

Mountaineers' mistakes	8
Natural forces	3
Gear failures	0

5.4.3.3 Common Mistakes at High Altitude Identified

The thematic analysis of the pre-intervention survey identified several recurring mistakes that participants perceived as common in high-altitude environments. Two participants emphasised poor decision-making as a significant contributor to dangerous or avoidable situations. One participant specifically noted the failure to turn back when encountering adverse conditions, illustrating how persistence in unsafe circumstances can heighten risk. Inadequate assessment of surroundings, reported by two participants, reflected gaps in situational awareness that could hinder hazard detection. Risk-taking behaviours, mentioned by one participant, suggested a willingness to push beyond safe limits despite environmental or personal constraints. Similarly, two participants identified a lack of practical knowledge and skills, indicating that insufficient technical competence may undermine safety. Some respondents reported more than one common mistake, while four participants provided no answer, likely because they lacked experience with high-altitude climbing or felt uncertain about identifying such mistakes. Collectively, these findings informed the VR training design by highlighting the need to

enhance decision-making, hazard awareness, and practical skill development in simulated high-stress scenarios.

Table 5. 30

Common Mistakes at High Altitude Identified

Poor decision-making	2
Failure to turn back when encountering adverse conditions	1
Inadequate assessment of surroundings	2
Risk-taking behaviors	1
Lack of practical knowledge and skills	2
No answer	4

5.4.3.4 Commonly Identified Risk Factors

The survey also identified several risk factors that participants commonly associated with high-altitude environments. The most frequently cited concern, noted by five participants, was unpredictable weather patterns, which can rapidly alter climbing conditions and increase the likelihood of accidents. Avalanches and hazardous terrain were reported by three participants, underscoring the constant presence of environmental dangers that require careful route selection and risk assessment. User error and overconfidence, mentioned by two participants, reflected behavioural risks where climbers may overestimate their abilities or underestimate hazards. One participant identified physical

limitations as a potential constraint on safety and performance. Some respondents reported more than one common mistake. Notably, three participants provided no response, which may indicate a lack of high-altitude climbing experience or uncertainty in recognising specific risk factors. Collectively, these insights emphasise the importance of integrating environmental awareness, self-assessment, and hazard management into the VR training design, ensuring participants are better prepared to anticipate and mitigate risks in alpine settings.

Table 5. 31

Commonly Identified Risk Factors

Unpredictable weather patterns	5
Physical limitations	1
Avalanches and terrain hazards	3
User error and overconfidence	2
No Answer	3

5.4.4 Familiarity with Virtual Reality (VR) Technology

5.4.4.1 Prior VR Usage

Among participants, eight reported prior use of VR technology, while two had no previous experience. Most participants' exposure to VR was limited, with the majority reporting using it 0 to 5 times.

Table 5. 32

Prior VR Usage

Have used VR	8
Have not used VR	2

5.4.4.2 Experience Levels with VR

Participants' experience with virtual reality varied: five reported no prior knowledge, four had between 1 and 5 years of VR use, and one reported over 20 years of experience.

Table 5. 33

Experience Levels with VR

0 years	5
1-5 years	4
20+ years	1

5.4.5 Perceptions of VR-Assisted Safety Education

5.4.5.1 Positive Perceptions

Participants expressed generally positive attitudes toward using VR for mountain safety education. The most reported benefit, mentioned by five participants, was the ability to

provide a safe, low-risk simulation of hazardous alpine environments, allowing learners to experience and respond to high-risk scenarios without physical danger. Four participants valued the enhanced accessibility offered by VR, particularly for beginners and geographically isolated learners who may have limited opportunities to train in real alpine settings. This accessibility was seen to broaden participation and reduce barriers to skill acquisition. Additionally, one participant emphasised the value of repetitive practice in decision-making and safety standards, noting that VR enables learners to revisit scenarios multiple times until mastery is achieved. Collectively, these perceptions reinforce VR's potential as both a risk-free training tool and an inclusive platform for skill development across diverse learner populations.

Table 5.34

Positive Perceptions

Safe, low-risk simulation of hazardous environments	5
Repetitive practice in decision-making and safety standards	1
Enhanced accessibility for beginners and geographically isolated learners	4

5.4.5.2 Concerns Identified

Although participants were generally supportive of VR integration into mountaineering safety training, they also identified several key concerns. Four participants expressed that VR lacked realism in replicating essential environmental factors such as cold, fatigue, and

altitude—elements considered critical for preparing climbers for actual high-altitude conditions. Another four participants highlighted the limitations of physical engagement, noting that VR could not fully replicate the bodily demands and kinesthetic feedback of real-life climbing. Cost and scalability were also cited by two participants as potential barriers, reflecting apprehension about the financial and logistical feasibility of implementing VR training on a wide scale. Additionally, one participant noted usability issues, suggesting that interface design and user experience could hinder accessibility for some learners. These concerns underline the need for careful consideration of realism, physicality, and cost-effectiveness in future VR training design and implementation.

Table 5.35

Concerns Identified

Lack of realism in replicating environmental factors (e.g., cold, fatigue, altitude)	4
Cost and scalability concerns	2
Limited physical engagement compared to real-life experience	4
Difficult usability	1

5.4.5.3 Recognised Benefits

Three participants valued the opportunity to practise decision-making, noting that VR offered a safe yet challenging environment to refine cognitive responses in high-risk scenarios. Two participants highlighted VR's role in enabling safe repetition and

reinforcement of essential skills, allowing learners to build competence without the physical risks of real-world training. Similarly, two participants identified VR as a valuable preparatory tool for novice and intermediate climbers, helping them build foundational skills and confidence before attempting real climbs. Increased learner engagement was also reported by three participants, who felt that the immersive nature of VR promoted greater involvement and interest in the learning process. Additionally, two participants pointed to potential financial benefits, such as reduced travel costs and resource expenditure compared to traditional training methods. Collectively, these recognised benefits underscore VR's potential as a complementary tool in mountaineering education, particularly in enhancing safety, accessibility, and learner motivation.

Table 5.36

Recognised Benefits

Decision-making process practice	3
Safe repetition and skill reinforcement	2
A valuable preparatory tool for novice and intermediate climbers	2
People are more involved in learning	3
Financial benefit	2

5.4.6 Heart Rate Analysis: Pre- and Post-Intervention

5.4.6.1 Heart rate measurement

The dataset comprises heart rate measurements (in beats per minute, bpm) collected from ten participants before and after a VR-based intervention. Valid readings were obtained from nine individuals, while one participant's data was unavailable due to a malfunction of the Suunto watch. Heart rate is frequently used as an indicator of physiological arousal and can reflect stress, emotional engagement, or cognitive workload during immersive experiences (Healey & Picard, 2005; Meehan et al., 2002).

All participants with valid data showed an increase in heart rate following the VR intervention. On average, participants experienced a 19.2 bpm increase in heart rate post-intervention. The New Zealand heart rate data shows a consistent increase in post-intervention readings compared to pre-intervention levels for nearly all participants, suggesting that the VR training induced a measurable physiological response. Pre-intervention heart rates ranged from approximately 51 bpm (Josh) to 82 bpm (N 4), while post-intervention values were uniformly higher, spanning from about 61 bpm to over 100 bpm. The variation—representing the difference between pre- and post-intervention—was the smallest for N 10 (+10 bpm) and largest for N 5 (+30 bpm). Most participants showed moderate increases between +10 and +20 bpm, with the most significant spikes clustered toward the end of the group (N 3 and N 5).

These trends suggest that while the VR session elevated heart rate across the board, the magnitude of change varied, potentially reflecting differences in individual fitness levels, engagement intensity, or stress responses during the simulation.

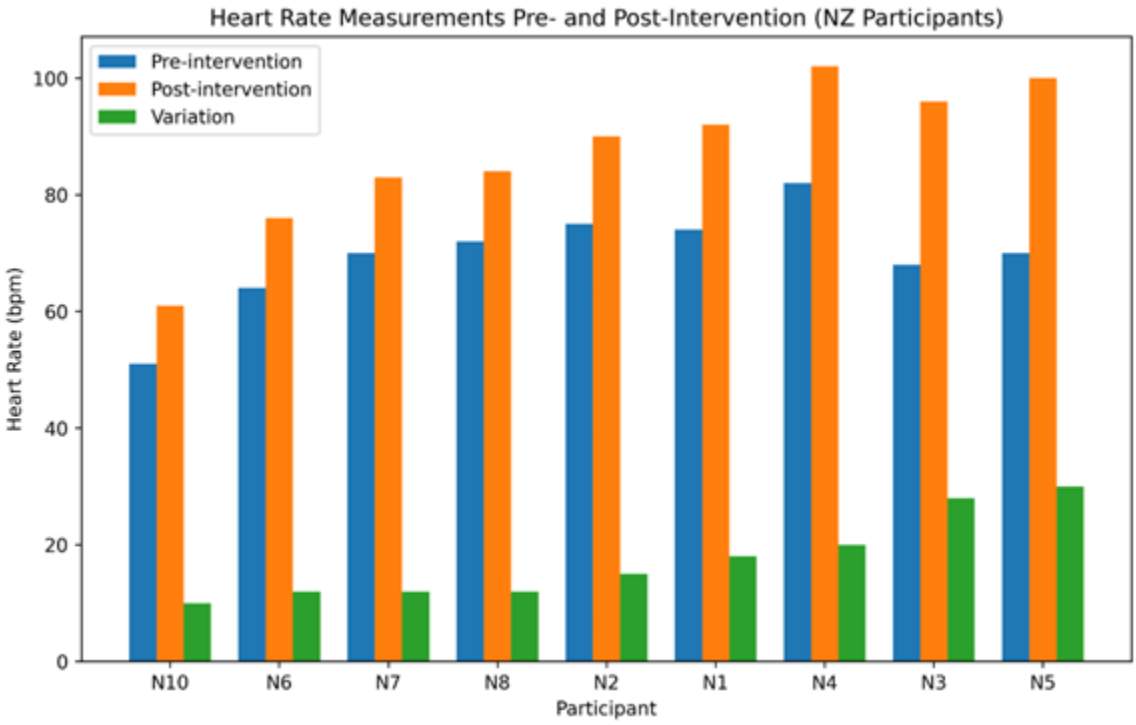
Table 5. 37

Heart rate measurement

Heart rate	**Pre-intervention (bpm)**	**Post-intervention (bpm)**	**Variation (bpm)**
N 10	51	61	+10
N 6	64	76	+12
N 7	70	83	+12
N 8	72	84	+12
N 2	75	90	+15
N 1	74	92	+18
N 4	82	102	+20
N 3	68	96	+28
N 5	70	100	+30
N 9	Missing (watch freezing)	Missing	N/A

Figure. 5.2

Heart rate pre- and post-intervention in New Zealand



5.4.6.2 Interpretation

The heart rate data revealed consistent increases across most participants following the VR-based mountain safety intervention, indicating heightened physiological arousal during or immediately after the simulation. On average, participants' heart rates rose by approximately 19.7 beats per minute (bpm) from pre- to post-intervention, suggesting that the VR experience successfully engaged users both cognitively and emotionally. This increase may be attributed to several factors, including the immersive and cognitively demanding nature of the virtual scenarios, the simulation of stressful or high-risk decision-

making situations, and the novelty or unfamiliarity of VR technology itself. For some participants, mild physical exertion associated with movement during the simulation may also have contributed to the elevated readings.

The variation in heart rate responses across individuals suggests differing levels of physiological reactivity and engagement with the training content. Some participants showed substantial increases, which may reflect a stronger stress or excitement response. In contrast, others exhibited more moderate changes, indicating lower perceived threat or greater familiarity with similar scenarios. Importantly, the elevated heart rates align with the hypothesis that realistic VR simulations can elicit emotional and physical responses comparable to those experienced in actual high-risk environments. This physiological activation may enhance the realism of the training and prepare participants not only cognitively but also psychologically for real-world challenges.

However, several limitations should be acknowledged. Heart rate data for one participant (N=9) were unavailable due to a malfunction of the Suunto wearable device, slightly reducing the completeness and generalisability of the dataset. Additionally, heart rate changes alone cannot determine whether the arousal experienced was positive (e.g., excitement, motivation) or negative (e.g., anxiety, stress). Without corresponding qualitative feedback, it is difficult to distinguish between beneficial training-induced stimulation and potentially counterproductive anxiety responses. Incorporating self-reported perceptions, stress ratings, or observational data would provide a more nuanced interpretation of these physiological findings.

Overall, the results suggest that VR training can trigger realistic stress and engagement responses, supporting its potential as an effective tool for enhancing readiness and decision-making in safety-critical environments such as mountaineering, where both technical skill and the ability to function under pressure are essential.

5.4.7 Summary - New Zealand Pre-Intervention Findings

The NZ participant group (n = 10) was predominantly male (70%), with most aged between 21 and 40 years, reflecting a relatively young and active mountaineering cohort. Climbing experience varied, with the majority having 1–5 years of involvement, and skill levels skewed toward beginner and intermediate. Training backgrounds were mixed: many received instruction through local mountain clubs or informal mentorship, but only one participant held formal mountaineering qualifications. High-altitude climbing experience (> 3000 m) and formal high-altitude training were rare, with only one participant reporting them.

Accident experience was also low, with only one reported incident. However, most participants perceived mountaineers' mistakes—particularly poor decision-making, inadequate hazard assessment, and risk-taking—as primary causes of accidents. Commonly cited risk factors included unpredictable weather, avalanches, terrain hazards, and user overconfidence.

Most participants had some prior exposure to VR technology, though experience levels varied. Positive perceptions of VR training centred on its ability to provide safe, low-risk

simulations and increased accessibility for isolated or novice climbers. At the same time, concerns included limited realism, reduced physical engagement, and cost. Recognised benefits included decision-making practice, safe repetition, and heightened learner engagement.

Heart rate data from nine participants showed a consistent post-intervention increase (average +19.2 bpm), suggesting that the VR simulation induced measurable physiological arousal. Variations in heart rate changes indicated differing levels of engagement and stress response, supporting VR's potential to simulate high-stakes conditions and enhance readiness for real-world mountaineering challenges.

5.5 A Comparative Analysis between Chile and New Zealand Participants based on Pre-Intervention Data and Heart Rate Responses to the VR Intervention:

5.5.1 Participant Profile

The study included 20 participants, evenly split between Chile and New Zealand (10 each). Gender distribution differed slightly: Chile's group was evenly balanced (50% male, 50% female), whereas New Zealand's group was predominantly male (70% male, 30% female). The average age in the Chilean group was 37.4 years, whereas the New Zealand participants were mostly aged between 21 and 40, with an average age of approximately 34.5 years.

Experience levels also varied notably between groups. The Chilean participants were primarily advanced or professional climbers, with 90% reporting high-altitude experience above 3,000 meters, and 80% holding formal mountaineering qualifications. In contrast, the New Zealand group skewed toward beginner and intermediate skill levels, with only one participant having high-altitude experience and another reporting formal qualifications.

Familiarity with virtual reality was comparable between groups, with most participants from both Chile and New Zealand having prior VR experience (8 out of 10 participants in each group).

The participant groups from Chile and New Zealand demonstrated distinct differences in climbing experience, qualifications, and high-altitude exposure, which are essential considerations for interpreting study findings and tailoring mountain safety interventions.

5.5.1.1 Experience and Qualifications

Chilean participants exhibited substantially higher climbing experience, with the majority classified as advanced or professional climbers. It was reflected in their extensive high-altitude expertise (90% above 3,000 meters) and a high rate of formal mountaineering qualifications (80%). Conversely, the New Zealand group was composed mainly of beginner and intermediate climbers, with limited high-altitude exposure (10%) and only one participant holding formal qualifications. These differences suggest that the Chilean group may possess greater technical skills and familiarity with mountain risks.

5.5.1.2 Demographics

While gender distribution was balanced in the Chilean cohort, the New Zealand group had a slight male predominance. Age distributions also differed: Chilean participants averaged 37.4 years, compared to a younger majority in New Zealand, where the average age was approximately 34.5 years. These demographic variations may influence risk perception, physical conditioning, and learning preferences.

5.5.1.3 VR Familiarity

Both groups reported similar levels of VR exposure, indicating a generally moderate familiarity with this technology. It suggests that differences in VR experience are unlikely to confound comparisons in intervention outcomes between groups.

5.5.1.4 Implications

Given these contrasts, findings indicate that mountain safety interventions, particularly VR-based training programs, may need to be adapted to suit different experience levels and cultural contexts, as reported in the literature (Section 2.3.3). The Chilean group's advanced skills and prior exposure may allow for more complex scenario training, whereas the New Zealand group might benefit from foundational safety education and basic skill reinforcement. Additionally, demographic factors such as age and gender composition could inform the design of tailored engagement strategies to maximise effectiveness across diverse learner profiles.

Table 5. 38

Chile and New Zealand Participant Profile

Category	**Chile**	**New Zealand**
Total Participants	10	10
Gender balance	50% male, 50% female	60% male, 30% female
Average age	37.4 years	34.5 years
Experience level	Mostly advanced/professional	Mostly beginner/intermediate
High-altitude experience	90% had>3000m experience	10% had>3000m experience
Formal qualifications	80% had some qualifications	Only 1 participant qualified
VR familiarity	Moderate (majority had tried VR)	Similar (8 out of 10 had tried VR)

5.5.2 Heart Rate Response to VR Intervention

Participants from Chile exhibited a markedly larger increase in heart rate during the VR sessions, indicating heightened physiological arousal. This elevated response may reflect more realistic engagement with the simulation. In contrast, participants from New Zealand showed more moderate increases in heart rate. This could result in less intense emotional responses or a more measured engagement with the VR scenarios. Variations in scenario design or individual emotional reactivity may also have played a role in these differing physiological responses.

Table 5. 39

Chile and New Zealand Participant Heart Rate Measurement

Participants with Complete Data	9	9
Avg. Pre-VR Heart Rate	61.2 bpm	69.6 bpm
Avg. Post-VR Heart Rate	106.8 bpm	88.8 bpm
Average increase	+45.6 bpm	+19.2 bpm
% Increase (Approx.)	+74.6%	+27.6%
Formal qualifications	80% had some qualifications	Only 1 participant qualified
Max Individual Increase	+64 bpm (Ana Maria Rivena)	+30 bpm (Sarah Jeong)

5.5.3 Interpretation

5.5.3.1 Chile

Participants showed a much larger increase in heart rate, suggesting higher physiological arousal during the VR sessions. This could be due to:

- More realistic engagement (possibly influenced by their existing climbing experience).
- Greater immersion due to familiarity with high-risk environments.
- Possibly more intense or challenging VR content.

5.5.3.2 New Zealand

Heart rate increases were more moderate, possibly reflecting:

- Lower prior experience with high-risk situations results in less emotional intensity.
- A more measured engagement with the simulation.
- Or potentially different scenario design or emotional response levels.

5.5.4 Attitudes Toward VR-Based Training

Table 5. 36 shows participants from both Chile and New Zealand expressed broadly positive views on VR-assisted mountain safety training, yet their perspectives reflected the influence of differing backgrounds and experience levels. Chilean participants adopted a constructive but critically reflective stance. They recognised VR's value in simulating realistic hazards and providing a safe space for skill rehearsal, but their advanced climbing experience prompted a more exacting appraisal. A primary concern was VR's inability to fully replicate the sensory and environmental realities of high-altitude climbing—such as cold, fatigue, and the unpredictability of weather conditions they likely encounter regularly in the field.

In contrast, New Zealand participants, many of whom had less mountaineering experience, focused on the accessibility and risk-free repetition afforded by VR. They valued its potential as a training platform for building foundational knowledge and decision-making skills, particularly for those with limited access to alpine environments. However, they also

noted limitations in realism, questioned its cost-effectiveness, and pointed out VR's inability to foster physical conditioning or fully reproduce the sensory depth of mountaineering.

Taken together, these perspectives suggest that VR is widely regarded as a valuable educational tool, but its perceived utility shifts with experience level. More seasoned climbers may prioritise technical and sensory fidelity, seeking complex, high-realism scenarios. At the same time, novice or intermediate users tend to value safety, accessibility, and the ability to practise skills without risk. These distinctions underline the importance of tailoring VR interventions to the needs of different user groups, balancing immersive engagement with appropriate levels of challenge and authenticity.

Table 5. 40

Chile and New Zealand Participant Attitudes Toward VR-Based Training

Aspect	Chile	New Zealand
Overall Attitude	Positive but critically reflective	Positive with recognition of limitations
Key Benefits Mentioned	Realistic risk simulation, safe skill rehearsal	Accessibility, risk-free repetition
Key Concerns	VR can't replicate real conditions (such as cold).	Realism limits, cost, and lack of whole physicality

5.6 Summary

The comparative analysis of Chilean and New Zealand participants in the VR-based mountaineering safety intervention revealed distinct differences in physiological engagement, experience-based interaction, and perceived training value. Chilean participants, with extensive high-altitude experience, showed markedly greater increases in heart rate following the sessions, suggesting deeper immersion and stronger emotional arousal. Their familiarity with real-world hazards amplified the realism of the scenarios, prompting more critical and technically informed feedback focused on environmental fidelity, decision-making pressures, and scenario complexity.

In contrast, the largely novice-to-intermediate New Zealand cohort exhibited more moderate increases in heart rate, reflecting a steadier physiological response. Their evaluations centred on VR's accessibility, safety, and potential to provide early exposure to mountaineering hazards in a controlled environment. While they acknowledged the limitations of realism, their emphasis was on the tool's ability to bridge geographical and environmental barriers for skill development.

Despite these differences, both groups viewed VR as a valuable addition to mountaineering education. For experienced climbers, it offers a supplementary platform for refining psychological readiness and high-stakes decision-making; for beginners, it serves as a safe, engaging introduction to core safety principles and hazard recognition. The results indicate that VR-based training may need to be adapted to participants' experience levels to maximise learning effectiveness.

Building on these insights, the next chapter examines the design of the intervention itself. Chapter 6 details how theoretical frameworks, empirical findings, and iterative feedback informed the refinement of the VR training system, leading to the development of targeted design principles for effective learning in extreme, high-risk environments.

Chapter 6: Intervention Findings

6.1 Introduction

This chapter presents the findings from the VR-based educational intervention implemented in Chile and New Zealand, focusing on the intervention experience, usability, and participant responses. The study design and data-collection procedures are described in Chapter 3, while participant baseline characteristics are presented in Chapter 5.

6.2 Methodology Overview of the Intervention

The evaluation of the intervention was carried out using a mixed-methods approach embedded within the DBR framework (see Figure 6.1). Data sources included:

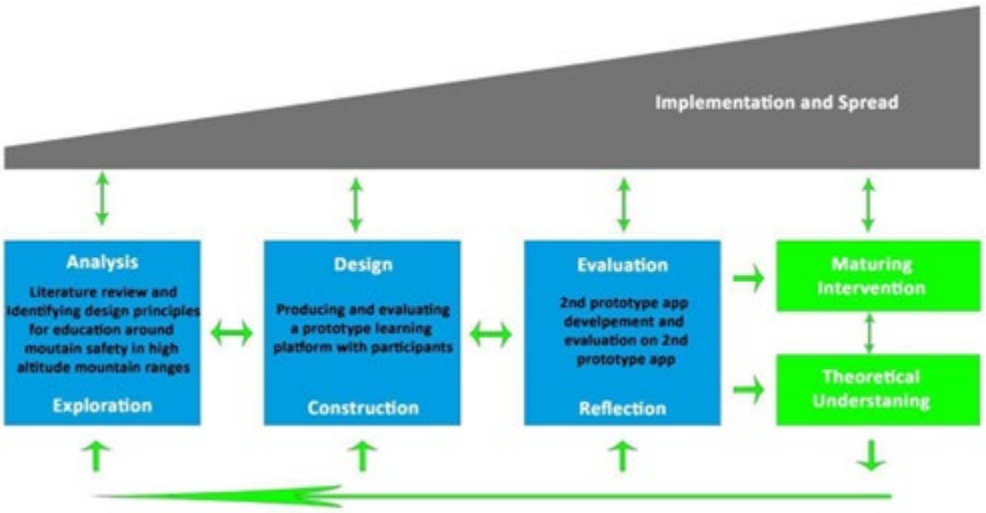
- Pre-intervention questionnaires to collect demographic data, mountaineering experience, and prior exposure to VR.
- VR training session data, including observational field notes, system logs, and video recordings of user interactions.
- Biometric measures, such as heart rate, are used to assess emotional arousal and stress during training.
- Post-intervention interviews were structured around user perceptions of usability, immersion, learning outcomes, and emotional response.
- Comparative thematic analysis across both Chilean and New Zealand cohorts to identify cultural, linguistic, and contextual variables affecting learner

engagement.

Together, these data sources enabled triangulation, providing multiple perspectives on the effectiveness of the VR intervention (Lincoln & Guba, 1985).

Figure 6. 1

Jin Hong (2019). Conducting educational design research for mountain safety (adapted from McKenney, S., & Reeves, T, 2012)



6.3 Analysis and Reporting of the Chilean and the New Zealand Case Study Intervention

6.3.1 Location and Context

The intervention took place in Santiago and Viña del Mar, Chile, from January to February 2023, and in Auckland, New Zealand, in May 2023. Participants included seasoned, professional, and novice climbers from three cities. The venues, located at Universidad Andrés Bello's Viña Del Mar and Santiago campuses, as well as Auckland University of Technology, featured spacious indoor areas equipped with VR headsets, computers, and projection screens for immersive and observational experiences.

The study was conducted in these areas as the researcher collaborated with Pablo Rebolledo Dujisin from Universidad Andrés Bello de Viña Del Mar, whom the researcher met at a conference in Chile in 2019. Pablo was happy to cooperate with the researcher in Chile. The researcher collaborated with Pablo's team on the Chilean intervention during a three-month visit to Chile, part of a Prime Minister's Scholarship to Latin America from the New Zealand Government. Additionally, Matthew Chan from the Auckland Alpine Community and the New Zealand Alpine Club (NZAC) assisted in arranging participants throughout New Zealand.

6.3.2 Dates and Timeline

The intervention, conducted over three days in Chile from January 27 to 29, 2023, and in New Zealand from May 26 to June 1, 2023, was meticulously planned to include individual VR training experiences, biometric data collection, follow-up interviews, and observations. This timeline encompassed multiple interactive phases to ensure participants were well-engaged and adequately prepared.

6.3.3 Participants

Pablo Rebolledo Dujisin and his team from Universidad Andrés Bello de Viña Del Mar assisted in arranging the intervention process. A diverse group of ten enthusiastic participants actively engaged in this transformative intervention, representing a rich cross-section of the Chilean mountaineering community. This group included:

- Demographics: The group consisted of five males and five females, with a mean age of 37.4 years, presenting a diverse mix of experiences, backgrounds, and perspectives (see Tables 5.2 and 5.3).
- Experience Level: This diverse cohort included capable novice mountaineers eager to acquire foundational skills and experienced climbers well-versed in the challenges of high-altitude environments. (See Tables 5.4 and 5.5.) Participants reported varying skill levels: one as a beginner, two as intermediate, five as advanced, and two as professional climbers.
- Affiliations: Participants hailed from notable organisations, including the esteemed FEACH (Federación de Andinismo de Chile), university-affiliated

outdoor programs, and independent climbing clubs, each contributing to the rich tapestry of insights shared within the study.

All participants willingly provided informed consent and were thoroughly briefed on the intervention's objectives, structure, and their respective roles, ensuring that everyone was on the same page.

Matthew from the New Zealand Alpine Club assisted with the organisation of the intervention process in New Zealand.

- Demographics: The group consisted of 7 males and 3 females. Most were between 21 and 40 years old. (See Tables 5.20 and 5.21).
- Experience Level: Most participants were young and had some climbing experience. They were mainly beginner to intermediate-level climbers, which makes them a good group for mountain safety training. (See Tables 5.22 and 5.23) Participants reported varying skill levels, with three identifying as beginners, six as intermediate, and one as an advanced climber.)
- Affiliations: Seven participants from the New Zealand Alpine Club (NZAC), and three participants from independent climbing clubs.

6.3.4 Intervention Procedure

The core of the intervention featured a carefully crafted VR training session utilising the VR application. The VR training session used the prototype application to simulate high-risk mountaineering environments and decision-making scenarios. This captivating

experience was designed to recreate high-risk mountain en vironments and scenarios that climbers frequently encounter, including:

- Dynamic Weather Events: Astonishing simulations of unpredictable conditions such as blustery snowstorms, dense fog blankets, and raging winds that can drastically alter a climber's course.
- Complex Navigation Challenges: Intricate terrain that poses significant tests to climbers' directional abilities, pushing their limits and decision-making skills.
- Altitude-Related Illness Symptoms: Authentic portrayals of symptoms associated with acute mountain sickness, providing critical insight into the physiological challenges of high-altitude environments.
- Crucial Emergency Response Scenarios: Thrilling simulations of potential avalanches and perilous crevasse situations that require quick and informed reactions from participants.

However, a prototypical VR application had created only one high-risk mountain scenario, acute mountain sickness, to conduct this research. Limiting the scope to one scenario ensured a more controlled investigation, allowing for consistent participant experiences. Additionally, acute mountain sickness was selected because it represents a critical, time-sensitive risk in high-altitude environments, making it a suitable test case for evaluating VR's potential as a tool for hazard recognition, decision-making, and psychological preparedness in mountaineering safety training.

The intervention followed a structured process composed of several essential steps:
The researcher administered a questionnaire to the participants before the intervention. Biometric feedback was also collected before and after the intervention. Following the intervention, the researcher conducted interviews with participants that lasted approximately 30 minutes each.

All participants were informed of the details regarding how biometric feedback would be collected before the research commenced. Participants wore a virtual reality (VR) head-mounted display (HMD). The research utilised a Suunto watch to measure heart rate. Qualitative data from pre- and post-intervention interviews were compared with biometric responses before and after using the app, as well as with participants' interview feedback.

Table 6.1

The Intervention Process

1. Questionnaire (30 minutes) 2. Biometric feedback	• Participants' experience with mountaineering and the VR app. The survey included demographic questions, prior expertise with high-altitude mountaineering, and educational background in high-altitude mountaineering (Figure 6.1). • Using a Suunto wearable watch to record participants' heart rate.

2. Intervention (20-30 min)	The intervention included using a VR app prototype for high-altitude mountaineering education. The intervention included: • Step 1: Check that the participant is comfortable in the VR environment; check that the biometric data collection (5 min) (Figure 6.2) is complete. • Step 2: VR use by the participant • Biometric feedback - Participants' biometric feedback A biometric data collection device, a Suunto smartwatch with biometric recording capabilities, was placed on the participant's wrist. The biometric data collection ran for the duration of the intervention (i.e., pre-intervention survey and the VR intervention). • Video recording: The researcher set up a video camera with a tripod in the corner of the room to minimise interruptions during the intervention. The researcher will inform participants when to start and stop recording.
3. Post-intervention Interview (30 minutes) 4. Biometric feedback	• Participants' experience before and after using a prototype app. Participants were interviewed immediately after using the VR app to discuss their experience with the app

	and the potential of immersive learning technologies for high-altitude mountaineering. • Using a Suunto wearable watch to record participants' heart rate after the intervention.

Figure 6.2

Participants survey Chile



Figure 6.3

An instructor set up a Suunto watch for the biometric data collection in New Zealand.



6.3.5 Orientation and Tutorial

The intervention commenced with a carefully structured onboarding session designed to orient participants to the virtual reality (VR) system and maximise their readiness for engagement. Each session began with a warm welcome and a comprehensive briefing covering the study's aims, ethical considerations, and technical instructions for using the VR headset and controllers. (See Figures 6.2, 6.3 and 6.4). This preparatory phase aligns with best practices in immersive learning design, in which minimising extraneous cognitive load prior to simulation is considered important for enabling learners to focus on core task demands (Mayer, 2009; de Koning et al., 2012). Immersive learning design focuses on developing interactive learning environments that promote active engagement through realistic simulation and learner participation. Such approaches leverage technologies like Virtual Reality (VR) to replicate real-world

scenarios, enabling learners to practise decision-making, problem-solving, and procedural skills in safe yet authentic settings (Strivr, 2020). Recent reviews of immersive learning frameworks highlight the importance of aligning technological affordances with pedagogical objectives, ensuring that elements such as presence, interactivity, and feedback are deliberately integrated into instructional design (Fernandes, Rodrigues, Teixeira, & Werner, 2022). This study adopts these principles to structure the VR-based mountaineering safety training, embedding authentic scenario design, iterative testing, and learner feedback to maximise cognitive and emotional engagement.

Participants were first introduced to the VR interface through a series of embedded interactive tutorials, designed to provide gradual familiarisation with the system. A demonstration of this onboarding process is available in the supplementary video here. These tutorials offered hands-on guidance on essential navigational skills, such as manoeuvring within the virtual environment, selecting menu options, and interpreting spatial and auditory cues. They also incorporated practical demonstrations of core in-app functions, including teleportation, environmental scanning, and interactive decision-making prompts. This structured, step-by-step orientation proved especially valuable for participants with limited prior exposure to VR, as it reduced initial anxiety, fostered a sense of control, and enhanced learner autonomy. By scaffolding the transition from novice user to active participant, the tutorials aligned closely with immersive learning principles, enabling participants to approach the simulation with greater confidence and preparedness (Makransky & Mayer, 2022).

Following the tutorial, each participant independently navigated the VR mountaineering training experience for approximately 5 minutes. The simulation was designed to immerse users in realistic, high-altitude climbing scenarios from a first-person perspective, allowing them to encounter and respond to various challenges associated with alpine environments. Key scenarios included navigating unstable terrain, assessing avalanche risks, responding to sudden weather changes, and making time-sensitive decisions in emergency contexts.

The immersive quality of the simulation was significantly enhanced by integrating multisensory cues. High visual fidelity was achieved by rendering detailed alpine landscapes and dynamically shifting weather conditions, which closely mirrored real mountain environments. Complementing these visuals, auditory elements—including the howling of wind, the crunch of snow underfoot, distant avalanches, and voice-over prompts—helped establish a compelling sense of environmental presence. These carefully designed sensory inputs were not only aesthetic features but were intentionally aligned with pedagogical objectives, aiming to trigger emotional engagement and replicate the cognitive demands of real-world high-risk contexts (Gaba, 2004; Slater & Sanchez-Vives, 2016). A demonstration of this immersive experience is available in the supplementary video here.

Throughout the session, participants encountered voice-guided prompts embedded within the narrative flow of each scenario. These prompts encouraged learners to assess risk, choose appropriate actions, and reflect on the consequences of their decisions. In doing so, the VR application supported experiential learning in line with Kolb's (1984) cycle—particularly the stages of concrete experience and active experimentation—while also reinforcing procedural memory and decision-making under pressure.

Overall, at this prototype stage, both the onboarding process and VR experience were delivered in English for participants in both cohorts. Future iterations of the application will include additional language options as the research develops. This structured and scaffolded approach to participant onboarding and simulation ensured a consistent and pedagogically sound learning experience across both Chilean and New Zealand cohorts. It also allowed researchers to observe a wide range of user behaviours, cognitive reactions, and emotional responses, providing a rich dataset for subsequent thematic analysis.

Figure 6.4

An instructor with a participant in Chile



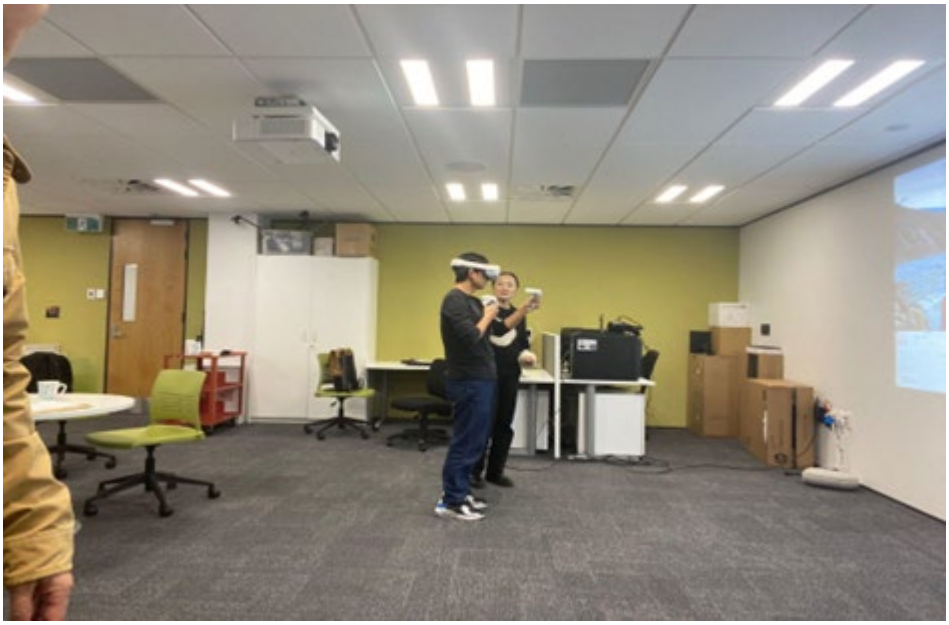
Figure 6.5

An instructor with a participant in New Zealand



Figure 6.6

An instructor with a participant in New Zealand



6.3.6 Debriefing and Post-Intervention Reflection

According to Fanning and Gaba (2007), well-organised debriefing is indispensable for "knowledge consolidation," as it provides a safe psychological space for learners to analyse their decision-making and errors. This phase of educational intervention shifts the focus from the "doing" of the simulation to the "understanding" of the underlying principles. In a high-stakes context like mountaineering, this process is vital for reinforcing safety-critical behaviours and ensuring that the learner leaves the session with a clear, corrected perception of their technical competence.

The debriefing process is an immediate verbal feedback session conducted in a semi-structured interview format. During the verbal feedback, participants were encouraged to articulate their overall impressions, emotional reactions, perceived realism, and key takeaways from the VR experience. Interview prompts invited participants to comment on the clarity of the simulation, the usefulness of decision-making scenarios, and the relevance of the training to their actual mountaineering practices.

In both Chile and New Zealand, the reflective dialogue revealed common themes across diverse user groups. Participants frequently emphasised the value of mental rehearsal, the safe environment for experiencing high-stakes decision-making, and the opportunity to visualise consequences without incurring real-world risk. Many also commented on the heightened emotional engagement elicited by the VR environment, particularly in response to time-pressured tasks and environmental hazards such as fog, wind, or terrain instability (see Chapters 7 and 8).

The debriefing sessions also served as a feedback mechanism for iterative improvement of the VR application. Several participants offered constructive suggestions for refining the user interface, expanding scenario diversity, and improving language accessibility, particularly among Chilean users who expressed a need for a fully localised Spanish-language version. These insights were systematically recorded and coded for inclusion in the broader thematic analysis, ensuring that the user voice played a central role in shaping subsequent design recommendations.

Notably, the debriefing phase facilitated the participants' emotional processing of the simulated experiences. As noted by Makransky and Mayer (2022), emotionally intense simulations can evoke stress responses that, if not appropriately addressed, may hinder learning rather than enhance it. Facilitated discussions allowed participants to unpack their feelings, compare experiences with peers, and gain validation for their reactions. This process not only reinforced learning objectives but also strengthened psychological safety, a foundational element in effective high-risk training environments.

In summary, the debriefing and reflective phases were not ancillary but essential components of the intervention, enriching both data collection and participants' learning journeys. The structured opportunity to reflect on the immersive training experience supported the internalisation of key safety concepts and clarified misunderstandings. It underscored the importance of affective and cognitive dimensions in high-risk outdoor education.

6.3.7 Observation and Data Collection

Throughout the immersive intervention, a multimodal data collection strategy was employed to capture a comprehensive view of participant engagement, cognition, and affective responses during the VR-based training sessions. Researchers conducted real-time, systematic observations of user interactions within the virtual environment, complemented by video recordings, audio feedback, and visual artefacts such as screen captures and photographs. This approach reflects established practices in qualitative and simulation-based research, where multiple forms of observational data are used to strengthen validity (Patton, 2015).

Key forms of observational data included:

- Verbal Responses and Self-Talk: Participants often articulated their reasoning processes during the simulation, providing insight into their decision-making strategies. These spontaneous utterances—ranging from expressions of confusion and surprise to reflective insights—provided an unfiltered view of their cognitive engagement. Such instances of self-talk served as real-time indicators of decision-making strategies, uncertainty management, and the interpretive framing of risks, echoing methods used in think-aloud protocols for cognitive task analysis (Ericsson & Simon, 1993).
- Body Language and Nonverbal Cues: Researchers carefully observed participants' physical comportment and micro-behaviours during the simulation, recognising these embodied cues as indicators of engagement and presence. Observable actions such as pausing before selecting an option, scanning the environment through deliberate head

movements, or leaning forward in moments of heightened tension provided valuable insights into participants' emotional involvement and situational awareness. A demonstration of these behaviours is available in the supplementary video here. These subtle, embodied responses are particularly significant in immersive learning contexts, where physical engagement often parallels affective investment and enhances the authenticity of tasks. Such findings reinforce arguments that immersive technologies foster not only cognitive but also behavioural and emotional dimensions of learning, blurring the line between simulated and real-world experience (Slater & Sanchez-Vives, 2016). By capturing these nuanced behavioural patterns, the study extended its analysis beyond self-reported data, incorporating observational evidence of how participants navigated risk, uncertainty, and decision-making in virtual high-altitude environments.

- Post-Session Interviews and Reflective Debriefing: After completing the VR experience, participants engaged in semi-structured interviews to elicit deeper reflections on their cognitive, emotional, and behavioural responses. These debriefings revealed moments of insight, stress, and surprise, offering valuable perspectives on how the simulation influenced their understanding of mountain hazards, decision-making, and preparedness. Several participants verbalised the emotional intensity of decision-making scenarios. For example, one explained, "When it asked me to make a decision, I felt a little scared—like if I choose wrong, something bad could happen", highlighting how

> the simulation created emotional tension around risk-based choices. Another reflected on physiological responses, noting, “My heart was beating faster, I think because it felt dangerous.” Similarly, one participant reported, “My heart was beating faster when I heard the voice telling me I had symptoms of altitude sickness,” directly linking bodily arousal to the perception of risk. Participants also emphasised the environment's immersive qualities. One described, “It is quite real, you can feel the wind noise, the environment of the mountains with the snow—it is like being in the mountains, and I thought it was a good experience. It really reflects the situation in a certain way.” Another climber added, “I actually felt nervous when I had to make a decision about the route, even though I knew it was not real.”

These reflective accounts enriched the dataset by situating in-simulation behaviours within participants’ subjective interpretations. This process aligns with Kolb’s (1984) experiential learning cycle, particularly the stage of reflective observation, where learners critically evaluate experiences to derive meaning and inform future practice.

In addition to verbal and behavioural data, researchers collected visual documentation, including photographs of participants during engagement, video footage of their real-time interactions, and screen captures from the VR application itself. These artefacts serve as critical analytical tools, providing both qualitative and illustrative evidence of participant experiences, interface interactions, and scenario progressions. They also support longitudinal reflection and comparison during the data interpretation phase.

Together, these data sources formed a holistic and ecologically valid record of participant engagement with the intervention, enabling the subsequent thematic analysis to be grounded in rich, contextualised, and multifaceted empirical evidence. This comprehensive observational framework enhances the study's rigour and reinforces the interpretive trustworthiness of its findings. As shown in the images below, the intervention process was carefully documented through observational records, offering valuable insights into participant interaction, levels of engagement, and the overall flow of the training sessions.

Figure 6.7

Observation in Chile



Figure 6.8

Observation in Chile



Figure 6.9

Observation in Chile



Figure 6.10

Observation in New Zealand



Figure 6.11

Observation in New Zealand



Figure 6.12

Vivid screen captures of the VR environments in Chile.

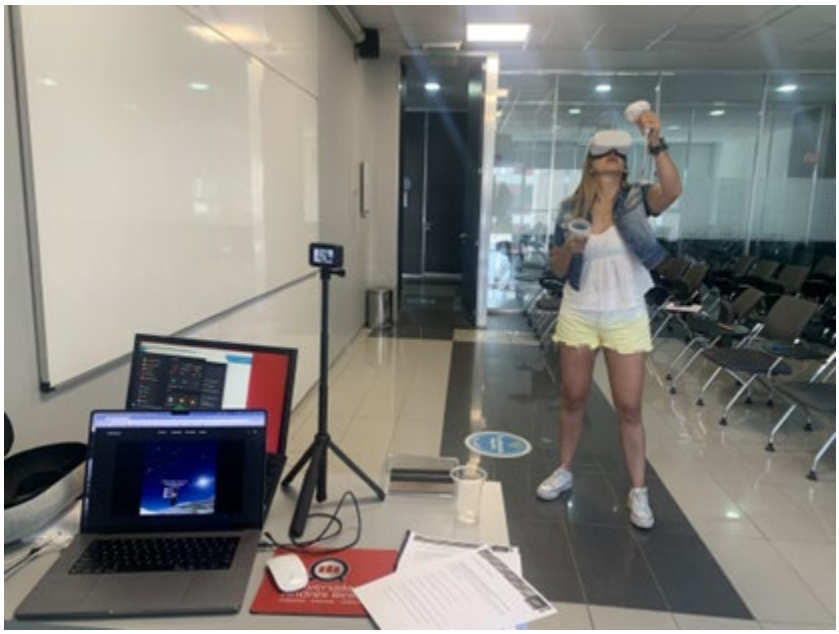


Figure 6.13

Vivid screen captures of the VR environments in Chile.

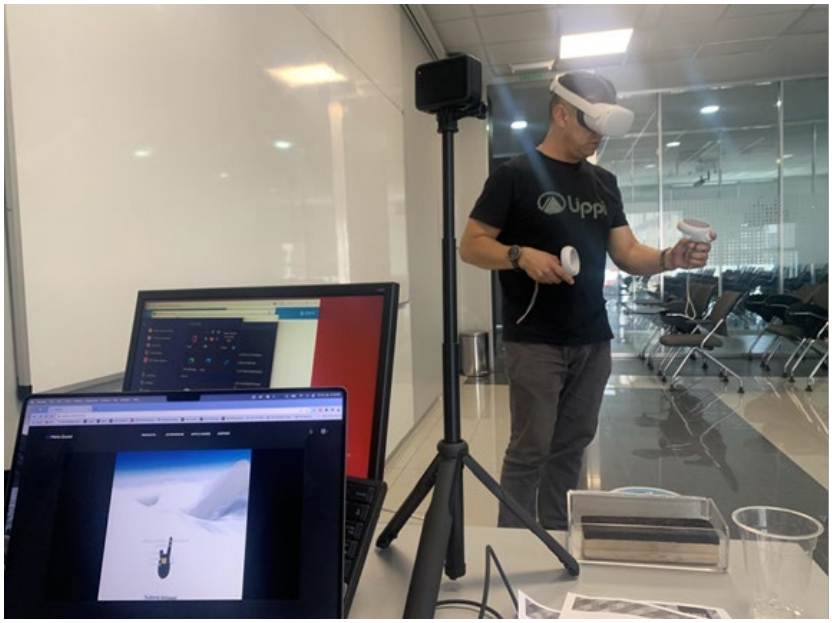


Figure 6.14

Vivid screen of the VR environments that participants navigated.

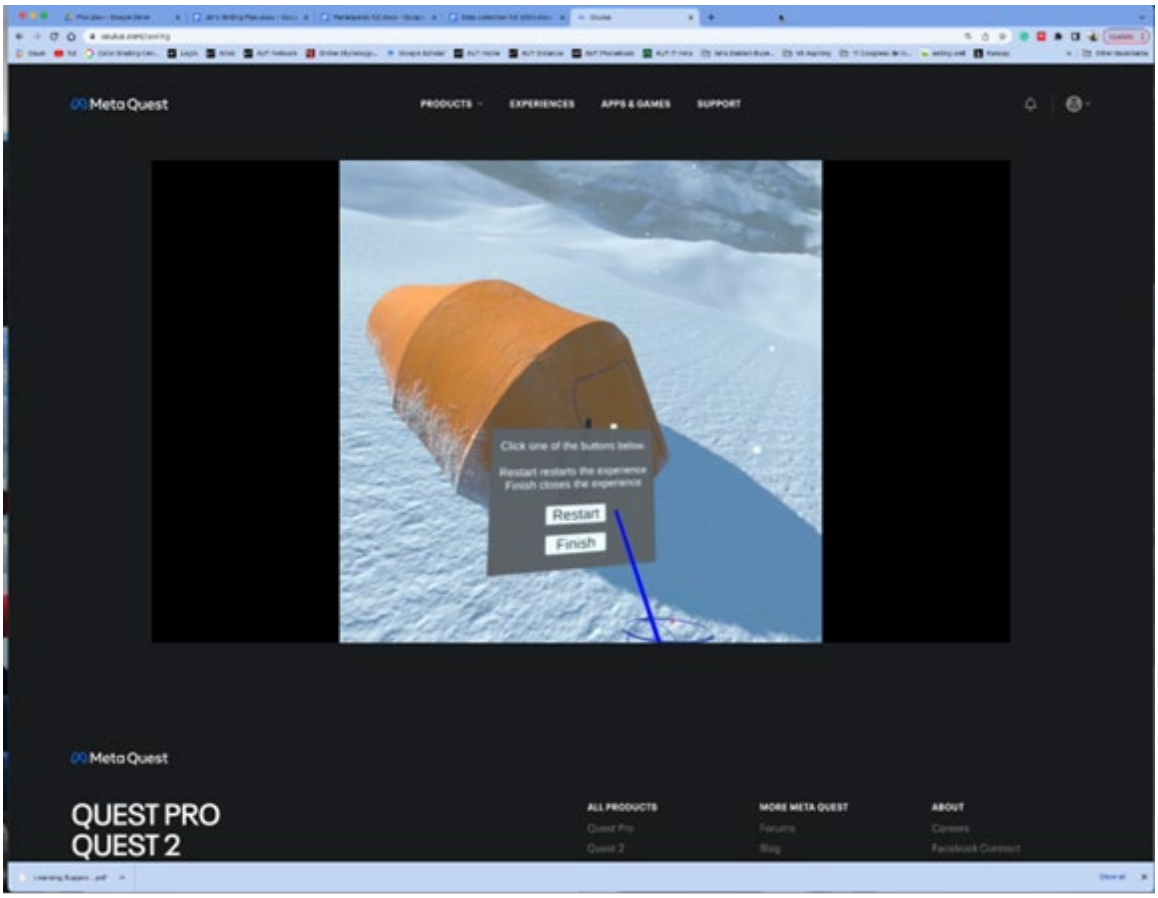
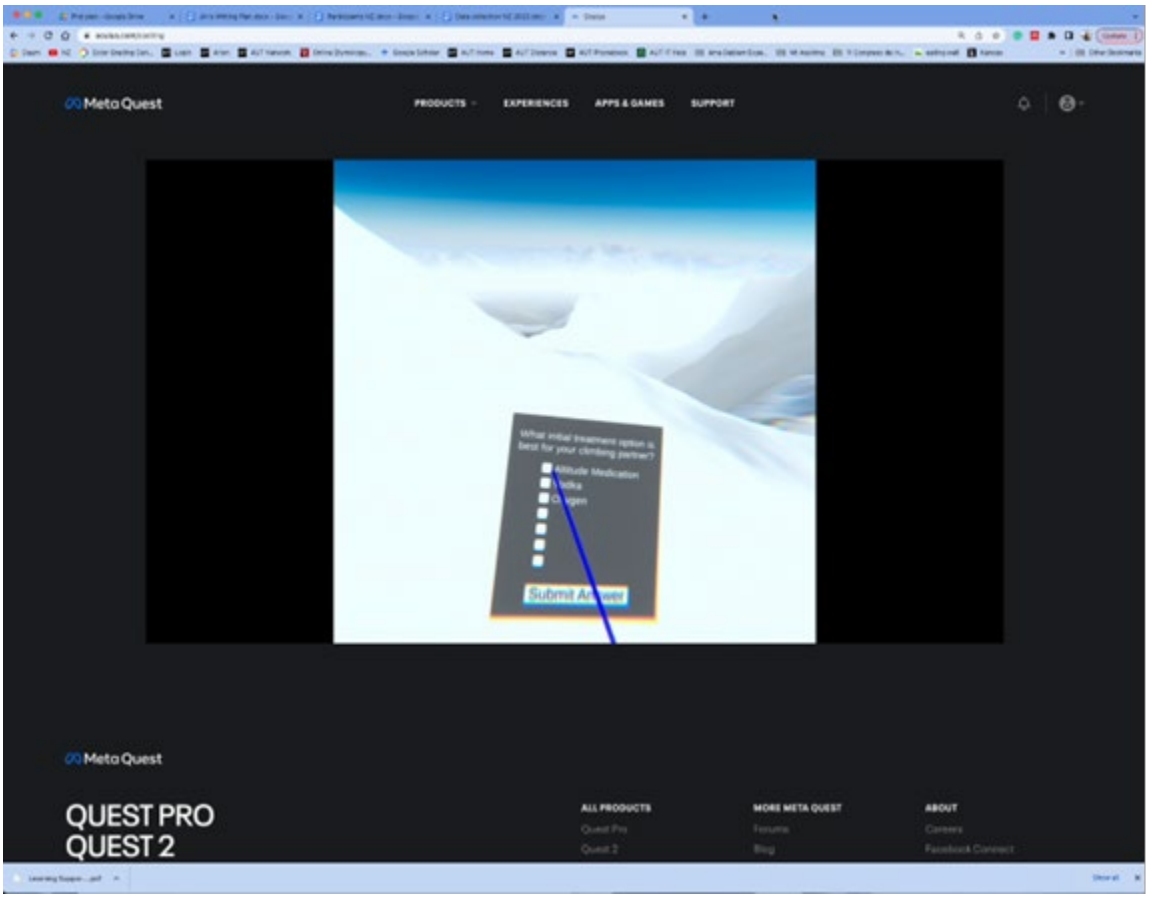


Figure 6.15

Vivid screen of the VR environments that participants navigated.

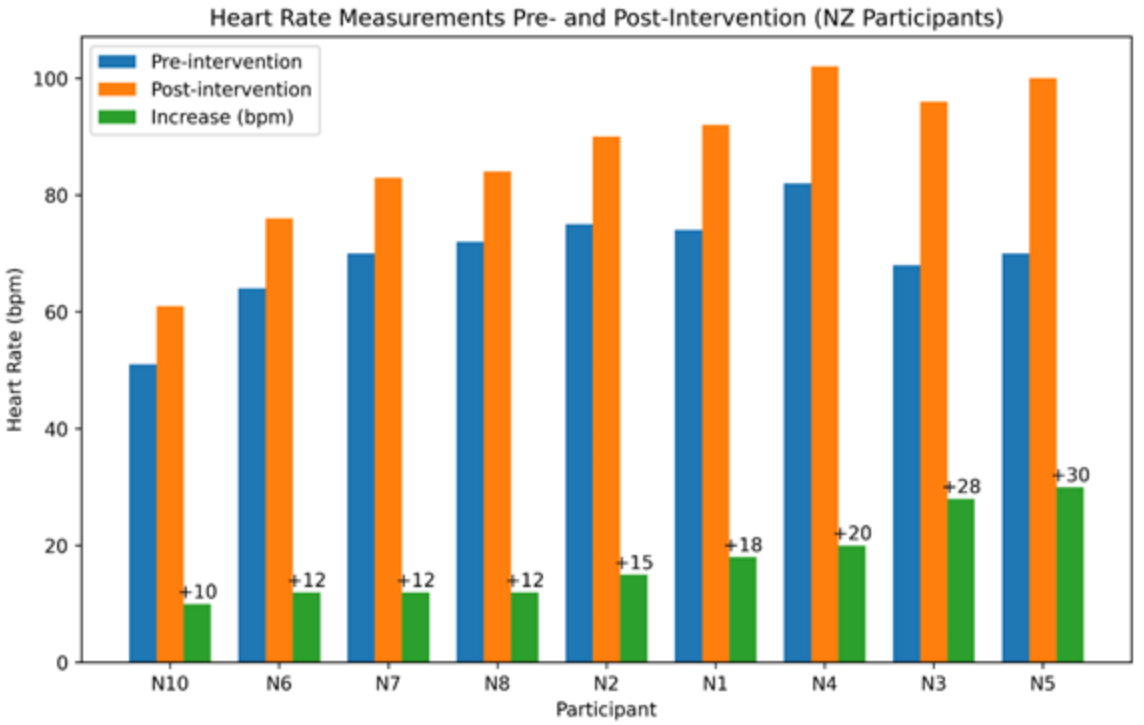


The following section presents the raw data collected during the intervention, which form the basis for the subsequent analysis presented in later chapters. The heart rate data for the New Zealand cohort shows (See Figure 6.16) a consistent upward trend from pre- to post-intervention across all participants with valid measurements, indicating a measurable physiological response to the VR-based mountain safety training. Resting pre-intervention heart rates ranged from 51 bpm (N 10) to 82 bpm (N 4), while post-intervention values ranged from 61 bpm (N 10) to 102 bpm (C 4). The magnitude of the

increase varied notably between individuals: N 5 (+30 bpm) and N 3 (+28 bpm) recorded the most significant increases, suggesting heightened arousal or engagement, whereas N 10 (+10 bpm) showed the smallest change. Moderate increases were observed among participants N 6 (+12 bpm), N 7 (+12 bpm), and N 1 (+18 bpm). One participant, N 9, had missing values due to a wearable malfunction, which slightly limited the dataset's completeness. Overall, the consistent post-intervention elevations in heart rate support the interpretation that the VR simulation successfully elicited physiological engagement, potentially reflecting immersive cognitive load, emotional involvement, or stress responses associated with the simulated high-risk scenarios.

Figure 6.16

Heart rate before and after VR intervention - NZ Cohort



The Chilean cohort's heart rate data reveals (See Figure 6.17) a consistent and notable increase from pre- to post-intervention, indicating heightened physiological engagement during the VR-based mountain safety training. Baseline resting heart rates ranged between 50 bpm (C 1) and 69 bpm (C 6 and C 4). Following the VR session, post-intervention heart rates rose substantially for all participants, with C 3 recording the highest at 126 bpm (+64 bpm) and C 1 showing a similar sharp increase to 112 bpm (+62 bpm). C 2 also demonstrated a marked rise of +50 bpm, while C 10 (+45 bpm), C 9 (+42 bpm), and C 4 (+42 bpm) exhibited robust elevations. More moderate increases were observed for C 5 (+40 bpm), C 7 (+36 bpm), and C 6 (+29 bpm).

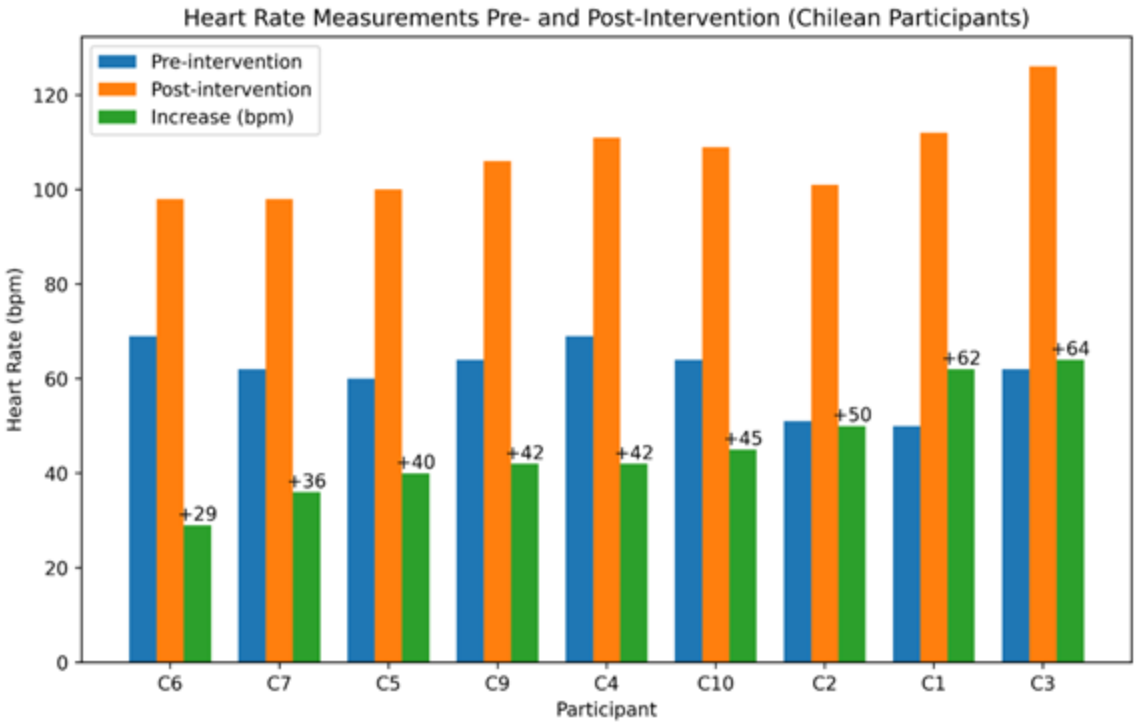
It is important to note that the heart-rate data were collected using the optical sensor of a commercially available Suunto watch and were not independently validated against a

chest-strap sensor or medical-grade equipment. Suunto advises that wrist-based optical heart-rate measurements are intended for recreational rather than medical use and may vary between individuals and activities (Suunto, n.d.). Therefore, these results should be interpreted cautiously as supplementary observations of changes in heart rate rather than as diagnostic or precise physiological measurements.

This trend indicates that heart rates increased during the immersive VR experience. However, given the limitations of the wrist-based optical measurement, these changes cannot be attributed to a specific emotional or physiological state. The variation across individuals may reflect a range of factors, including physical fitness, individual responses to the VR environment, movement during the activity, or familiarity with high-stakes mountaineering situations. When considered alongside the questionnaire, interview, and observational findings, the heart-rate data provide supplementary evidence of participants' engagement with the VR experience.

Figure 6.17

Heart rate before and after VR intervention - Chile Cohort



6.3.8 Participant Reactions

Participant responses to the VR-based educational intervention were overwhelmingly positive, underscoring the perceived value and relevance of the immersive training experience. Many participants expressed strong engagement, praising the application's ability to simulate high-risk scenarios in a realistic and emotionally impactful way.

One participant said: "I feel like I'm really there, it's so real with the sound of wind and snow." (Chilean cohort). Participants explicitly stated that VR felt "something more real" and "closer to practice." The opportunity to mentally rehearse critical decision-making processes in a controlled, consequence-free environment was frequently cited as a significant strength of the intervention. Research suggests that immersive simulations can

enhance learners' cognitive engagement and risk awareness in complex environments. (Radianti et al., 2020).

Numerous participants, particularly novice climbers, noted that the VR environment provided a psychologically safe space in which they could make mistakes, learn from them, and build confidence without facing the physical dangers typically associated with high-altitude mountaineering. Some participants from Chile commented on the learning value, with one saying: "This is a good way to practice without danger", highlighting VR's role as a safe training environment. Some New Zealand participants also noted the training value, saying, "This is good for beginners, we can practice without danger", framing VR as an accessible learning tool.

The interactivity and scenario-based learning design were described as "engaging," "realistic," and "motivating," further reinforcing the application's pedagogical efficacy. It reflects the principles of Kolb's (1984) Experiential Learning Cycle, particularly the phases of active experimentation and reflective observation, where learners engage with complex tasks and subsequently process those experiences to derive meaningful insights.

However, several challenges emerged that warrant attention in future iterations of the application:

- Visual Discomfort and Interface Design: A recurring issue concerned visual clarity within the VR headset. Three participants—particularly those wearing prescription glasses—reported difficulty focusing, citing blurred vision, poor calibration, and reduced text legibility. As one Chilean participant observed, "I

was surprised by how real the environment looked… but sometimes the graphics were not clear, so it distracted me." A New Zealand participant echoed this sentiment: "The environment feels alive, but the graphics could be clearer." These limitations disrupted immersion and hindered instructional coherence, underscoring the need for adjustable visual and interface options to accommodate diverse users (Gaba, 2004).

- Language Barriers and Cultural Accessibility: In Chile, the absence of a Spanish-language version of the application posed a significant obstacle. Participants consistently highlighted difficulties in navigating menus and understanding prompts delivered in English. One participant remarked during onboarding, "I don't understand all the instructions… it would be better in Spanish." Another explained, "I had difficulty answering questions in English; it made me nervous." For these users, language barriers introduced an additional layer of cognitive load, diverting attention from the core safety scenarios to translation and comprehension tasks. This finding reinforces the importance of linguistic localisation in educational technology. As Gay (2018) emphasises in culturally responsive teaching, accessibility is inherently tied to language and overlooking this dimension risks excluding key learner groups.
- Cognitive Overload Among Novices: Participants with limited digital literacy or VR experience reported feeling overwhelmed by the simultaneous demands of the simulation. They struggled to manage environmental scanning, navigation, and decision-making under pressure. One Chilean participant

admitted, “Sometimes I didn’t understand the questions; I needed help from the researcher.” Similarly, a New Zealand participant said, “I started to feel stressed when I couldn’t decide which way to go.” These reactions suggest instructional overload, especially where technical navigation intersected with linguistic challenges. Emotional arousal also played a role; as one participant reflected, “It feels so real, I actually felt nervous when I heard the wind.” Others expressed frustration when expected affordances were absent: “I didn’t have my walkie-talkie… I was missing equipment.” Such discrepancies between real-world mountaineering practices and virtual design increased cognitive demands by forcing participants to reconcile gaps between simulation and reality. These findings align with cognitive load theory, which emphasises the importance of scaffolding and progressive task design to mitigate overload in novice learners (Sweller, Ayres, & Kalyuga, 2011).

Despite these limitations, the overall reception of the VR intervention was highly favourable. Participants consistently affirmed the training's value in enhancing their understanding of safety protocols, improving situational awareness, and building emotional resilience. The application was widely viewed not as a replacement for real-world training, but as a complementary tool that could significantly augment traditional pedagogical strategies, particularly for learners who face logistical, geographic, or experiential barriers to on-site mountaineering education.

In summary, participant feedback reinforces the potential of VR as a viable and impactful training modality in high-risk educational environments. The findings from this

intervention highlight both the promise of immersive technologies and the need for continued refinement to ensure usability, accessibility, and contextual relevance across diverse learner populations.

6.4 Findings

The findings indicate that immersive VR has considerable potential as a tool for supporting cognitive training in mountain safety education. Through its immersive and engaging design, the VR application enabled participants to practise essential skills—such as risk assessment and emergency response—within a safe, simulated environment (Makransky & Lilleholt, 2018; Wiederhold & Riva, 2019).

Participants widely reported high levels of engagement, frequently describing the experience as immersive and stimulating, which aligns with previous studies suggesting that immersive technologies may enhance learner motivation and attention through increased perceptions of presence (Parong & Mayer, 2018). However, some usability challenges were identified, particularly around language accessibility and visual clarity, emphasising the importance of inclusive, user-centred design in educational VR tools (Dede, 2009). Novice climbers, in particular, valued the intervention as a preparatory tool, allowing them to rehearse decision-making and safety practices in a low-risk setting (Radianti et al., 2020). Chilean participants further recommended adapting the content to better reflect local environmental conditions—such as lower altitudes and warmer climates—thereby underscoring the need for culturally and geographically relevant simulations (Merchant et al., 2014).

Cross-country comparisons revealed notable differences. Chilean participants exhibited significantly greater increases in heart rate following the intervention, suggesting stronger emotional and physiological engagement, consistent with previous findings linking heart rate changes to immersion and psychological arousal in VR settings (Meehan et al., 2002). This heightened reactivity may be attributed to the Chilean group's more advanced mountaineering experience, which likely made them more attuned to the realism and risks portrayed in the simulation. In addition, language barriers may have influenced participants' physiological responses. Several Chilean participants reported difficulty following English instructions and answering questions during the VR session, which may have increased cognitive load and, in turn, contributed to elevated heart rates. They expressed a preference for a Spanish-language version of the application, underscoring the importance of localisation to enhance both accessibility and comfort.

In contrast, New Zealand participants, primarily beginners or intermediates, demonstrated more moderate physiological responses and described the experience as applicable but less intense, possibly due to their limited exposure to real high-risk scenarios (Slater & Sanchez-Vives, 2016). While both groups were receptive to the VR training, the Chilean participants offered more critical, experience-based feedback, whereas the New Zealand cohort highlighted its utility for introductory learning. It aligns with prior research suggesting that VR is particularly effective for learners with limited real-world experience (Makransky et al., 2021).

These findings have clear training implications. For Chilean climbers, VR may be best applied as a high-fidelity simulation tool to enhance psychological preparedness and decision-making under pressure (Krokos et al., 2019). For the New Zealand group, VR offers an accessible and engaging entry point for developing foundational skills, enhancing risk awareness, and promoting cognitive readiness in a controlled environment (Radianti et al., 2020).

6.5 Summary

While virtual reality (VR) cannot fully replicate the physical exertion, environmental unpredictability, or multisensory stimuli associated with high-altitude mountaineering—such as the tactile sensation of cold, altitude-related fatigue, or shifting terrain—this intervention nonetheless demonstrated substantial value in using VR as a cognitive and affective training aid for mountain safety. The immersive, scenario-based design allowed participants to engage meaningfully with complex decision-making tasks, hazard recognition, and emergency response protocols in a psychologically safe environment, without exposure to the inherent risks of real-world alpine settings. When VR is thoughtfully designed, contextually adapted to reflect local environmental conditions, and accompanied by structured onboarding that introduces both the technological interface and safety learning objectives, it can effectively foster the development of key competencies such as situational awareness, cognitive preparedness, and risk perception (Dede, 2009; Slater, 2009). These outcomes are particularly critical in mountaineering, where rapid judgment, environmental interpretation, and emotional regulation are essential to safety and survival.

This chapter details the implementation and evaluation of a VR-based educational intervention designed for Chilean mountaineers, situated within the broader framework of a comparative study that includes participants from New Zealand. The findings contribute to the growing body of empirical evidence supporting the integration of immersive technologies into outdoor safety education and experiential learning programs. Moreover, the study underscores the importance of tailoring VR content not only to users' skill levels and cultural contexts but also to their physiological and emotional readiness to engage with high-stakes scenarios in simulated environments. As experiential learning increasingly moves into digital domains, interventions like this one point to a promising future in which virtual training environments complement—and in some cases enhance—traditional field-based instruction, particularly for novice learners and geographically isolated populations who may otherwise lack access to structured mountaineering education.

Chapter 7: Thematic Analysis

7.1 Introduction

Virtual reality (VR) technologies have gained increasing attention in the field of outdoor education and risk management training due to their capacity to deliver immersive, repeatable, and context-specific learning experiences. As mountaineering and alpine recreation involve complex decision-making under unpredictable and often hazardous conditions, innovative training approaches are required to prepare individuals for real-

world challenges. Virtual reality provides an interactive training environment in which learners can rehearse safety procedures, simulate emergency decision-making, and develop cognitive preparedness for hazardous situations without exposure to physical risk (Radianti et al., 2020; Slater & Sanchez-Vives, 2016).

This chapter presents a thematic analysis of user experiences with VR-based mountain safety training in two distinct geographical and cultural contexts: Chile and New Zealand. Drawing on qualitative feedback from study participants, the analysis identifies core themes related to the immersive potential of VR, cognitive and psychological benefits, sensory limitations, contextual relevance, and implementation challenges. The findings are interpreted through the dual lens of Experiential Learning Theory (Kolb, 1984; see Section 2.3.6) and Immersive Learning Design Principles (Makransky & Lilleholt, 2018; see Section 2.6), providing a framework to evaluate both the pedagogical affordances and the inherent limitations of VR as a tool for mountaineering safety training.

While both countries share a strong mountaineering culture and exposure to alpine risk, their socio-economic, linguistic, and environmental contexts differ substantially. These differences provide a valuable comparative lens for exploring how VR training must be adapted to ensure accessibility, cultural relevance, and educational efficacy. In particular, this chapter highlights the importance of localised content, usability enhancements, and integration with existing training frameworks to maximise the impact of VR in high-risk outdoor education.

The chapter is structured around six interrelated thematic domains: (1) immersive potential and usability gaps, (2) cognitive and psychological benefits, (3) limits of simulated

experiences, (4) features needed for realism and relevance, (5) cost, access, and cultural acceptance, and (6) recommendations for future development and implementation. These findings offer actionable guidance for developers, educators, and policymakers seeking to integrate VR into mountain safety training programs across diverse contexts.

7.2 Thematic analysis

This study employed thematic analysis to examine participants' experiences with VR-based mountain safety training in Chile and New Zealand. The approach provided a systematic framework for interpreting participants' reflections on the VR training application and enabled the researcher to move beyond simple descriptions of responses. Instead, the analysis focused on identifying recurring patterns in how participants perceived the realism, usability, educational value, and limitations of the virtual training environment. By organising these patterns into themes, the analysis generated a structured understanding of how the VR training was experienced across the two study contexts.

Thematic analysis is a qualitative analytical method used to identify, organise, and interpret patterns of meaning within qualitative datasets. Through the process of coding and theme development, researchers can examine how participants interpret their experiences, behaviours, and social contexts (Braun & Clarke, 2006, 2012). One of the key strengths of thematic analysis lies in its methodological flexibility. The approach is not restricted to a single theoretical framework and can therefore be applied across a range of research paradigms, including realist, interpretivist, and constructionist perspectives. This flexibility has contributed to its widespread use across disciplines such as psychology, education, sociology, healthcare, and media studies.

In qualitative research, thematic analysis enables researchers to explore deeper meanings embedded in data sources such as interviews, open-ended questionnaires, focus group discussions, and field notes. Within this analytic approach, a theme represents a meaningful pattern in the data that is relevant to the research questions and captures important aspects of participants' experiences (Braun & Clarke, 2006). By systematically organising coded data into themes, researchers can develop a coherent interpretation of how individuals understand and respond to particular phenomena.

Another advantage of thematic analysis is its adaptability to different research designs and epistemological perspectives. Unlike more theory-bound qualitative methodologies, such as grounded theory or ethnography, thematic analysis allows researchers to tailor the analytic process to the specific objectives of the study while maintaining methodological transparency and rigour. When implemented systematically—such as through the six-phase analytic framework proposed by Braun and Clarke (2006)—the method provides a clear and structured approach for organising qualitative data while remaining sufficiently flexible to accommodate complex interpretations.

For this research, thematic analysis was particularly appropriate because the study sought to understand how participants experienced and interpreted VR-assisted mountain safety training. The method enabled the identification of both shared patterns and individual variations in participants' responses, providing insight into how users engaged with the immersive training environment and how they evaluated its potential as a tool for mountaineering safety education.

According to Braun and Clarke (2006), the six-phase framework is one of the most influential and widely applied models for conducting thematic analysis. The process is not entirely linear; researchers often move back and forth between phases as they refine their understanding of the data.

- Familiarisation with the data: The first phase of thematic analysis involves developing a thorough understanding of the dataset. During this stage, the researcher repeatedly reviews interview transcripts, observational notes, or other collected materials in order to become fully immersed in the data. As the material is examined, preliminary observations, reflections, and potential points of interest are recorded through initial notes or memos. This process enables the researcher to gain a comprehensive sense of the scope and depth of the data, forming the foundation for subsequent stages of coding and thematic development.
- Generating initial codes: In the second phase of the analysis, the researcher systematically examines the dataset to identify meaningful segments of information and assign descriptive labels to them. These labels, or codes, represent concise summaries of specific ideas, actions, or perceptions expressed in the data. Each code captures a distinct concept—for example, issues related to clarity, emotional reactions, or technical difficulties. Coding may focus on semantic content, which reflects explicit statements made by participants, or latent meanings, which involve interpreting underlying assumptions, ideas, or patterns embedded within the data, depending on the analytical objectives of the study.
- Searching for themes: At this stage of the analysis, the researcher moves beyond individual codes to identify broader patterns of meaning within the dataset. Related

codes are systematically examined and grouped according to conceptual similarities, allowing preliminary themes to emerge. These provisional themes represent recurring ideas or issues relevant to research questions. Researchers often use visual tools—such as thematic maps, coding matrices, or diagrams—to assist in organising relationships between codes and supporting the development of coherent thematic structures.

- Reviewing themes: At this stage, the preliminary themes are critically examined and refined to ensure that they are conceptually coherent, internally consistent, and clearly distinguishable from one another. This process typically occurs at two analytical levels. First, the researcher reviews the coded data extracts within each theme to confirm that they form a meaningful and consistent pattern. Second, the themes are evaluated in relation to the entire dataset to ensure they accurately represent the broader data. During this stage, some themes may be merged, subdivided, redefined, or removed if they do not sufficiently capture significant patterns within the data.
- Defining and naming themes: In this stage, the researcher refines and clearly articulates the meaning of each identified theme. Each theme is carefully defined to capture its central idea and is assigned to a concise and descriptive label that reflects its core concept. The researcher explains what the theme represents, how it contributes to addressing the research questions, and how it differs from other themes within the dataset. This interpretive process may also involve identifying related sub-themes and developing analytical descriptions that illustrate how the theme is expressed across the data.

- Producing the report: The final phase involves integrating the developed themes with relevant data extracts and the researcher's analytical interpretation to produce a coherent and well-structured narrative. In this stage, the analysis is presented in a way that clearly demonstrates how the themes were derived from the data and how they relate to the research questions. Selected excerpts from the dataset are used to illustrate and support each theme, while the accompanying discussion interprets their significance in relation to the study's conceptual or theoretical framework. The aim is to present a clear and persuasive account of the findings that contribute meaningful insights to the research problem.

Through this structured analytic process, the thematic analysis generated a detailed understanding of how users perceived the immersive potential, educational benefits, practical limitations, and implementation challenges associated with VR-assisted mountain safety training in both Chile and New Zealand.

7.3 Thematic analysis: VR-assisted Mountain Safety Training in Chile and New Zealand

7.3.1 General Experience with the VR App

Participants in Chile consistently found the audio component of the VR experience to be highly immersive and engaging, significantly enhancing their sense of presence and making them feel as though they were situated in a real alpine environment. (See more details Appendix K, Chile Theme Codebook).

"I think that at least the audio part is really well done. I knew that it was a simulation, but the audio part really gets the job done to involve you in that scenario" (Participant C 1).

“In general terms, it is quite real, you can feel the wind noise” (Participant C 4).

However, issues with visual clarity—such as blurry screens and limited focus adjustment—were frequently noted, detracting from the overall realism of the experience. While the sound design was widely praised for enhancing the training's immersive quality, participants suggested that improving visual resolution and adding adjustable focus settings would further strengthen the simulation’s authenticity and usability.

“And of the visual part, it's blurry. It's blurry because you need to focus using edgers, so it's blurry” (Participant C 1).

Additionally, several participants expressed a need for pre-training support to better understand how to navigate the VR controls and interface menus.

“Maybe some pre-training for understanding how to use the controls, the buttons... I needed some training, some help from you” (Participant C 2).

Additionally, language barriers—particularly the absence of a Spanish-language option—posed challenges for non-English-speaking users.

“Yes, definitely, an international version, like Spanish, English, French, Italian etc” (Participant C 1).

“I don’t understand all the instructions… it would be better in Spanish” (Participant C 3).

“I had difficulty answering questions in English; it made me nervous” (Participant C 7).

To enhance accessibility and the overall user experience, it was recommended that the application incorporate structured onboarding tutorials alongside multilingual support

options—such as Spanish and French—to better accommodate diverse participants and reduce potential barriers to engagement. Therefore, as part of the DBR methodology, findings from the Chilean intervention directly informed the design modifications trialled in New Zealand. Feedback from Chile revealed that participants—particularly those with limited exposure to virtual reality—struggled with the lack of clear guidance during onboarding and had difficulty hearing voice-over instructions in immersive environments.

In response, the researcher and developer incorporated two key refinements before the New Zealand phase. First, an interactive onboarding tutorial was introduced to familiarise participants with the VR interface, including basic navigation, menu selections, and decision-making functions. This scaffolding was designed to reduce initial cognitive load and provide a smoother transition into the high-altitude simulation. Second, the volume of instructional audio was increased to enhance clarity and ensure that participants could follow prompts more effectively, even when layered against environmental sound effects such as wind or avalanches.

While these changes addressed some of the technical and perceptual barriers identified in Chile, they remained partial solutions. Importantly, multilingual support was not implemented at this stage, leaving the application entirely in English. For Chilean participants, this omission posed a persistent challenge, as comprehension difficulties during onboarding and decision-making tasks increased cognitive load. From a DBR perspective, the New Zealand iteration illustrates the value of responsive design adjustments and underscores the importance of cultural and linguistic inclusivity in subsequent refinements.

In this way, the iterative cycle between Chile and New Zealand demonstrates how empirical data were used to progressively enhance the VR prototype. Technical refinements improved usability and engagement, but gaps in linguistic accessibility highlight the ongoing need for localisation strategies in order to achieve broader educational relevance and inclusivity across diverse learner groups.

Participants in New Zealand described the VR environment as highly immersive, frequently highlighting the impact of realistic visual and auditory cues such as wind, snowfall, and ambient mountain sounds. These sensory elements contributed to a strong sense of presence and engagement. Many users reported experiencing emotional responses—most notably fear and anxiety—which suggests that the simulation effectively conveyed the psychological intensity characteristic of real alpine conditions.

“It's very real... and I feel a little bit nervous in the beginning” (Participant N 4).

“Good, something new. Well, I can compare it with watching videos or reading some books, but this is more interactive” (Participant N 8).

“Well, it's a good opportunity to immerse yourself in a simulated alpine environment and make decisions as if you were there” (Participant N 10).

However, while this heightened realism enhanced the overall training experience, it also proved intimidating for some participants, particularly those with less mountaineering experience. This feedback highlights the importance of incorporating onboarding tutorials or guided orientation modules to help users acclimate the virtual environment in a gradual and supportive manner.

“It really feels a little scary. Mhmm. It's big, it's like you imagine yourself in that situation Mhmm. Authentic. Like changing the scenery or something like the snow comes in” (Participant N 1).

“It's very real. Very real, yeah, and I felt a little bit nervous in the beginning. Okay. Because I suddenly went into the mountains. Oh, because you are suddenly into the mountains” (Participant N 4).

Additionally, participants identified several usability challenges that impacted their interaction with the VR training environment. Some participants who wore prescription glasses reported discomfort and reduced visual clarity when using the Oculus Quest 2 headset.

“I think the only thing is like in the beginning, I don't know how to use the devices” (Participant N 4).

“I can't see it quite clearly there. That's the problem because of my glasses. Okay. Yeah. I think the headset can be adjusted” (Participant N 1).

This limitation was primarily due to the headset's physical fit over glasses, which made it difficult to maintain proper focus and comfort during the simulation. Although Oculus provides prescription lens inserts as an optional accessory to mitigate this issue, these were not available or feasible for the present study. Consequently, the visual discomfort reported here should be understood as a contextual constraint of the research setup rather than a universal technical shortcoming of the device itself. It was not well-suited for individuals who require optical aid. In addition, non-native English speakers experienced difficulties

understanding the instructional content and navigating the menus, underscoring the need for multilingual support, replay functions, and clearer user interfaces.

“English is not my first language, so I sometimes maybe missed the question or like a hint... [I would] replay it again” (Participant N 1).

To enhance accessibility and usability, participants recommended including focus calibration settings and localised content to better accommodate diverse user needs and improve the overall learning experience.

Table 7.1

General experience with the VR App

Theme	**Theme code**	Participant Comment
Immersion and Psychological Engagement	1.15 3.055	Participants highlighted the realism of the alpine environment, including weather effects, and found navigation relatively intuitive, which fostered immersion.
Usability Challenges - instruction	3.060 3.070	Some participants struggled with the initial learning curve, emphasising the importance of onboarding tutorials to improve accessibility and ease of use.
Functional issues - visual and audio issues	3.070	Several participants—especially those wearing prescription glasses—reported blurred imagery, poor focus calibration, and difficulties reading in-app text. In the Chilean intervention, participants reported low sound levels and difficulty hearing instructions, resulting in confusion during decision-making tasks.
Language barrier and accessibility	3.095 3.060	Some participants reported difficulties understanding the English instructions, as it was not their first language. This language barrier reduced their ability to engage with the VR simulation fully and

		highlighted the need for multilingual support to improve accessibility and inclusivity
Good pre-training tool	4.30	Participants consistently described the VR application as a valuable *pre-training tool* that allowed them to rehearse safety strategies before attempting real-world climbing.
Authentic environment	2.15	Participants highlighted how realistic visual, auditory, and interactive cues made the experience feel comparable to actual high-altitude conditions.

7.3.2 Benefits of VR for Mountain Safety Training

Participants in Chile emphasised the value of VR as a preparatory tool that enables climbers to practice decision-making and safety procedures in a controlled, risk-free environment. This was particularly beneficial for novice climbers, as the simulation helped bridge the gap between theoretical knowledge and real-world application, fostering confidence and readiness before engaging in actual high-risk alpine activities.

“Because of some common experience, you can prepare it here, but those are so specific and special, that I think being exposed to that previously and to make decisions, maybe it will help” (Participant C 9).

“You don't need to be in the mountains to train in some factors, like mental factors or decision-making... you don't have to be in the mountains” (Participant C 3).

Participants also reported that VR-based training supported the development of problem-solving skills, particularly in simulated emergency scenarios requiring quick decision-making. The interactive and experiential nature of the training was seen to enhance

memory retention more effectively than traditional, passive classroom methods. Additionally, the immersive experience contributed to mental preparation, helping users rehearse responses to high-pressure situations.

“It's like theory and practice at the same time... it stores the actions, it memorises the actions... [and is] more efficient compared to a simple theory delivered in a classroom” (Participant C 5).

“I think it's a more interactive way to learn... if it's developed in advance... then it would benefit mountain safety” (Participant N 3).

“Because you feel like you are in that environment. So, it's more engaging. You feel like you are in the environment, right? In an authentic environment” (Participant N 4).

“I like the idea of... practising certain... emergency scenarios in a safe environment before doing it in a potentially dangerous environment” (Participant N 7).

However, participants also acknowledged that while VR strengthens cognitive readiness, it cannot replace the need for physical training in real environments, where variables such as fatigue, weather, and terrain play a critical role in shaping climber performance.

“A disadvantage can be…. that it doesn't involve physical activity; it can …different … physically involved. If you teach …, right? This one, it's a bit hard” (Participant C 3).

“The main disadvantage would be the lack of equipment. And, for someone who has done mountains, it's the lack of reality” (Participant C 7).

“There is certain, you know, ….., a lot of the physical aspects of the situation … recreate. …was helpful” (Participant N 7).

Participants in New Zealand described VR as a risk-free and highly effective platform for developing essential technical skills, navigation strategies, and survival techniques in high-risk alpine contexts. This simulated environment enabled users—especially novice climbers—to build confidence and foundational competence before encountering real-world conditions. Many participants reported feeling better prepared for field-based activities after engaging with virtual training.

"You get involved in it, like being in action, and without any harm to yourself" (Participant N 8).

"I think it would be quite useful especially for beginners because they are not ready to get into those harsh and dangerous environments yet" (Participant N 5).

A key strength of the VR experience was its ability to offer repeated exposure to high-stakes scenarios, such as avalanche responses and altitude sickness identification. This repetition was perceived as critical for reinforcing procedural memory and enhancing decision-making speed and accuracy. However, participants also acknowledged the limitations of simulation, noting that VR cannot replicate the full range of environmental stressors—such as cold, fatigue, or hypoxia—that significantly affect judgment and behaviour in real mountaineering situations. As such, VR was viewed as a powerful complement to, but not a substitute for hands-on physical training.

Table 7.2

Benefits of VR for Mountain Safety Training

Theme	**Theme code**	Participant Comment

Preparation before real expeditions	3.065 2.15	Participants emphasised the role of VR as a preparatory tool, allowing them to rehearse scenarios before facing them in the mountains. The ability to simulate risk without exposure to physical danger created a bridge between theoretical knowledge and experiential practice.
Safe and controlled learning environment	3.080 2.20	VR offered participants a safe space to experiment with decision-making, failure, and recovery. Unlike real mountains, where errors may lead to injury or fatality, the virtual setting allowed learners to "fail safely".
Support for decision-making and procedural memory	2.20	Several participants described how VR helped them practice structured decision-making under pressure. Repeated exposure to critical scenarios (e.g., recognising acute mountain sickness, responding to weather changes) reinforced procedural memory, making responses more automatic.
Cognitive & psychological advantages	2.15 2.10	Participants reported feelings of nervousness, excitement, or stress that mirrored the real pressures of an expedition.

7.3.3 Limitations & Challenges of VR for Mountain Training

Participants in Chile emphasised that while VR offers a cognitively rich and immersive environment, it fails to replicate key physical stressors integral to real-world mountaineering, such as cold temperatures, physical exhaustion, and altitude sickness.

"A disadvantage can be that it doesn't involve physically... If you teach students how to use a rope or harness... this one, it's a bit hard" (Participant C 3).

"It's not the same as when you make a decision... being exhausted. When you are exhausted, the patience is less and the anguish is greater" (Participant C 5).

“Yeah, experience. Maybe being here in this experience, you know that you are in a virtual experience and you are not in the stress of doing the decision-making with the stress. It's very different to being at home” (Participant C 3).

These physiological factors are known to affect judgment and decision-making, and their absence in the simulation led some users to feel overly comfortable, making critical decisions in VR that would be far more challenging under real-world stress conditions.

Several users noted that the lack of tactile or haptic feedback—such as the ability to feel cold or physical fatigue—limited their ability to assess risk in the virtual environment fully. As a result, decision-making in VR did not adequately mirror the cognitive strain or physical limitations experienced in real-life alpine settings. Participants agreed that, to support realistic skill development, VR should be integrated into a blended learning model that combines immersive simulations with field-based physical training to expose learners to authentic environmental challenges.

“It's you having a controller versus actually working with gear... ropes, all of that stuff” (Participant N 7).

In New Zealand and Chile, participants noted that the VR training environment, although immersive, could not simulate the critical physical conditions inherent to alpine environments. Specifically, the simulation did not replicate cold temperatures, wind intensity, or altitude-related physiological effects such as hypoxia.

“Like you cannot feel the cold weather. So, it's not a real experience. And in that situation, you might be scared or more nervous” (Participant N 3).

“You don't get the full experience... fatigue, cold weather... [and] altitude sickness... impact judgment... it can't be reproduced in VR” (Participant N 5).

"It is a good approach to this kind of topic, but it wouldn’t replace technical experience” (Participant C 9).

As a result, essential experiential components—including fatigue, physical discomfort, and altitude sickness—were absent, which significantly reduced the overall realism and ecological validity of the experience.

This limitation raised concerns about the potential for overconfidence, particularly among inexperienced climbers who may conflate success in a controlled VR environment with readiness for high-risk, real-world scenarios. Several participants stressed that VR should be regarded as a supplementary tool rather than a substitute for hands-on, physical mountaineering training.

“If it's like a beginner, they probably overlook something... they thought they knew everything. But... you cannot include all of the things” (Participant N 1).

"I could tell it can be overconfidence because of the app” (Participant C 2).

Table 7.3

Limitations & Challenges of VR for Mountain Training

Theme	**Theme code**	Participant Comment

Lack of Physical Sensation & Environmental Stressors	1.101	Participants frequently noted that the VR simulation could not replicate key physical sensations such as cold, fatigue, or the bodily strain of climbing. These absent stressors reduced the authenticity of the experience, highlighting a gap between the simulated and real high-altitude environments.
Absence of Physical Environmental Conditions	2.15 3.060 3.105	Beyond personal sensations, the lack of broader environmental conditions—such as sudden temperature drops, unstable terrain underfoot, or reduced oxygen levels—was a recurring concern. Participants emphasised that these factors are central to mountaineering risk but were absent in the VR prototype.
Over-Reliance on Visual & Audio Cuesprocedural memory	2.20 3.060	The simulation leaned heavily on sight and sound—through visual landscapes, voice-over instructions, and environmental soundscapes. While participants appreciated these elements, some reported that relying only on visual and auditory channels limited realism and potentially overloaded their working memory.
Risks of Overconfidence	1.15 3.060	Several participants cautioned that the safe, controlled nature of VR might inadvertently foster overconfidence. By repeatedly practising scenarios without physical danger, learners may develop a false sense of preparedness for real expeditions.

7.3.4 Essential Features Needed in the VR App

Participants in Chile suggested that the educational value of the VR training could be significantly strengthened by incorporating more complex and dynamic risk simulations. Proposed enhancements included simulating adverse weather conditions—such as snowstorms, fog, and landslides—as well as modules for avalanche rescue and crevasse self-rescue techniques. Additionally, the incorporation of first-aid training for altitude

sickness and injury response was identified as a critical feature to improve the simulation's real-world applicability.

“Advanced First Aid... if they teach me a technique in virtual reality... I can remember it better” (Participant C 1).

“It would be nice to add some training regarding how to wear gear. How to use the gears” (Participant C 2).

“Like maybe more scenes with other risky scenes. Okay, like an avalanche, or a landslide” (Participant C 3).

“How to use the tools. So, if your client partner falls into crevasse, how to rescue the tools include using an ice axe” (Participant C 6).

From a technical perspective, users recommended improvements to the VR system's environmental adaptability. For example, given the regional variation in mountain climates, particularly in countries like Chile where mountains are not always snow-covered, participants advocated for diverse climate settings to ensure greater contextual relevance.

“The majority of accidents occur in low-altitude mountains, not in snowy places... because of the lack of education among the people” (Participant C 1).

The use of real-world case studies, including past accidents and rescue operations, was also proposed to enhance decision-making and situational awareness. A broader range of emergency scenarios, grounded in authentic alpine experiences, was seen as key to making VR training more realistic, educational, and responsive to both local conditions and evolving safety needs.

Participants in New Zealand recommended enhancing the simulation experience by incorporating dynamic weather systems, such as snowstorms and wind shifts, avalanche response modules, navigation and route-finding training, and altitude acclimatisation techniques to simulate environmental and risk conditions more realistically.

“Oh, the weather. Weather patterns. Yes, weather” (Participant N 9).

“And then how to read the weather patterns” (Participant N 4).

“You might use an avalanche buddy tool... practise using [it] and locating somebody under the snow” (Participant N 10).

To further enhance interactivity and learning, suggestions included integrating real-world accident case studies, incorporating haptic (vibration) feedback for terrain simulation, and implementing time-based challenges to assess learner readiness, ultimately creating a more robust, scenario-driven experience that would enhance realism and instructional value.

Table 7.4

Essential Features Needed in the VR App

Theme	**Theme code**	Participant Comment
Enhanced Risk Simulations		Participants emphasised the value of including more advanced risk scenarios in the VR training. While the prototype provided a foundation, they expressed interest in scenarios such as avalanches, crevasse rescues, and altitude-related illnesses, which reflect the realities of high-altitude mountaineering.

Simulation of Environmental and Risk Conditions		Many participants pointed out that authentic environmental dynamics were missing from the simulation. For instance, rapid weather changes, unstable terrain, and sensory stressors such as cold or fatigue were absent but deemed essential for realism.
Technical and Interactive Enhancements		Participants also recommended features to make the simulation more interactive and pedagogically rich. Suggestions included branching scenarios based on decision-making, integration of real accident case studies, haptic feedback, and time-based challenges.

7.3.5 Differences Between VR and Traditional Mountaineering Training

Participants in Chile acknowledged that VR serves as a valuable complement to, rather than a replacement for, real-world training, emphasising that hands-on experience in actual environments remains essential for developing physical and survival skills. They highlighted VR's advantages in terms of accessibility and cost, noting its affordability compared to traditional training, which makes it available to individuals unable to travel to remote locations and enables repeated practice regardless of weather conditions. Thus, VR is best utilised for pre-training and decision-making practice before engaging in real-world experiences.

“I would certainly say this is pre-training before going up” (Participant C 2).

“We put you in a new situation in different scenarios with different equipment and with different conditions” (Participant C 8).

“Have experience with accidents without actually happening so they can learn. You can control the situation” (Participant C 7).

Participants in New Zealand recognised VR as a valuable supplementary tool for preparatory learning in mountaineering training, though not a replacement for embodied experiences such as cold exposure, fatigue, or real-time decision-making under physical stress. They identified key economic and accessibility benefits of VR, including reduced training costs (e.g., travel, gear) and fewer weather- or time-related constraints, which also enable repetitive practice and scalability. Ultimately, this suggests that a hybrid model combining VR with in-field instruction would be most beneficial.

“People don't have equipment or financial ability. They couldn't. Don't need equipment. Financially benefit them” (Participant N 3).

“All of the sort of visual, audio-visual, that can sort of be sufficient to simulate a similar response, even though I'm not cold or wrapped up in jackets or anything” (Participant N 6).

“There's definitely... familiarity, rehearsals, dry training and safety awareness. It's accessible... because you don't have to go to the mountains to train” (Participant N 10).

“Especially if you're a beginner... you've never used a crampon [or] ice axe... it's scary. It's overwhelming” (Participant N 9).

Table 7.5

Differences Between VR & Traditional Mountaineering Training

Theme	**Theme code**	Participant Comment

VR as a Complement, Not a Replacement	3.105 3.110 4.55	Participants consistently emphasised that VR should serve as a supplementary tool rather than a substitute for traditional mountaineering training. While they recognised the value of immersive simulations in building situational awareness, decision-making skills, and hazard recognition, they also noted that VR cannot replicate the physical demands, sensory stressors, and unpredictability of real-world expeditions.
Economic and Accessibility Benefits	3.075 3.085	Participants noted that traditional mountaineering training often requires costly expeditions, specialised equipment, and travel to remote locations. By contrast, VR allows learners to experience high-risk environments in a cost-effective and controlled manner, lowering barriers for those who might otherwise lack access.
Safe training	3.080	Safety emerged as one of the most significant benefits of VR training. Participants appreciated that the simulations allowed them to practice risk assessment and decision-making without exposure to real physical danger. This was especially important for novice climbers, who could build confidence in a low-stakes environment before confronting actual hazards. For more advanced climbers, VR provided a platform to rehearse responses to high-risk scenarios that would be impractical or unsafe to replicate in the field.

7.3.6 Implementation Challenges in Chile & New Zealand

Chilean participants noted that most mountaineering accidents in their country occur at lower altitudes and in non-snowy conditions, largely because access to high-altitude environments is limited. As a result, they emphasised the importance of designing VR training scenarios that reflect Chile's diverse mountain conditions—including rock, volcanic terrain, and variable weather—rather than focusing solely on winter or snow-based settings.

"The majority of accidents occur in low-altitude mountains, not in snowy places... because of the lack of education among the people" (Participant C 1).

“If you want to bring this technology to Chile, it has to adapt to the environment here in Chile... [not only] a snowy, wintry place” (Participant C 1).

This adaptation would ensure that the training aligns more closely with the realistic risks and contexts faced by climbers in Chile. However, significant economic and accessibility barriers exist: VR technology is expensive, many Chilean climbers lack access to headsets, and some even prefer traditional real-world training.

“Access to this tool. Affordable. Access to this one is affordable” (Participant C 10).

“Probably the first thing is expensive technology. Yes. Then, yeah, I imagine that if this technology comes to Chile, probably it must be like universities or specific programs” (Participant C 3).

To increase adoption, it was suggested that localised VR experiences (e.g., focusing on low-altitude mountains and warm-weather settings) be developed, with essential funding from government or industry sponsors needed to make such VR training widely accessible.

A significant challenge for VR implementation in New Zealand and similar regions is the limited access to VR equipment and infrastructure in rural and low-income areas. Furthermore, the high development and hardware costs associated with VR technology may exclude smaller training providers or communities from adopting these innovative solutions. One highly experienced older mountaineer expressed scepticism toward VR training, and this, combined with language barriers and low levels of digital literacy, was identified as a significant hurdle to the broader adoption of VR in mountaineering education.

“It would be nice if it were a little easier” (Participant N 2).

“The most important thing is to feel touch in the most realistic situations. The most important thing is always realism” (Participant N 2).

To overcome these, there were calls for localised content, multilingual support, and culturally relevant design to broaden adoption.

Table 7.6

Implementation Challenges in Chile & New Zealand

Theme	**Theme code**	Participant Comment
Environmental & Cultural Adaptation	3.095 3100 3115	Participants highlighted the importance of tailoring VR training to reflect local mountain conditions and cultural practices. In Chile, for example, mountaineering accidents often occur in lower-altitude, rocky terrain rather than exclusively in snowy, high-altitude environments. Learners stressed that VR simulations must therefore incorporate diverse environmental scenarios that resonate with their lived experiences.
Economic & Accessibility Barriers	3075 3080 3085	Cost emerged as a recurring concern, with participants questioning the affordability and scalability of VR technology for widespread use. The price of headsets, software development, and maintenance was viewed as a significant obstacle, particularly in regions or communities with limited financial resources. Accessibility was also linked to infrastructure challenges, such as the availability of stable internet connections or institutional funding.
Cultural and Linguistic Considerations	3095 3100	Language and cultural accessibility were identified as critical barriers to engagement. In the Chilean cohort, participants explicitly reported difficulties with the English-only onboarding and training instructions, which introduced additional cognitive load and reduced focus on learning tasks. Requests for Spanish-language support underscored the importance of multilingual interfaces to ensure inclusivity. More broadly, cultural considerations—such as local terminology, safety protocols, and mountaineering practices—were seen as essential to creating simulations that feel authentic and relevant across different learner groups.

7.3.7 Recommendations for Successful Implementation

In Chile, participants emphasised that sustainable VR development would necessitate forming partnerships with outdoor brands and academic institutions. These collaborations could provide not only financial backing but also visibility within the mountaineering community, while simultaneously supporting evidence-based, iterative refinement of the technology. By drawing on both industry resources and academic research expertise, VR interventions in Chile could evolve to remain aligned with real-world needs while gaining broader credibility and adoption.

In New Zealand, participants similarly recognised the value of partnerships but framed them within the context of established national organisations. They identified the Mountain Safety Council (MSC), the Department of Conservation (DOC), leading outdoor brands such as Macpac, and research bodies as key collaborators to drive further innovation. Such partnerships would help expand the reach of VR training into both formal and community-based education programs, ensuring that the technology supports national safety priorities while benefiting from the reputational weight of trusted outdoor organisations.

Taken together, these perspectives suggest that while Chilean participants emphasised academic-industry synergies to secure sustainability and evidence-driven growth, New Zealand participants highlighted the importance of embedding VR within existing institutional and community frameworks to maximise its innovation and reach. Both approaches reflect context-specific strategies that can strengthen the integration of VR into outdoor safety education.

To ensure the successful implementation of VR training in Chile, participants highlighted the importance of government and institutional support, suggesting collaboration with Chilean mountaineering organisations like FEACH (The Federación de Andinismo de Chile) and the integration of VR training for visitors by tourism agencies and safety federations. They also recommended sponsorship and private sector involvement, proposing that outdoor brands (e.g., Patagonia, The North Face) could fund VR development in exchange for sponsorship, and that universities and research centres (e.g., Centro de Estudio en Montaña – CEM) could integrate VR into their training courses.

"You need to fund it... different organisations, institutions that have a real interest in this, like federations, clubs, mountain organisations [and] associations" (Participant C 3).

"To target large companies... Patagonia could also do something similar... a brand that needs advertising and that has a lot of money" (Participant C 7).

Ultimately, a blended learning approach combining VR training with real-world physical exercises was deemed crucial for comprehensive skill development. Strategic partnerships, sponsorships, and government funding were identified as key enablers of VR training success in Chile.

For successful VR implementation, participants emphasised the necessity of government and institutional support, specifically recommending government funding to integrate VR into national safety curricula and proposing partnerships with organisations such as the New Zealand Alpine Club and the Mountain Safety Council. They also identified industry sponsorship opportunities, where collaboration with outdoor gear brands (e.g., The North

Face, Patagonia) could provide equipment donations, sponsored content, and financial backing in exchange for brand visibility.

“Government support. University could have a course for people who want to become a mountain guide” (Participant N 3).

“In reality, this is something that big companies have to pay for, but there are limits to what schools can do” (Participant N 2).

“And also, individual sponsors. like North Face. Yeah. Or Patagonia” (Participant N 3).

“Alpine club would probably be interested in it” (Participant N 8).

Finally, a blended learning framework that combines VR simulations with physical fieldwork was strongly recommended, as such an approach would mitigate VR's limitations while significantly enhancing learner preparedness and safety.

Table 7.7

Recommendations for Successful Implementation

Theme	**Theme code**	Participant Comment
Government & Institutional Support		Participants emphasised that the long-term sustainability of VR-based mountaineering training would depend heavily on governmental and institutional backing. They highlighted that universities, national sports organisations, and public agencies could play a pivotal role in providing resources, infrastructure, and legitimacy.
Sponsorship & Private		Alongside public support, the importance of private sector engagement was repeatedly noted. Outdoor equipment brands, technology companies, and local sponsors were identified as potential partners capable of providing both financial resources and

Sector Involvement		technical expertise. Participants viewed such collaborations as mutually beneficial: companies could gain visibility and brand association with innovation and safety, while mountaineering communities could access cutting-edge training tools that might otherwise be financially out of reach.
Industry Sponsorship Opportunities		Participants also saw specific opportunities for industry-driven sponsorship models that could expand access and reduce barriers to adoption. For example, partnerships with outdoor gear brands or VR technology providers could subsidise costs, making the intervention more widely available to diverse communities, including those in remote or resource-limited areas. By aligning with industries that already have a vested interest in mountain safety and outdoor sports, VR training could achieve both greater reach and stronger financial stability.

7.3.8 Findings, Benefits, Limitations and Adoption and Support the VR app in Chile and New Zealand

VR is highly effective for training cognitive skills and decision-making. However, it cannot fully replace physical training due to its inability to replicate critical real-world physical sensations, such as cold, fatigue, and altitude effects, which are essential for survival. To improve adoption in Chile, it is crucial to customise VR training to suit local environments, particularly those with low altitudes and non-snowy conditions. Ultimately, securing funding, sponsorships, and institutional support will be necessary to scale VR training successfully across Chile.

VR offers an innovative and scalable method for enhancing mountain safety training, particularly for beginners, due to its strengths in immersion, cost efficiency, and repetitive, scenario-based learning. However, its effectiveness as a standalone solution is limited by its inability to replicate real-world physical stressors, suggesting that a hybrid model

combining VR with traditional training presents the most comprehensive and effective educational strategy. Ultimately, strategic investment, cross-sector collaboration, and localised content development will be critical to ensuring the success and sustainability of VR-based mountain safety education.

Table 7.8

Findings, benefits, limitations and adoption and support of the VR app in Chile and New Zealand

Findings	**Chile**	**New Zealand**
Benefits	Participants in Chile highlighted the value of VR primarily as a cognitive and decision-making training tool. They emphasised that the immersive scenarios—such as encountering acute mountain sickness or facing sudden weather changes—allowed them to practise recognising hazards and making timely decisions in ways that would be difficult or dangerous to replicate in real mountains. Several participants noted that the VR environment enabled them to identify risks and rehearse responses in a safe setting. Importantly, while they acknowledged VR's strength in fostering situational awareness, critical thinking, and psychological preparedness, experienced climbers stressed that VR should not be seen as a complete replacement for physical training. Instead, they viewed it as a complementary resource that could enhance readiness by mentally preparing climbers for stressful or high-stakes scenarios.	For participants in New Zealand, who were largely novice or intermediate climbers, VR was seen as an accessible and innovative learning tool. They valued the opportunity to engage with simulated hazards and decision-making challenges without exposure to real-world danger. The ability to repeat scenarios in a low-risk environment was considered particularly useful for building confidence and reinforcing safety protocols. Moreover, New Zealand participants identified VR's scalability and portability as important, particularly in educational contexts where students often have limited access to alpine environments due to geographic or financial barriers. For this group, VR was less about replicating the physical sensations of climbing and more about safely and engagingly bridging the gap between theory and practice.
Limitation	The most significant limitation identified by Chilean participants was the absence of physical sensations and environmental stressors — such as cold, fatigue, or oxygen deprivation—that are critical to real-world survival in high-altitude environments. Participants felt that while VR could effectively simulate visual and auditory elements, it could not fully replicate the embodied challenges of	New Zealand participants also acknowledged VR's limitations, particularly its inability to reproduce the physical demands of climbing. While the technology created engaging and realistic simulations, participants made it clear that essential physical and technical skills—such as rope handling, balance, and endurance—still required real-world practice. Some

	mountaineering, such as the strain of carrying heavy equipment or the physiological impact of altitude. This limitation meant that VR was not perceived as a stand-alone solution but rather as a supplementary aid to traditional training. Additionally, participants emphasised the need for greater contextual alignment, noting that most mountaineering accidents in Chile occur in low-altitude, non-snowy environments where factors like loose rock, changing terrain, and variable weather play a larger role than snow-specific conditions.	users also reported visual discomfort, especially those wearing prescription glasses, due to headset fit and clarity issues. Although Oculus offers prescription lens accessories, these were not available during the study, which limited the experience's visual accessibility. For novices, the steep learning curve of VR navigation and the reliance on English-only instructions added extra layers of cognitive load, occasionally leading to stress or confusion.
Adoption and Support	In the Chilean context, participants stressed the importance of customising VR content to reflect local conditions, such as low-altitude volcanic landscapes and non-snowy terrain. They felt that aligning simulations with the realities of Chilean mountaineering would enhance relevance and adoption within training communities. Moreover, participants identified government funding, institutional backing, and academic partnerships as essential to scaling the VR initiative. Without structural support, they argued, the intervention risked remaining a niche tool rather than achieving widespread impact. Collaborations with national organisations such as FEACH (Federación de Andinismo de Chile) or CEM (Centro de Estudios de Montaña) were viewed as key pathways to integrating VR into existing blended training programs and to securing long-term sustainability.	In New Zealand, participants recommended adopting VR within formal training and assessment frameworks, suggesting its integration as a pre-training module for novice climbers in courses offered by institutions such as the New Zealand Alpine Club or the Mountain Safety Council. By embedding VR into structured curricula, they believed learners could build baseline knowledge and risk awareness before undertaking field training in real environments. Additionally, participants highlighted the value of multilingual versions of the app, including support for Te Reo Māori, to ensure inclusivity and accessibility for diverse learners. They also identified potential partnerships with government bodies, outdoor brands (such as Macpac), and research institutions as crucial to advancing innovation, reducing costs, and ensuring equitable access.

7.4 Summary

This thematic analysis reveals the transformative potential of virtual reality (VR) as a pedagogical tool in mountain safety education, particularly in enhancing cognitive preparedness, fostering emotional engagement, and facilitating scenario-based learning. Participants consistently highlighted the value of immersive simulations for rehearsing decision-making under pressure, visualising hazardous environments, and internalising critical safety procedures without exposure to real-world risks. VR allows learners to repeatedly practise decision-making in simulated alpine scenarios, which may support the development of procedural knowledge and hazard recognition skills such as navigating avalanche-prone terrain or recognising symptoms of altitude sickness.

However, the findings also underscore critical limitations that must be addressed for VR to achieve its full educational impact. Most notably, VR cannot replicate the physical and physiological stressors—such as cold, fatigue, and altitude effects—that profoundly shape behaviour and judgment in real-world mountaineering contexts. This absence risks creating a false sense of preparedness, particularly among novice climbers who may not yet have developed the embodied experience necessary to assess risk fully. Additionally, access inequities—including technological infrastructure gaps, high equipment costs, and varying levels of digital literacy—may limit VR's reach, especially in rural or under-resourced regions. Participants also stressed the importance of cultural and geographic localisation, noting that scenarios must be contextually relevant to regional climbing conditions, languages, and learning expectations to be genuinely effective.

As such, VR should be positioned not as a replacement for traditional training but as a complementary component within a blended learning framework. When integrated with hands-on fieldwork, mentorship, and reflective practice, VR can significantly enrich the

learning process by offering repeatable, low-risk exposure to high-stakes situations. For successful scaling and sustainability, strategic partnerships with government agencies, academic institutions, and stakeholders in the outdoor industry will be vital. Likewise, localisation of content, multilingual access, and iterative design processes—informed by ongoing user feedback—are essential to ensure that VR training tools are culturally responsive, pedagogically sound, and technically accessible across diverse learner populations.

Chapter 8 Reflection and Emerging Design Principles

8.1 Introduction

This chapter critically examines and reflects the intersection of theory, data collection, and empirical research to propose a refined set of design principles for the development and implementation of VR-based mountain safety training. Drawing on the foundational literature reviewed in Chapter 2; this chapter reflects on how theoretical concepts—particularly Engeström's (2001) Third-Generation Activity Theory—offer an analytical lens for understanding the socio-cultural dynamics of high-risk mountaineering education between Chile and New Zealand. Activity Theory serves as both a diagnostic and design tool, helping to identify systemic tensions, contradictions, and affordances within the activity systems of climbers, trainers, and educational institutions in both countries. Furthermore, this chapter integrates insights from the participatory design process described in Chapter 4, during which the researcher consulted with mountaineers from local training organisations and climbing communities in Chile and New Zealand. These consultations highlighted critical needs for localised, culturally appropriate, and technologically accessible solutions—factors that were instrumental in shaping both the content and delivery of the VR training application.

Building on this foundation, the chapter then turns to the empirical findings reported in Chapters 5 through 7. The pre-intervention data helped identify gaps in existing knowledge and training related to altitude sickness. The intervention and post-intervention phases revealed how participants engaged with the VR simulation, what they found immersive and instructive, and where they experienced limitations or barriers. Participants' experiences provided valuable insights into the practical efficacy and emotional impact of the learning environment, as well as the usability and realism of the VR interface. By

integrating conceptual theory, participatory design processes, and empirical user data, the chapter demonstrates how theoretical constructs can be operationalised in practice while empirical findings refine and extend theoretical insights. The overall objective is to synthesise these insights to guide the design of VR learning environments that are not only pedagogically robust but also grounded in the real-world conditions, cultures, and cognitive demands of high-altitude mountaineering.

The chapter is organised into two main sections. The first revisits the theoretical design principles derived from Activity Theory and the literature on immersive learning, framing the educational goals of VR-assisted mountain training in terms of mediated learning, distributed cognition, and expansive knowledge. Following a Design-Based Research logic, the second section presents a set of emergent, empirically grounded design principles that reflect user experiences, their priorities, and contextual constraints. Together, these two sections provide a comprehensive foundation for developing future VR-based interventions in high-risk educational settings.

8.2 Combined Reflection and Development of Emerging Design Principles from both Case Studies

8.2.1 Theoretical Design Principles

The design of a VR-assisted mountain safety training intervention must be grounded in sound pedagogical theory. Chapter 2 highlighted the critical need for high-altitude safety education that extends beyond conventional guidebooks and practical tips. The literature revealed a concerning gap in systematic training, particularly in recognising and responding to dynamic hazards such as altitude sickness, avalanches, and sudden weather

changes. Drawing on the theoretical foundations discussed in Chapter 2, the following design principles were developed to guide the conceptual and practical implementation of VR-based training for high-risk alpine environments. These principles integrate insights from constructivist and heutagogical learning theories, Engeström's Activity Theory (1987, 2001), models of authentic and simulation-based learning, experiential learning theory (Kolb, 1984), and immersive learning design (Makransky & Lilleholt, 2018). Activity Theory (Engeström, 1987, 2001) informed the research, emphasising how learning is mediated by tools (in this case, VR) within a complex and dynamic socio-cultural activity system involving climbers, trainers, mountain clubs, and environmental constraints. The theory predicted that contradictions and tensions—such as the gap between practical needs and existing training resources—would become apparent through learner interaction and feedback.

Based on these foundations, the following theoretical design principles guide the conceptual and practical implementation of VR-based training for high-risk alpine environments.

8.2.1.1 Heutagogy - Learner-Centred and Self-Determined Learning

A key pedagogical foundation informing the design of the VR intervention is heutagogy, or self-determined learning, which places the learner at the centre of the educational process. Unlike traditional pedagogical models, in which the instructor directs content and progression, heutagogy emphasises autonomy, capability development, and learner agency. The design should empower learners to control their educational journey, enabling self-directed engagement and flexible pathways. It means enabling users to explore scenarios at their own pace, select modules based on their skill level, and critically reflect on their decisions and outcomes, aligning with the principle that it is the learner themselves who determines what and how learning should take place, as Hase and Kenyon (2001) explain. Heutagogy conceptualises learning as a self-determined process in which learners exercise substantial autonomy over both the direction and methods of their learning activities, assuming responsibility for identifying learning needs and selecting appropriate strategies (Hase & Kenyon, 2001).

This principle aligns closely with the goals of high-risk outdoor education, where learners must independently assess risk, make decisions in uncertain conditions, and reflect critically on their actions. In the context of VR-based mountain safety training, heutagogical principles informed several design choices, including allowing users to explore immersive scenarios at their own pace, choose learning modules tailored to their experience level, and receive formative feedback to support reflection and self-evaluation. This approach not only empowers learners to personalise their learning pathways but also encourages the development of metacognitive skills essential for navigating real-world mountaineering challenges. By incorporating heutagogy into the design, the intervention

enables learners to become more capable, confident, and self-directed in their learning journey.

8.2.1.2 Social Constructivism - Socially Situated and Collaborative Learning

Another key theoretical foundation guiding the VR intervention is social constructivism, which emphasises the fundamental social nature of learning and the importance of interaction, collaboration, and shared meaning-making. Rooted in the work of Lev Vygotsky (1978), this perspective asserts that cognitive development is mediated through social engagement and language, and that learning is most effective when it occurs within a supportive community of practice. Vygotsky's sociocultural theory highlights the importance of social interaction in learning, with the Zone of Proximal Development (ZPD) serving as a central concept.

He defined the ZPD as "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). This framework emphasises that learners achieve higher levels of understanding and performance when supported by guidance or collaboration, a principle highly relevant to training in complex, high-risk environments such as mountaineering. Applying this principle to VR-based mountain safety training, the design should go beyond isolated, individual learning experiences and integrate mechanisms for collaborative learning, peer-supported feedback, and growth.

Although VR is often associated with solitary immersion, the intervention can incorporate socially situated elements in both virtual and real-world contexts. A key area for

development in VR-based mountaineering training lies in supporting learners as they voice their experiences and process them in real time. Beyond individual immersion, features such as multiplayer decision-making scenarios, in-app chat, and post-scenario virtual debriefs can simulate the collaborative dynamics that climbers encounter during actual expeditions. These social layers mirror the team-based decision-making, negotiation, and conflict resolution required in high-risk outdoor environments, thereby extending VR from a purely individual experience into a collective training space.

In addition, structured guided prompts, interactive tutorials, and AI-generated feedback can act as forms of digital scaffolding, echoing Vygotsky's (1978) concept of the Zone of Proximal Development. By providing timely support and just-in-time guidance, these tools enable novice climbers to engage with complex scenarios that may otherwise exceed their current ability. For example, prompts could highlight overlooked environmental cues (such as changes in weather or terrain instability) or suggest alternative strategies when poor decisions are made. AI-driven debriefs could then reinforce reflective observation by providing personalised feedback on performance, encouraging learners to analyse their choices and consider alternative outcomes.

Together, these features would not only deepen experiential authenticity but also create a more inclusive and adaptive training environment. For beginners, digital scaffolding ensures smoother onboarding into complex risk scenarios. For more experienced climbers, multiplayer dynamics and debriefing tools provide opportunities to refine decision-making under simulated pressure while engaging with peer perspectives. This layered design strengthens the educational impact of VR training by combining presence, social interaction, and adaptive feedback, elements essential for bridging the gap between

simulation and real-world application. Such scaffolding mirrors the social guidance a novice climber might receive from a more experienced mentor or group leader in the field.

In practice, this design approach supports not only knowledge acquisition but also the co-construction of meaning, encouraging participants to reflect on their own decisions, learn from peer responses, and engage in shared problem-solving. It is particularly vital in high-risk environments, such as mountaineering, where teamwork, effective communication, and adaptive thinking are essential for ensuring safety and achieving success. By embedding social constructivist principles into the VR experience, the intervention not only facilitates individual learning but also promotes collective competence and preparedness, key outcomes for real-world climbing scenarios.

8.2.1.3 Activity Theory - Expansive Learning through Contradictions

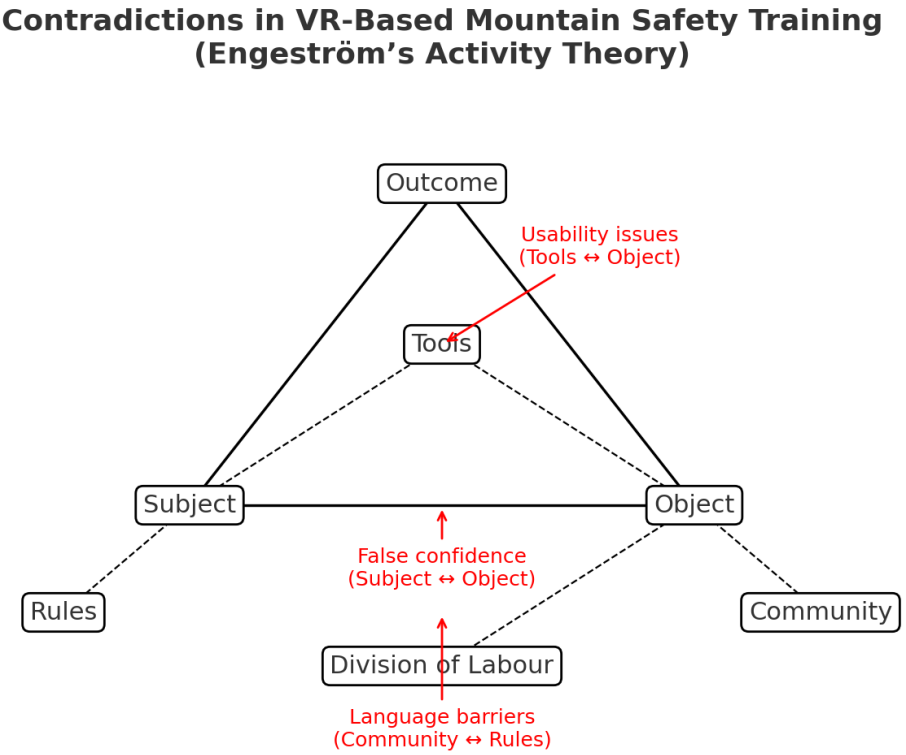
A central theoretical lens informing the design of this intervention is Engeström's (2001) Third-generation Activity Theory, which conceptualises learning as a collective, systemic activity mediated by tools, shaped by cultural and historical context, and driven by internal tensions or contradictions within the system. This model extends Vygotsky's original concept of mediated action into a multi-voiced system comprising elements such as subject, object, tools, community, rules, and division of labour. When contradictions emerge—such as a misalignment between user expectations and a tool's actual affordances—these disruptions do not signal failure but rather present opportunities for expansive learning. Within Activity Theory, learning is often stimulated when individuals encounter tensions or obstacles in the course of routine activity, prompting reflection and adaptation of existing practices (Holzkamp, 2004, as cited in Grotlüschen, 2010). In this sense,

breakdowns or frictions within the activity system can trigger reflection, adaptation, and ultimately transformation of both the learner and the system itself.

In the context of the VR-based mountain safety training, several contradictions were anticipated and surfaced through empirical observation (see Table 8.2 and Figure 8.1 below).

Figure 8. 1

Contractions in VR-Based Mountain Safety Training (Engeström's Activity Theory)



For example, participants occasionally experienced a false sense of confidence after successfully navigating VR scenarios—an unintended outcome that contradicted the training objective of promoting caution and preparedness. Several participants from the Chilean cohort reported that completing the mountain sickness scenario without incident

made them feel more capable than they might in real-world conditions. One participant noted that "because I could complete the scenario and avoid high altitude mountain sickness, it made me feel more confident, but I know in real life the mountain is much more unpredictable." It illustrates a contradiction between the intended learning objective—developing cautious, risk-aware decision-making—and the psychological effect of successful task completion in a controlled, repeatable virtual environment. Similarly, a New Zealand participant reflected that the ability to repeat the simulation until achieving a successful outcome reduced their perception of real-world risk, stating that "it felt achievable in VR, but I realise that in reality, fatigue, weather, and stress would make it very different." This highlights a subject–tool contradiction: the VR system, while designed to enhance preparedness, simultaneously produced unintended confidence that could undermine risk awareness if not appropriately contextualised.

Similarly, usability limitations—including visual blurriness, restricted field of view, and physical discomfort—interfered with participants' ability to fully engage with the simulated environment, revealing contradictions between the technological tools and the intended learning outcomes. Participants from both Chile and New Zealand reported that visual clarity limitations affected their ability to interpret terrain features and environmental cues accurately. For instance, a Chilean participant commented that "sometimes the image was slightly blurry, and it was harder to judge distances or terrain details." In contrast, a New Zealand participant noted that "the headset became uncomfortable after some time, which distracted me from focusing on the task." These issues demonstrate a tool–object contradiction, in which the technological affordances intended to enhance immersion simultaneously constrain the user's ability to engage in

authentic experiential learning fully. Furthermore, some participants reported mild motion discomfort, which disrupted cognitive focus and reduced the continuity of engagement with the learning task. This physical discomfort reflects tensions between the subject's physiological limitations and the tool's technological properties, highlighting the embodied nature of immersive learning and its dependence on ergonomic and perceptual compatibility.

These tensions align with Engeström's (2001) assertion that contradictions between components—such as subject–tool, tool–object, and subject–object relationships—are inherent and generative mechanisms within activity systems. Rather than representing failures, these contradictions reveal structural misalignments that prompt reflection, adaptation, and system refinement. In this study, contradictions arising from unintended confidence and usability limitations exposed critical areas for pedagogical and technological improvement, such as incorporating structured debriefing to recalibrate learners' risk perception and enhancing visual fidelity and ergonomic design to support sustained engagement. Therefore, Engeström's (2001) Third-Generation Activity Theory posits that contradictions between system elements function as catalysts for expansive learning, enabling the evolution of both technological tools and pedagogical practices to better align with the overarching objective of developing safe and effective mountaineering decision-making.

8.2.1.4 Experiential Learning Theory

Experiential Learning Theory (ELT), as conceptualised by Kolb (1984), provided a foundational theoretical basis for the design and implementation of VR-based mountaineering safety training. Experiential Learning Theory conceptualises learning as an iterative process in which knowledge develops through the transformation of experience. Kolb (1984) describes this process as a cycle involving concrete experience, reflective observation, abstract conceptualisation, and active experimentation. This cyclical model emphasises that effective learning occurs not through passive information transmission but through active engagement, critical reflection, and iterative application of knowledge in meaningful contexts.

The VR training intervention was intentionally designed to align with Kolb's four-stage experiential learning cycle, enabling participants to engage in immersive, embodied experiences that simulated real-world mountaineering risks and decision-making processes. The first stage, concrete experience, was facilitated through immersive VR scenarios that exposed participants to realistic mountaineering environments, including avalanche risk situations, terrain navigation, and environmental hazard assessment. These simulations provided learners with direct, experiential engagement that approximated real-world conditions while maintaining a safe and controlled learning environment. Participants from both Chile and New Zealand reported that the immersive nature of the VR experience enabled them to "feel present in the mountain environment," allowing them to engage cognitively and emotionally with risk scenarios in ways that traditional instructional methods could not replicate.

The second stage, reflective observation, was facilitated by structured post-experience reflection, during which participants critically evaluated their actions, decisions, and outcomes in the simulation. This reflective process enabled learners to recognise gaps between their perceived competence and actual performance, fostering metacognitive awareness. For example, several participants acknowledged discrepancies between their confidence during simulation and their awareness of real-world complexity, highlighting the importance of reflective processes in recalibrating risk perception. Reflection thus served as a critical mechanism for transforming immersive experience into meaningful learning.

The third stage, abstract conceptualisation, occurred as participants integrated their experiential insights with prior knowledge and mountaineering safety principles. Through this process, learners developed or refined mental models related to hazard recognition, decision-making under uncertainty, and risk mitigation strategies. The VR environment provided opportunities for participants to connect experiential learning with theoretical understanding, thereby strengthening conceptual comprehension of mountaineering safety principles. This stage was particularly evident when participants articulated improved understanding of avalanche risk factors and decision-making processes, demonstrating the internalisation of safety concepts beyond procedural familiarity.

The final stage, active experimentation, was enabled through the repeatable and adaptive nature of the VR environment, allowing participants to apply newly developed knowledge and strategies in subsequent simulation attempts. Unlike real-world mountaineering, where opportunities for repeated safe experimentation are limited, VR provides a unique affordance for iterative learning. Participants could test alternative decision-making

strategies, observe different outcomes, and refine their responses in a risk-free environment. This iterative process supported the development of adaptive expertise and enhanced preparedness for real-world scenarios.

Importantly, the VR intervention supported the continuity of Kolb's experiential learning cycle by facilitating movement between these stages rather than treating them as isolated events. The immersive experience provided the experiential foundation, while reflective and iterative engagement enabled learners to construct a deeper, more integrated understanding. This aligns with Kolb's (1984) assertion that learning is a continuous, dynamic process in which experience serves as the primary source of knowledge development.

Furthermore, applying Experiential Learning Theory in the VR context revealed important insights into the strengths and limitations of immersive technologies as experiential learning tools. While VR effectively facilitated concrete experience and active experimentation, findings from both Chilean and New Zealand participants indicated that reflective observation required additional pedagogical scaffolding, such as structured debriefing, to ensure that experiential learning translated into appropriate risk awareness rather than overconfidence. It highlights the importance of integrating technological affordances with pedagogical design to support the full experiential learning cycle.

From a theoretical design perspective, Experiential Learning Theory informed several key design principles underpinning the VR intervention. These included the prioritisation of immersive, authentic learning experiences; the incorporation of opportunities for reflection and feedback; the support for iterative experimentation; and the alignment of simulation

scenarios with real-world contexts. These principles ensured that the VR intervention functioned not merely as a technological tool but as a pedagogically grounded experiential learning environment.

8.2.1.5 Authentic Learning - Authentic Context and Realistic Scenarios

Authentic Learning provided an important theoretical foundation for the design of the VR learning experience in this study. However, this does not mean that the VR environment was intended to reproduce the complete experience of being in a real alpine environment. A real mountain environment involves many physical and environmental factors, including wind, cold, fatigue, dehydration, physical exertion, changing weather conditions and genuine exposure to risk. These factors cannot be fully recreated through a VR headset.

Instead, Authentic Learning was used to guide the design of particular aspects of the experience that were relevant to this research. The aim was to create realistic situations in which participants could recognise environmental and personal risk factors, interpret information, make decisions and experience the consequences of those decisions within a safe environment. Therefore, authenticity in this study refers primarily to the authenticity of the learning context, tasks and decision-making process rather than a claim that the complete physical mountain experience was authentic.

This distinction is consistent with Herrington, Reeves and Oliver's (2007) discussion of cognitive realism, which suggests that an authentic learning experience does not necessarily require an exact physical reproduction of the real environment. What is important is that learners engage with realistic problems and tasks that reflect how

knowledge and decisions are used in practice. More recent VR research has similarly described authenticity in terms of different forms of fidelity, including physical, psychological, functional and social aspects of the learning experience (Lowell & Tagare, 2023).

Previous studies have also examined learners' perceptions of authenticity in VR-based learning. Lowell and Tagare (2023), for example, found that participants perceived VR learning tasks and environments as realistic, while research using VR and mixed reality for safety education found that immersive simulation could support aspects of authentic learning. These findings do not suggest that VR reproduces reality completely. Rather, they show that VR can reproduce selected features of real-world practice sufficiently to support meaningful learning activities.

Therefore, the VR environment developed in this study should be understood as an approximation of selected aspects of an alpine experience rather than a replacement for the real environment. The purpose was not to make participants believe that they were experiencing all the physical realities of being in the mountains, but to recreate, as authentically as possible, the particular situations, cues and decisions being investigated in this research.

8.2.1.6 Multi-Sensory, Immersive, and Simulation-Based Learning

Simulation-based learning is an essential principle underpinning the design of immersive educational technologies, particularly in high-risk domains such as mountaineering.

Simulation-based learning environments enable learners to practise complex or hazardous tasks within controlled conditions that approximate real-world situations without exposing participants to actual risk (Cant & Cooper, 2010). According to Cant and Cooper (2010), "Simulation-based learning provides a realistic and interactive environment… so that learners can learn while solving problems on their own" (p. 2). This approach is particularly effective in building decision-making, procedural competence, and situational awareness under pressure, which are critical capacities for climbers operating in unpredictable alpine conditions.

The value of this approach can also be seen in other high-risk fields, particularly aviation, where simulation has a long history of supporting safe and effective training. Simulation allows pilots and crews to practise decision-making, teamwork, and responses to emergency situations without being exposed to real danger (Salas et al., 1998). Importantly, effective simulation does not always require the highest level of physical realism; instead, the design should focus on the skills and learning outcomes being developed (Salas et al., 1998). Research into Crew Resource Management has also shown that simulation-based training can positively influence knowledge, attitudes, and behaviours in high-risk situations (O'Connor et al., 2008). This provides a useful foundation for the present study, where VR was used to recreate selected aspects of a mountain environment and allow participants to experience and respond to risk in a safe setting.

In the context of this VR-based mountain safety intervention, simulation design focuses on fidelity, interactivity, and consequence-driven scenarios. High-fidelity simulations aim to replicate not only the visual and auditory elements of the environment but also the physical,

emotional, and cognitive demands of real-world experiences. For example, the inclusion of 3D spatial audio, vibration-based haptic feedback, and biometric response tracking enhances realism, helping to evoke stress responses and emotional engagement comparable to those in actual high-stakes settings. The integration of a data collection system, such as biometric tracking and observational video, significantly enhances realism by capturing learners' authentic physiological and behavioural responses within the simulation. For example, when a participant's heart rate spikes during a sudden snowstorm scenario, the biometric data confirms that the simulation is not only visually or auditorily engaging but also provoking a genuine stress response akin to real-world conditions. It makes the simulation more than a "game-like" activity. It serves as a valid proxy for high-stakes environments because the learner's body and mind respond as they would in real life. By systematically collecting these responses, the research team gains a feedback loop that informs the Design-Based Research (DBR) process. Data on stress spikes, hesitation points, or repeated decision errors identify where the simulation succeeds and where it needs refinement. For instance, if participants consistently misinterpret symptoms of altitude sickness, this signals a gap that can be addressed by redesigning prompts or increasing scenario fidelity.

Interactivity is also central: learners are not passive observers but active participants, required to make decisions such as whether to continue a climb during a sudden weather shift or how to respond when a teammate shows symptoms of altitude sickness—with each decision leading to immediate, branching consequences.

These interactive components align with experiential learning theory by enabling learners to reflect on their actions and outcomes, revise their strategies, and rehearse alternate

approaches. Furthermore, the design promotes deliberate practice, a key factor in skill acquisition, allowing learners to repeat and refine their responses to critical incidents such as avalanche rescues, fall scenarios, or high-altitude first aid. By embedding learners within dynamic, evolving environments that simulate the uncertainties of real mountaineering, the simulation fosters both technical preparedness and psychological readiness. This approach not only enhances knowledge of retention and transfer but also increases learner confidence and resilience, both of which are vital for safety and effectiveness in extreme conditions.

8.2.1.7 Reflective Practice for Deeper Learning

Reflective practice is a cornerstone of both heutagogical learning and simulation-based education, serving as a critical bridge between experience and deeper understanding. In high-risk learning environments such as mountaineering, where decisions can have life-threatening consequences, fostering self-awareness, metacognition, and professional judgment is essential. Reflection enables learners to make sense of complex scenarios, assess their responses, and identify areas for growth. As Herrington and Oliver (2000) highlight in their principles of authentic learning, effective design should "promote reflection to enable abstractions to be formed" (p. 25), encouraging learners to move beyond surface-level engagement and develop transferable insights from their experiences. Similarly, Hase (2009) defines reflection as "a critical learning skill associated with knowing how to learn" (p. 49), aligning it directly with the self-determined ethos of heutagogy.

In the VR-based mountain safety training intervention, embedded reflection mechanisms were integrated into the learning experience to support this cognitive process. These

include after-action reviews, where learners revisit key decisions and outcomes; decision logs, which prompt users to justify and later evaluate their choices; and guided prompts that encourage self-questioning during and after immersive scenarios. These elements are particularly important when using VR and simulation technologies, which can provide intense and emotionally charged learning moments that require structured reflection to translate into long-term behavioural change.

By scaffolding opportunities for reflection within and beyond the immersive experience, the intervention helps learners internalise lessons, identify cognitive or emotional biases, and adapt future behaviour. This not only supports the development of judgment under pressure but also cultivates lifelong learning habits, reinforcing the broader aims of heutagogical learning. Reflective practice thus becomes both an outcome and a method of the learning process, supporting learners to transform discrete training experiences into integrated professional competencies.

8.2.1.8 Inclusive and Culturally Responsive Design

Designing effective educational tools for high-risk environments requires not only technical and pedagogical excellence but also cultural responsiveness. Activity Theory, particularly developed by Engeström (1987), emphasises that tools are never culturally neutral; rather, they are shaped by—and, in turn, shape—the traditions, values, and practices of the communities that use them. This theoretical construct, referred to as multivoicedness, underscores the importance of recognising and incorporating diverse perspectives within a single activity system.

As articulated by Engeström (1987), the "multivoicedness" of an activity system reflects the various viewpoints and cultural legacies that participants bring to a task (p. 136). Because of this diversity, the mediating artifacts and social regulations (tools and rules) must be "culturally situated" to be effective. This framework suggests that the success of a learning intervention depends on its ability to harmonise these differing perspectives within the unique environmental and social conditions of the local setting.

In the context of this study, which spans two distinct geographical and cultural settings—New Zealand and Chile—this principle has significant design implications.

To honour this diversity, the VR-based mountain safety intervention was developed using inclusive and context-sensitive design strategies. Language was an initial consideration: the app needed to be available in multiple languages (including Spanish and English) to ensure accessibility for all participants. More importantly, the visual environments, risk scenarios, and learning priorities had to reflect the specific regional and cultural characteristics of each mountaineering context. For example, Chilean participants emphasised the importance of including non-snowy alpine terrain and club-based learning practices. In contrast, New Zealand participants referenced their structured safety frameworks and institutional training systems. These differences necessitated a flexible and modular design that could adapt to varied cultural expectations and environmental conditions.

The participatory process embedded in the Design-Based Research (DBR) approach further supported inclusivity. Early consultations with climbing experts, training organisations (e.g., NZAC, FEACH), and end-users ensured that local knowledge, values,

and needs informed about the design. It aligns with the Activity Theory principle that effective tools must reflect the social and cultural realities of the community they serve. Culturally responsive design also helps build trust and engagement, particularly in high-risk domains where users must believe in the credibility and relevance of the training materials.

By foregrounding multivoicedness as a design imperative, this research underscores the importance of user-informed design, co-design, localisation, and adaptability in the development of educational technologies for diverse learner populations. Inclusive design is not merely an ethical imperative—it is a functional necessity for ensuring the relevance, accessibility, and effectiveness of learning in culturally diverse, real-world contexts.

8.2.1.9 Summary

In summary, these principles (see Table 8.1) collectively represent a theoretically grounded and pedagogically informed approach to designing virtual reality learning environments for high-risk contexts such as mountaineering. Drawing from a synthesis of Activity Theory, Heutagogy, Authentic Learning, Social Constructivism, and Simulation-Based Learning, the framework positions learners not as passive recipients of information but as active, reflective, and culturally situated participants operating within complex, dynamic activity systems. Each principle underscores the need for learning environments that are immersive, contextualised, responsive to learner diversity, and structured to promote critical decision-making under realistic constraints.

Importantly, this approach shifts the function of VR from simply a medium for content delivery to a transformative learning space—one that fosters adaptive expertise, critical

self-reflection, and collaborative sense-making. In doing so, the design aspires to prepare learners for the unpredictability and complexity inherent in real-world, high-risk environments. When VR is embedded within a broader pedagogical system that includes reflective practice, social interaction, and cultural relevance, it becomes a powerful tool for cultivating the kinds of judgment, resilience, and situational awareness that are essential in fields such as mountaineering, emergency response, and beyond.

Table 8.1

Summary of Learning Theories and Design Principles Informing the VR Intervention

Learning Theory	**Key Principles**	**Application to VR-Based Mountain Safety Training**
Heutagogy (Hase & Kenyon, 2001)	• Learner-centred, self-determined learning • Focus on autonomy, capability development, and agency • Learners decide both what and how they will learn	The VR intervention allowed learners to explore scenarios at their own pace, select modules by skill level, and reflect on decisions. This promoted self-directed engagement and the development of metacognitive skills.
Social Constructivism (Vygotsky, 1978)	• Learning is socially situated and mediated by collaboration • Zone of Proximal Development (ZPD): learners progress further with peer/mentor support • Emphasis on interaction, dialogue, and co-construction of meaning	The design incorporated collaborative elements such as multiplayer scenarios, post-scenario debriefs, and AI-guided feedback. These mirrored team-based decision-making in mountaineering and supported scaffolding for novice learners.
Activity Theory (Engeström, 1987, 2001)	• Learning occurs within systemic, multi-voiced activity systems • Contradictions (e.g., tool–object, subject–rules) drive expansive learning • Focus on cultural and contextual mediation	Contradictions observed—such as false confidence or technical discomfort—were used as opportunities for reflection and redesign. Reflective prompts and integration with real-world training supported expansive learning cycles.

Experiential Learning Theory (Kolb, 1984)	• Learning occurs through the transformation of experience via a cyclical process • Four-stage experiential learning cycle: concrete experience, reflective observation, abstract conceptualisation, and active experimentation • Emphasises embodied, contextual, and iterative learning through direct engagement • Reflection is essential for transforming experience into deeper conceptual understanding	The VR intervention provided concrete experiential learning through immersive mountaineering simulations, enabling learners to engage with realistic risk scenarios. Reflective prompts and debriefing supported reflective observation, while repeatable scenarios enabled active experimentation and strategy refinement. This experiential cycle helped participants develop hazard awareness, decision-making skills, and preparedness for real-world mountaineering contexts.
Authentic Learning (Herrington & Oliver, 2000)	• Learning tasks should reflect real-life contexts • Ill-structured problems promote critical thinking • Emphasises relevance and transferability	Scenarios replicated real mountaineering conditions, including sudden weather changes, medical emergencies, and navigation tasks. This authenticity promoted risk awareness, decision-making, and knowledge transfer.
Simulation-Based Learning (Cant & Cooper, 2010)	• Safe, realistic rehearsal of complex or hazardous tasks • Builds procedural competence and situational awareness • Interactive, consequence-driven learning	The VR prototype integrated 3D spatial audio, haptic vibration feedback, and biometric tracking to simulate stressful, high-risk conditions. Learners engaged in decision-making under pressure, with branching consequences.
Reflective Practice (Hase, 2009; Herrington & Oliver, 2000)	• Reflection bridges experience and deeper understanding • Encourages metacognition and professional judgment • Enables abstraction and long-term learning	Reflection was built into the design through after-action reviews, decision logs, and guided prompts, helping learners critically analyse choices and adapt strategies for future climbs.

Inclusive & Culturally Responsive Design (Engeström, 1987)	• Tools must reflect cultural and contextual realities • Multivoicedness acknowledges diverse perspectives • Adaptability and localisation are essential	The VR training was adapted to Chilean and New Zealand contexts by reflecting local environments and safety frameworks. However, language localisation (e.g., Spanish) remained a gap, highlighting the need for inclusive design.

Note. This table summarises the theoretical frameworks and design principles that informed the VR-based mountaineering safety training intervention. Sources: Hase & Kenyon (2001); Vygotsky (1978); Engeström (1987, 2001); Kolb, 1984; Herrington & Oliver (2000); Cant & Cooper (2010); Hase (2009)

8.2.2 Reflection on the Theoretical Framework

Engeström's (2001) Third-Generation Activity Theory offered a robust conceptual lens for situating virtual reality (VR) training within the socio-cultural landscape of mountain safety education. By examining the interrelations between subjects, tools, objects, rules, communities, and divisions of labour, the framework enabled a systemic view of how learning activities unfold in high-risk environments.

One of the key advantages of Activity Theory is its capacity to reveal contradictions that arise within and between system elements. In this study, tensions emerged most clearly in the relationship between learners and the VR tool. Reports of visual discomfort, language barriers, and usability challenges highlighted the extent to which the tool is not neutral but carries socio-technical constraints that shape how participants engaged with the learning task (Engeström, 1987; Kaptelinin & Nardi, 2012).

Equally significant were contradictions between the VR tool and the intended learning outcomes. While VR was effective in fostering cognitive preparedness and psychological

engagement, it fell short in replicating physical stressors such as cold, fatigue, and altitude sickness. This limitation underscores Engeström's (2001) view that contradictions can drive expansive learning by highlighting what cannot be resolved within the current system, thereby pointing to the need for complementary forms of practice beyond digital simulation.

The interplay between community and object further revealed the role of cultural expectations in shaping perceptions of VR. Some experienced climbers and instructors resisted the idea of substituting embodied, field-based training with simulated environments, reflecting the multivoicedness inherent in activity systems, where multiple perspectives, histories, and priorities intersect (Engeström & Sannino, 2010).

Overall, Activity Theory proved useful not only for mapping socio-cultural dynamics but also for explaining how innovation develops iteratively over time. The design and refinement of the VR prototype—guided by user feedback and contextual consultation—mirrored the process of expansive learning (Grotlüschen, 2010), where contradictions trigger reflection, adaptation, and systemic transformation.

In summary, Activity Theory provided a framework for interpreting both the potential and the limitations of VR training in mountaineering education. By foregrounding the frictions within and between system components, it highlighted where VR could meaningfully enhance safety training and where additional pedagogical strategies remained necessary. This analysis provides a foundation for the following section, which contrasts the two national case studies—Aotearoa New Zealand and Chile—through the lens of Activity Theory (Engeström, 1987, 2001).

8.2.2.1 Activity Theory Analysis of VR-Based Mountain Safety Training in Chile and New Zealand

8.2.2.2 Conceptual Framework: Activity Theory

This section examines how Engeström's (2001) Third-Generation Activity Theory provides an effective theoretical lens for analysing the thematic findings from a virtual reality (VR)–based mountain safety training intervention conducted in Chile and New Zealand. Within the framework of Activity Theory, the analysis not only highlights critical usability issues, immersive strengths, and socio-cultural dynamics but also reveals system-wide tensions and developmental possibilities arising from the integration of immersive technologies into outdoor safety education.

Activity Theory (AT), rooted in Vygotskian socio-cultural psychology and later expanded by Engeström, offers a systemic lens for investigating how individuals (subjects) interact with mediating tools (artefacts) to pursue shared goals (objects) within broader socio-cultural contexts. Engeström's Third-Generation AT Theory expands the original model by incorporating interacting activity systems and foregrounding contradictions as sources of change and development (Engeström, 2001). Within this model, the key components include the subject, object, mediating artefacts/tools, rules, community, division of labour, and outcome. This framework is beneficial for understanding how digital technologies, such as VR, reconfigure traditional learning practices within specific cultural and institutional environments, including the outdoor education sectors of Chile and New Zealand.

Engeström's (2001) Third-Generation Activity Theory highlights the expansion and interaction of multiple activity systems, particularly when new technologies intersect with traditional pedagogical models. In this case, the VR training system exists alongside conventional mountaineering education, which includes field-based training, mentorship, and culturally embedded practices. Tensions were identified between the community of traditional mountaineers—who may be sceptical of digital tools such as VR—and the emerging generation of learners who are more receptive to immersive technologies.

Moreover, the implementation of VR training is influenced by economic and technological disparities, especially in rural or underfunded communities. Limited access to headsets, high development costs, and digital literacy gaps create systemic barriers to the broader adoption of this technology. These issues highlight contradictions between the community, division of labour, and tools, calling for greater institutional and governmental support to ensure equitable access.

The application of Engeström's (2001) Third-Generation Activity Theory illuminates the Chilean VR mountaineering initiative as an evolving, interconnected network of activity systems characterised by inherent tensions, diverse voices, and substantial potential for transformation. The observed contradictions are not impediments but rather generative forces that can drive expansive redesign, ultimately leading to more inclusive, practical, and context-sensitive VR safety training. For this promise to be realised, all involved systems—learners, developers, institutions, and communities—must collaboratively redefine the shared object: safe, embodied, and culturally rooted mountaineering preparation.

In this study, the VR application serves as a mediating artefact within the mountain safety education activity system. Participants (subjects) engage with this digital tool to enhance safety skills (object), operating within broader institutional, cultural, and physical constraints. Through this framework, the thematic findings are interpreted as expressions of systemic tensions and potentials for expansive learning.

Given the central role of Activity Theory in this study, the following sections provide a detailed exploration of how the interventions in Chile and New Zealand were shaped and interpreted through this theoretical lens.

8.2.2.3 Activity Theory Analysis of VR in Mountain Safety Education in Chile

In the Chilean context of the VR-based mountain safety training intervention, the participants (subjects) have a similar age distribution to that in New Zealand. However, they are often from regions where virtual reality technologies are less accessible or familiar. The tools employed consist of comparable VR setups, with a strong emphasis on immersive sound design. However, users consistently expressed concerns about the blurry visual quality and the absence of a Spanish-language user interface, both of which limited engagement and comprehension. The object of the activity mirrors that of the New Zealand intervention—mountain safety education—but with additional emphasis on adapting training content to reflect local conditions, such as lower-altitude, dry mountain environments. The rules shaping the activity system highlight the importance of cultural and geographic relevance, economic barriers to access, and a degree of scepticism toward VR technology within specific communities. The community supporting or influencing the intervention includes national mountaineering bodies, such as Federación de Andinismo

de Chile (Chilean Mountaineering Federation, FEACH), regional tourism authorities, and local universities, all of which present opportunities for collaboration and scaling. Regarding the division of labour, recommendations were similar to those in New Zealand, with participants advocating for government and institutional funding mechanisms, as well as support from outdoor brands, to ensure sustainable implementation and contextual relevance.

Table 8.2

Activity Theory component for Chile cohort

Activity Theory component	**Chile**
Subject (Who is learning?)	The Chilean participants represented a diverse mix of individuals, many of whom were highly experienced mountaineers with substantial exposure to real-world climbing environments. However, a distinctive feature of this cohort was that several participants came from regions where virtual reality (VR) technologies are less common and less easily accessible than in countries with more established digital infrastructure. This created a unique learning dynamic: while their mountaineering expertise enabled them to critically assess the simulation's realism, limited prior exposure to VR interfaces occasionally hindered their initial engagement. It reflects a core tenet of Activity Theory, where the subject's prior knowledge, skills, and context shape how tools are used and experienced.
Tools (What is used?)	The primary mediating tool was the VR prototype developed in Unity 5.5 and deployed through the Oculus Quest 2 headset. For Chilean participants, the auditory design—such as the immersive sounds of wind, snow, and avalanches—was particularly impactful in enhancing their sense of presence, often compensating for limited visual clarity. However, several participants, particularly those wearing prescription glasses, experienced discomfort and difficulty focusing due to the headset design. Additionally, the English-only interface posed a barrier for many Chilean participants, who preferred Spanish-language instructions and menus. These limitations represent contradictions within the activity system: while the VR tool aimed to enhance learning, its technical and linguistic constraints created additional challenges, increasing cognitive load.
Object (What is the goal?)	The overarching goal of the VR intervention was to improve participants' safety knowledge, decision-making, and preparedness for high-risk mountaineering scenarios. For the Chilean participants, this goal was understood and valued. Still, many noted that the simulation's alpine setting—characterised by snow and high altitudes—did not fully reflect

	the realities of their local environment. Chilean mountains are often dry and rugged rather than snow-covered, and accidents typically occur at lower altitudes. This discrepancy highlighted a need to adapt VR content to local conditions to maximise relevance and authenticity, ensuring that the learning objectives were directly aligned with the participants' real-world experiences.
Rules (Constraints, norms?)	Cultural and contextual factors significantly shaped the way Chilean participants perceived the VR training. Several highlighted the importance of cultural relevance, noting that for VR to be truly useful, it should simulate environments and challenges familiar to Chilean climbers. In addition, economic constraints were identified as potential barriers to widespread adoption, with participants acknowledging that while VR is valuable, the cost of hardware and development could limit access for many mountaineers. Some participants also expressed scepticism toward VR as a legitimate training method, reflecting broader community attitudes that privilege traditional, experience-based learning in the mountains. These dynamics illustrate how rules, norms, and cultural expectations influence the reception and integration of new technologies.
Community (Who supports or resists?	The Chilean participants identified several potential supporters within their broader activity system, including mountaineering organisations such as the Federación de Andinismo de Chile (FEACH), local climbing clubs, tourism agencies, and academic institutions. These organisations could serve as valuable partners in legitimising and embedding VR-based training into existing programs. At the same time, participants acknowledged that some segments of the mountaineering community might resist adopting VR, particularly those who place a strong emphasis on physical experience and traditional approaches to mountain training. It reflects the Activity Theory concept of multivoicedness, where diverse perspectives within a community shape the trajectory of innovation (Engeström, 1987).
Division of Labour (Who does what?)	Chilean participants highlighted the importance of shared responsibility for developing and sustaining VR-based training. They argued that effective implementation would require financial support and institutional buy-in from government agencies, mountaineering federations such as FEACH, and academic research partners like CEM. They also suggested that outdoor equipment brands—such as Patagonia and The North Face—could play a role through sponsorship, providing resources or funding in exchange for visibility. This distribution of roles illustrates how activity systems depend on coordinated contributions from multiple stakeholders, and how VR training initiatives could benefit from cross-sector collaboration to ensure long-term sustainability.

8.2.2.3.1 Contradictions and Tensions across and within Activity Systems

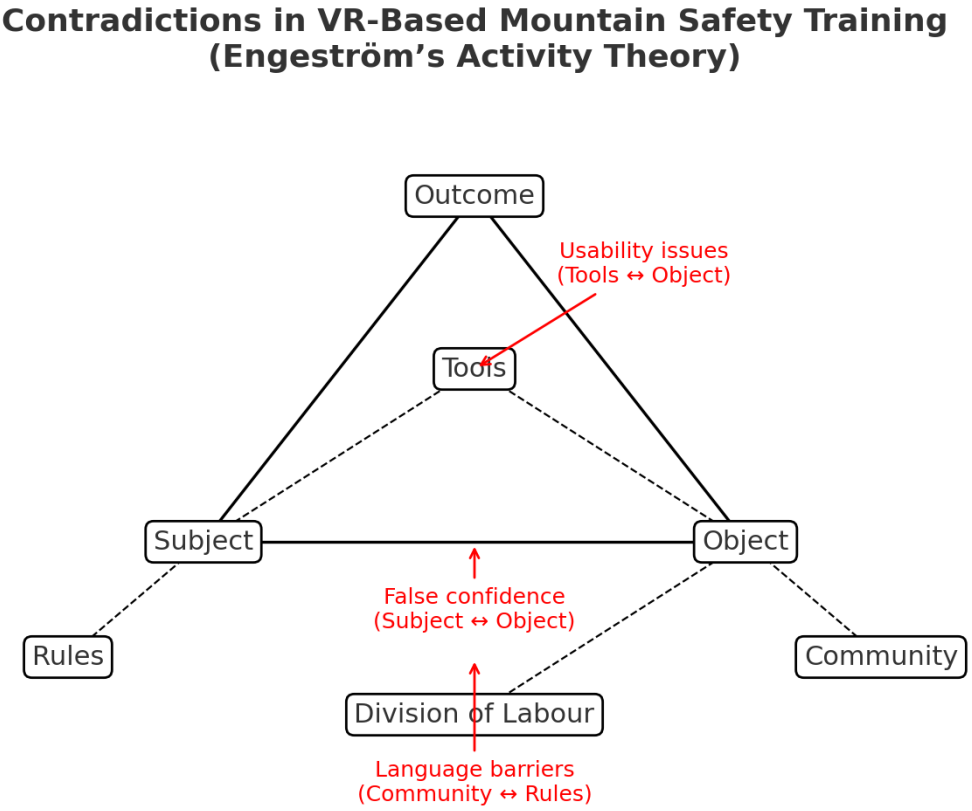
Activity Theory conceptualises contradictions not as shortcomings but as drivers of systemic development and expansive learning (Engeström, 2001). Within the Chilean VR-based mountaineering training intervention, several inconsistencies were identified across the activity system, highlighting tensions between design intentions and real-world use. At the intra-component level, participants consistently praised the immersive sound design—particularly environmental effects such as wind and avalanches—yet this strength was undermined by poor visual resolution, unreadable text, and limited focus adjustment, especially for users wearing glasses. This created a dissonant sensory experience that detracted from the pedagogical effectiveness of immersion. Similarly, the absence of Spanish language support and onboarding tutorials conflicted with basic usability norms, especially for users with lower digital literacy, thereby reducing accessibility and learner engagement.

Between components, contradictions surfaced in the relationship between subjects and tools, as learners struggled with unintuitive controls and low visual clarity, resulting in cognitive overload that impeded task focus. Further tension emerged between the community and division of labour: the development team—many of whom were located outside Chile—overlooked local environmental and cultural contexts, producing content that focused on snowy alpine scenarios, which were largely irrelevant to the dry, low-altitude terrain typical of Chilean mountaineering in the southern part of Chile. At a broader level, the introduction of VR as a learning tool generated friction with traditional pedagogical values. Many seasoned mountaineers and instructors expressed scepticism, viewing VR as insufficient to replace the embodied, mentor-led learning intrinsic to Chile's

outdoor education culture in pre-consulation 2019. Collectively, these contradictions—between tools and subjects, tools and outcomes, and communities and learning objectives—highlight the need for iterative design processes that integrate local user feedback, cultural relevance, and hybrid training models to ensure effective and context-sensitive implementation.

Figure 8. 1

Contractions in VR-Based Mountain Safety Training (Engeström's Activity Theory)



1. The 1st Contradiction (Tool ↔ Subject)

- Tool-related: Participants widely praised the immersive quality of the sound design, including environmental cues like wind and avalanches. However, this was undermined by poor visual resolution, blurry text, and an overall lack of focus calibration. This mismatch created cognitive dissonance, reducing the effectiveness of the immersive learning experience.

- Rules vs Tools: The absence of Spanish language support and a lack of onboarding tutorials contradicted basic accessibility expectations. Learners with lower digital literacy found it challenging to navigate the system, which limited their engagement and negatively impacted their learning outcomes.

2. The 2nd Contradiction (Tool ↔ Outcome)

- Subject–Tools: Learners reported cognitive overload due to low visual clarity, unintuitive controls, and inadequate navigation support. These issues disrupted their ability to focus on learning tasks and made it difficult to make sense of the scenarios.
- Community–Division of Labour: The developers, many of whom were not based in Chile, failed to incorporate key local environmental and cultural elements into their projects. For example, training scenarios focused on snowy alpine conditions are less relevant to some of the dry, low-altitude climbing environments prevalent in Chile. This disconnect between the design and the learners' lived realities limited the training's authenticity and applicability.

3. The 3rd Contradiction (Community ↔ Object)

- The introduction of VR-based training challenged traditional modes of instruction in Chile, which are often hands-on and guided by local mentors. Some experienced mountaineers and instructors were sceptical of digital simulations, expressing concern that VR could never replace the embodied knowledge gained through real-life experience in the mountains.

Table 8.3

Contradictions in Activity Theory: Chilean VR Mountaineering Training

Type of Contradiction	**Description**	**Illustrative Examples from Chilean Data**
Contradiction 1 Tool ↔ Subject	Mismatch between the physical/linguistic affordances of the VR system and users' needs.	• Headset discomfort and focus issues for glasses wearers. • No translation or replay features for non-native speakers.
Contradiction 2 Tool ↔ Outcome	VR fails to simulate key physical stressors, limiting preparation for real-world decision-making.	• Absence of cold, fatigue, wind, and altitude simulation. • Risk of false confidence without physical stressors.
Contradiction 3 Community ↔ Object	Conflict between traditional experiential training values and the integration of digital tools, such as VR.	• Scepticism from experienced mountaineers. • Resistance to replacing embodied learning with simulation.

In the Chilean context, several contradictions emerged during the VR-based mountaineering safety intervention, highlighting the tension between the intended learning

outcomes and participants' actual experiences. The first major contradiction arose between the tool and the subject: while the VR system aimed to enhance engagement through immersive visuals and audio, many Chilean participants—particularly those wearing glasses—reported blurred imagery and difficulty adjusting focus. Additionally, the English-only interface and absence of replay functions created linguistic and cognitive barriers, as reflected in participants' comments such as "I don't understand all the instructions… it would be better in Spanish" (Anita). These mismatches demonstrate how technological affordances did not always align with participants' needs, generating additional cognitive load and reducing immersion.

The second contradiction arose between the tool and the intended learning outcomes. While the simulation effectively recreated the visual and auditory aspects of the alpine environment, participants highlighted its inability to replicate physical stressors such as cold, fatigue, or the physiological effects of altitude. These insights suggest that although the VR system succeeded in evoking emotional arousal, the absence of embodied risk elements may have generated a false sense of preparedness.

The third contradiction was located between the community and the object, reflecting cultural and institutional tensions surrounding VR adoption. While organisations such as Federación de Andinismo de Chile (FEACH) and Centro de Estudio en Montaña (CEM) were identified as potential allies in Chile, some experienced mountaineers expressed scepticism toward digital substitutes for traditional, embodied training practices. It echoes Engeström's (2001) observation that contradictions between elements of an activity system—such as tools, rules, and community expectations—can disrupt established practices but also serve as catalysts for innovation. In this sense, the challenges encountered

in Chile not only reveal gaps in the current VR design but also highlight opportunities for culturally responsive, collaborative, and contextually grounded enhancements that could strengthen the legitimacy and long-term integration of VR into mountain safety education.

8.2.2.3.2 Summary

The Chilean implementation of the VR-based mountain safety training intervention reveals how key elements of Engeström's Activity Theory interact within a culturally specific context. The participants, or subjects, came from diverse backgrounds, many with limited prior exposure to virtual reality. While the VR tool was praised for its immersive audio design, several usability barriers—such as blurry visuals, lack of Spanish-language support, and limited onboarding—hindered accessibility and engagement.

The object of the activity system, namely, enhancing mountain safety education, aligned with the New Zealand counterpart but required contextual adaptation for Chile's low-altitude, dry mountain environments. Rules governing the activity system included the need for cultural realism and the challenge of economic and technological constraints. Communities such as FEACH, CEM, tourism bodies, and local universities showed support. At the same time, the division of labour highlighted a shared responsibility among the government, educational institutions, and outdoor brands to ensure the sustainable implementation.

Multiple contradictions surfaced across the system. Within components, intense audio immersion was undermined by poor visual quality, and the absence of localised language features limited usability. Between components, learners experienced cognitive overload due to interface complexity, and a disconnect existed between the international

development team and the local environmental realities. On a broader level, tensions arose between digital innovations and traditional hands-on training culture, as experienced mountaineers questioned the legitimacy of VR as a substitute for embodied learning.

These contradictions underscore the importance of culturally responsive, inclusive, and hybrid educational design. They also demonstrate how Activity Theory can be applied to identify systemic tensions and guide iterative improvements in VR-based training for high-risk environments.

8.2.2.4 Activity Theory Analysis of VR-based Mountain Safety Training in New Zealand

In the context of mountain safety education in Aotearoa New Zealand, a VR-assisted training intervention was developed to simulate alpine hazards and decision-making scenarios. To analyse the effectiveness and limitations of this intervention, Engeström's (2001) Third-Generation Activity Theory offers a robust theoretical framework for exploring complex, tool-mediated, and socially situated learning systems.

The subject of the activity system comprises mountaineers with varying levels of experience. Notably, beginner climbers and outdoor enthusiasts demonstrated particularly strong engagement with the VR platform. The tools mediating the activity are virtual reality headsets, which provide immersive visual and auditory experiences. However, participants reported usability challenges, particularly about visual clarity and headset comfort, especially for users who wear glasses.

The objective of the activity is to enable learners to acquire critical mountain safety skills—such as altitude sickness, avalanche response, navigation, and emergency procedures—

within a safe and immersive virtual environment. These learning experiences aim to simulate real-world challenges while minimising physical risk.

Several rules or norms emerged throughout the intervention. A key understanding among participants and users was that VR should complement, not replace, traditional physical training. Participants also cautioned that VR can create a false sense of confidence, especially when users are not exposed to the physical stressors inherent in real-world mountaineering. Additionally, linguistic accessibility and cultural sensitivity were acknowledged as factors that shape user experience and engagement.

The community surrounding the intervention included significant interest and support from safety-focused organisations such as the New Zealand Alpine Club and the Mountain Safety Council. These groups recognise the value of VR as an innovative training tool and offer potential pathways for partnerships, as well as government and outdoor brand sponsorships.

Finally, the division of labour within the system reflects a hybrid approach to training. While participants advocated for VR as a foundational or early-stage educational tool, they emphasised the continued need for expert-led, field-based instruction. There is also recognition of the collaborative role industry and academia could play in developing and refining VR training content.

Table 8.4

Activity Theory component in New Zealand

Activity Theory component	**New Zealand**
Subject	The subject of the New Zealand intervention comprised mountaineers and

(Who is learning?)	outdoor enthusiasts with varying levels of experience, ranging from novices with limited exposure to alpine environments to more experienced climbers. Many participants were relatively new to mountaineering, which shaped both their expectations of the VR tool and their reliance on structured guidance during the simulation. Beginners, in particular, approached the technology with great enthusiasm, often viewing it as an accessible and engaging entry point to the complexities of mountain safety.
Tools (What is used?)	The tools used in the intervention centred on the Oculus Quest 2 headset, which delivered immersive visual and auditory experiences of high-altitude mountain environments. Participants praised the simulation's audio fidelity, noting that the wind, snow, and environmental sounds contributed to a strong sense of presence. However, certain functional limitations also emerged. Those who wore prescription glasses reported discomfort and reduced clarity, pointing to constraints in the headset's physical design. While Oculus offers prescription lens adapters as an accessory, these were not available within the study, highlighting the importance of considering both technological affordances and ergonomic inclusivity in future iterations.
Object (What is the goal?)	The objective of the activity system in New Zealand was to acquire fundamental mountain safety knowledge and skills, with particular emphasis on scenarios involving altitude sickness, navigation challenges, avalanche awareness, and emergency responses. For novice and intermediate participants, the VR intervention functioned as a safe, controlled environment in which they could experiment with decision-making under simulated high-risk conditions without facing the physical dangers of real expeditions.
Rules (Constraints, norms?)	The rules guiding the activity highlighted an important tension. While participants recognised the value of VR for enhancing safety training, they stressed that the technology should not replace physical training in the mountains. Several individuals warned that an over-reliance on VR could foster a false sense of preparedness, potentially leading learners to underestimate the unpredictability and physical demands of real alpine environments. Language and cultural norms also shaped participants' experiences. For instance, those for whom English was not their first language reported difficulties understanding the instructions and menu prompts, emphasising the need for localised versions—particularly in languages such as Te Reo Māori and Spanish—to ensure equitable access.
Community (Who supports or resists?)	The community dimension was especially significant in the New Zealand context. Participants identified strong potential support from established national organisations such as the New Zealand Alpine Club (NZAC) and the Department of Conservation (DOC), both of which play central roles in mountaineering education and safety initiatives. Additionally, participants saw opportunities for collaboration with outdoor brands, such as Macpac, as well as with universities and research institutions. These partners could provide resources, legitimacy, and platforms for integrating VR into both formal educational programs and community-based safety initiatives.

Division of Labour (Who does what?)	The division of labour highlighted participants' nuanced perspectives on how VR should be positioned within the broader educational ecosystem. While they valued VR as a pre-training tool, particularly for beginners who may lack opportunities to experience alpine conditions firsthand, they were clear that expert human instructors remain essential for teaching physical techniques, guiding field practice, and modelling decision-making under real stress. In this sense, the VR intervention was perceived as a valuable preparatory and complementary resource rather than a replacement for traditional experiential learning. Moreover, participants suggested that the long-term sustainability of VR-based training in New Zealand would depend on joint efforts between educators, safety organisations, government agencies, and commercial sponsors. Such distributed responsibilities align with Engeström's (1987, 2001) conceptualisation of activity systems as collective enterprises in which tools, rules, communities, and divisions of labour must evolve together to support expansive learning.

8.2.2.4.1 Contradictions and tensions across and within Activity Systems

Within Engeström's (2001) Third-Generation Activity Theory (see Figure 8.1), contradictions are viewed as historically accumulating tensions within or between elements of an activity system. These contradictions, when identified and addressed, can serve as powerful drivers of systemic transformation and expansive learning. The New Zealand VR-assisted mountain safety training intervention revealed several such contradictions, which are discussed in the following sections.

In the New Zealand mountain safety context, VR functions as a mediating artefact designed to enhance learner engagement, decision-making, and preparedness for real-world alpine environments. Participants widely reported the VR simulations as immersive and emotionally engaging, citing strong audio-visual elements (e.g., wind, snow, altitude effects) that replicated aspects of alpine psychological stress. These immersive qualities

indicate a productive alignment between the tool (VR) and the object (acquisition of mountain safety skills), contributing positively toward the desired outcome—improved learner readiness and risk awareness.

However, systemic contradictions emerged. Some users experienced discomfort or visual limitations due to the headset hardware, especially those who wear glasses. Language barriers were also evident for non-native English speakers, affecting accessibility and comprehension. These issues represent tensions between the subject and the tool, as well as between rules (e.g., English-only instruction) and the broader community of diverse learners. Participants suggested solutions, such as headset calibration options, translation tools, and replay functions, to accommodate linguistic and physiological diversity better.

One of the central benefits of VR, as revealed in this study, is its ability to provide a safe and controlled learning environment. Beginners, in particular, valued the opportunity to build foundational skills and confidence without being exposed to the inherent risks of real-world mountaineering. Repeated exposure to high-stakes scenarios, such as identifying avalanches or altitude sickness, enabled users to develop muscle memory and faster cognitive responses, thereby strengthening the link between the subject, tool, and object.

Nonetheless, a key contradiction within the activity system lies in VR's inability to replicate physical stressors such as cold, fatigue, and altitude effects—factors that are crucial to real-world decision-making. As a result, participants raised concerns that an exclusive reliance on VR could foster overconfidence, particularly among inexperienced users. This tension highlights a mismatch between the tool's outcomes and its limitations,

underscoring the need for a blended learning approach that integrates VR simulations with physical training in authentic outdoor settings.

This table outlines key systemic contradictions identified within the New Zealand VR-assisted mountain safety training activity system, based on Engeström's (2001) Third-Generation Activity Theory. Each type of contradiction reveals tensions within or between system components that may hinder or facilitate learning. These examples are drawn from empirical participant feedback.

Table 8.5

Contradictions in Activity Theory: New Zealand VR Mountaineering Training

Type of Contradiction	**Description**	**Illustrative Example from New Zealand Data**
Contradiction 1 Tool ↔ Subject	Misalignment between the VR hardware/tool and the learner using it.	Participants wearing glasses struggled with headset fit and blurry visuals, which reduced immersion and learning effectiveness. Non-native English speakers found the lack of translation and reply options challenging.
Contradiction 2 Tool ↔ Outcome	The VR tool fails to replicate essential physical stressors needed to achieve the learning outcome.	VR lacked sensations such as cold or fatigue. Participants feared that this gap could create a false sense of readiness, as real-life stressors in alpine environments are not encountered in the simulation.
Contradiction 3 Community ↔ Object	Tensions between the community's traditional practices and VR-mediated training.	Senior mountaineers and instructors expressed scepticism toward VR, questioning its legitimacy compared to mentorship and field-based learning. This resistance created a cultural barrier to the adoption of VR.

1. The 1st contradiction (Tool ↔ Subject)

- A primary contradiction was observed between the VR tool and the subject, the learners using the technology. Participants reported issues with headset fit and focus, particularly those who wore glasses, which affected visibility and immersion. Such hardware-related discomfort limited their ability to fully participate in the training, revealing a misalignment between the tool's physical affordances and users' diverse needs. This exemplifies what Kaptelinin and Nardi (2006) describe as a breakdown in instrumental mediation, where tools fail to support goal-directed activity effectively.
- Additionally, non-native English speakers encountered difficulties with audio instructions and terminology, citing a lack of translation features and replay options. These linguistic barriers disrupted the flow of learning. The current form of VR learning may not adequately support a multilingual or culturally diverse learner base. As Engeström (2001) emphasises, contradictions at the tool–subject interface often reveal deeper socio-cultural limitations that must be resolved through redesign and inclusive practices.

2. The 2nd contradiction (Tool ↔ Outcome)

- Another contradiction emerged between the tool (the VR simulation) and the intended outcome—preparing participants for real-world mountain safety scenarios. While the VR application offered high levels of visual and auditory immersion, it could not replicate critical physical stressors such as cold temperatures, wind,

fatigue, and hypoxia. These environmental and physiological factors are crucial for making accurate decisions under pressure in actual alpine conditions.

- As noted by Engeström (1987), when tools are unable to mediate the object of an activity fully, the gap between simulated experience and intended outcome can become a limiting factor in learning. Participants themselves acknowledged this limitation, expressing concern that exclusive reliance on VR could create a false sense of preparedness. To mitigate this, a hybrid model—in which VR is complemented by physical, field-based training—is necessary to ensure that learning transfers effectively to real-world settings (Engeström, 2001; Kaptelinin & Nardi, 2006).

3. The 3rd Contradiction (Community ↔ Object)

- A third systemic contradiction occurred between the community of practice (i.e., instructors, mountaineers, institutions) and the object of digitally mediated mountain safety training. While younger and more tech-oriented participants were generally enthusiastic about VR, more experienced mountaineers expressed scepticism. These individuals questioned the legitimacy of digital simulation as a substitute for embodied, mentorship-based learning traditions deeply embedded in New Zealand's outdoor education culture. This reflects what Engeström (2001) calls multi-voicedness—the coexistence of differing perspectives within an activity system. Tensions between innovation and tradition are typical in such systems and can obstruct shared commitment to the object of learning. Without broad community support and engagement, the implementation of new tools risks being perceived as externally imposed or culturally dissonant. To reconcile this

contradiction, Engeström (1987, 2001) advocates for boundary-crossing dialogue between interacting activity systems. In this case, integrating community voices through participatory design, pilot testing, and evaluation could align stakeholder values and promote co-ownership of the learning transformation.

These contradictions—between tool and subject, tool and outcome, and community and object—illustrate the challenges of embedding VR within a complex educational ecosystem. Far from being obstacles, these tensions serve as developmental triggers that, when acknowledged and addressed, can lead to more adaptive, inclusive, and expansive learning environments (Engeström, 2001; Kaptelinin & Nardi, 2006).

In the New Zealand cohort, several contradictions within the activity system surfaced during the VR-based mountaineering safety training. These tensions highlight how mismatches among subjects, tools, objects, and community expectations can shape learning outcomes and indicate areas requiring further design refinement (Engeström, 2001).

One key contradiction arose between the VR hardware (the tool) and the learners using it. Participants who wore prescription glasses reported discomfort and difficulty achieving visual clarity within the Oculus Quest 2 headset. As one participant explained, “I can’t see quite clearly there. That’s the problem because of my glasses” (Robin, New Zealand cohort). This mismatch between the headset's physical design and the needs of glasses wearers disrupted immersion, detracting from the overall learning experience. Similarly, non-native English speakers highlighted challenges with understanding English-only instructions and the lack of a replay function for prompts. As Robin described, “I think it’s

like English is not my first language, so I sometimes maybe missed the question or like a hint" (Robin, New Zealand cohort). These examples show how technical and linguistic limitations placed an additional cognitive burden on participants, creating barriers to effective learning.

Another contradiction was identified between the VR tool and the intended learning outcomes. While the simulation successfully created immersive visual and auditory experiences, it could not replicate critical physical stressors such as cold, fatigue, or low-oxygen conditions. Participants noted this absence as a limitation, suggesting that the lack of embodied challenges might lead to a false sense of preparedness. Without experiencing the physical and physiological strain of real-world mountaineering, learners may overestimate their readiness for actual expeditions. This tension undermines the training's goal of fostering accurate risk perception and preparedness.

The third contradiction concerned the relationship between the mountaineering community and the object of VR-mediated training. Some senior or highly experienced mountaineers expressed scepticism about the legitimacy of VR as a substitute for traditional field-based learning and mentorship. It reflects broader cultural norms in mountaineering, where experiential knowledge gained through direct exposure to natural environments has long been privileged. Such scepticism represents a cultural and institutional barrier that may slow the adoption of VR-based training, even when its potential benefits are recognised. It also highlights Engeström's (2001) notion of multivoicedness, where different perspectives within the activity system—novices seeking accessible training and experts prioritising embodied experience—can come into tension.

Together, these contradictions reveal the complex dynamics of implementing immersive technologies in high-risk education. Rather than signalling failure, these tensions act as generative forces for system-level change. Addressing them—through improved hardware accessibility (e.g., prescription lens support), multilingual and replay functions, and the integration of VR within a blended learning framework—can strengthen the alignment between tools, subjects, outcomes, and community expectations. In doing so, the intervention can move closer to becoming a credible and sustainable component of New Zealand's mountaineering safety education landscape.

8.2.2.4.2 Summary

The implementation of a VR-assisted mountain safety training intervention in Aotearoa, New Zealand, was analysed using Engeström's (2001) Third-Generation Activity Theory to identify the systemic strengths and tensions within this tool-mediated learning environment. The intervention aimed to support climbers—particularly beginners—by simulating high-risk alpine scenarios in a safe, immersive setting.

Participants praised the immersive quality of the VR simulations, which effectively replicated the auditory and visual cues of real-world hazards. However, usability issues emerged, including poor headset comfort and blurry visuals, which were particularly noticeable for those wearing glasses. Non-native English speakers also faced challenges due to a lack of translation and replay options, which revealed contradictions between the tool and its subject, and raised concerns about accessibility and inclusivity.

Another key contradiction arose between the VR tool and its intended outcome. While VR promoted cognitive preparedness, it failed to replicate essential physical stressors such as

cold, fatigue, and altitude. This limitation led some participants to express concern about a false sense of readiness, emphasising the importance of integrating VR with traditional, field-based training for complete transfer of learning.

Cultural tensions also emerged. While younger learners were generally enthusiastic, more experienced mountaineers were sceptical of replacing mentorship-based instruction with simulation-based learning. This contradiction between the community and the object highlighted the need for broader stakeholder engagement and participatory design to foster acceptance and co-ownership.

Overall, the New Zealand case study illustrates how contradictions—among tools, subjects, outcomes, and community expectations—can drive refinement and innovation. Addressing these tensions through inclusive design, localisation, and blended learning strategies can enhance VR's educational potential in high-risk outdoor training.

Building on the insights gained from the New Zealand case, a broader perspective emerges when this system is examined alongside the Chilean intervention. While both countries share a common goal of improving mountain safety education through immersive VR simulations, their socio-cultural, linguistic, and environmental contexts differ significantly. These contextual differences give rise to unique contradictions and learning dynamics within each Activity System. The following section presents a comparative Activity Theory analysis of the New Zealand and Chilean interventions, identifying shared challenges, divergent user experiences, and culturally specific considerations. This cross-case examination deepens our understanding of how VR training systems must adapt to local realities to maximise educational relevance, accessibility, and impact.

8.2.2.5 A Comparative Activity Theory analysis of VR-based mountain safety training in New Zealand and Chile

This section presents a comparative analysis of VR-based mountain safety training interventions in Aotearoa New Zealand, and Chile, examining them through the lens of Engeström's Third-Generation Activity Theory (2001) (see Figure 8.1). Activity Theory provides a socio-cultural framework for examining complex learning environments, enabling the identification of contradictions, tensions, and interactions among key system components—including learners (subjects), tools (such as VR systems), community stakeholders, and the rules and norms that govern participation.

By applying this framework, the section explores how contextual variables—such as language accessibility, environmental realism, institutional support, and cultural attitudes toward technology—shape the implementation and reception of VR training in both countries. While the two interventions share a common educational objective—enhancing climbers' decision-making and preparedness—they differ in technological familiarity, resource availability, and users' socio-cultural backgrounds and expectations. These differences generate distinct patterns of systemic contradictions that reveal both shared challenges and locally specific insights.

Through this comparative analysis, the section aims to inform more adaptive, inclusive, and context-sensitive design and implementation strategies for VR-based learning in mountaineering education. It highlights how expansive learning can emerge when contradictions are recognised and addressed, and how international comparisons can

surface valuable lessons for the future of simulation-based training in diverse geographic and cultural contexts.

Table 8.6

The key differences between Chile and New Zealand

Activity Theory component	**New Zealand**	**Chile**	**Key contractions (Key differences)**
Subject (Who is learning?)	Mountaineers with varying levels of experience—strong engagement from beginners and outdoor enthusiasts.	A similar mix of users, but often from regions where VR is less accessible or less familiar.	Chilean users often face more barriers to entry (e.g., economic and technological).
Tools (What is used?)	VR headsets offer immersive visuals and sound, but they also present visual clarity and usability issues for individuals who wear glasses.	A similar VR setup strongly emphasises immersive sound, but there are consistent concerns about blurry visuals and the need for a Spanish-language UI.	Chile highlights the need for stronger multilingual support and improved UI for first-time users.
Object (What is the goal?)	Learn mountain safety skills (including avalanche, navigation, and emergency response) in a safe, immersive environment.	Same goals, but also focused on adapting content to local terrain (low-altitude, dry conditions).	NZ focuses more on altitude-based risks, while Chile focuses more on terrain-related risks and low-altitude dangers.
Rules (Constraints, norms?)	VR should not replace physical training. The risk of overconfidence was discussed. Language and cultural norms influence perception.	Emphasis on the need for cultural relevance (e.g., realism of Chilean mountains), economic constraints, and scepticism about VR among some communities.	Chile faces scepticism and needs localisation. NZ already benefits from stronger VR literacy.
Community (Who supports or resists?)	Strong interest from safety organisations (e.g., NZ Alpine Club, Mountain Safety Federation) and potential for	Mountaineering bodies (e.g., FEACH), tourism agencies, and local universities are key potential allies.	Both face similar opportunities for support, but Chile requires more effort to build trust and adapt its content.

	government/brand partnerships.		
Division of Labour (Who does what?)	Participants recommend VR for early training; experts are still needed for real-world teaching. Industry/academia are potential content creators.	Similar recommendations, with an emphasis on government/institutional funding, as well as brand sponsorships	Chile emphasises public-private collaboration to overcome access barriers. NZ is more focused on the implementation in the education sector.

As Virtual Reality (VR) increasingly emerges as a powerful tool in experiential education, its deployment in mountain safety training reveals significant insights into the interplay between technological tools and diverse cultural and environmental contexts. Utilising Activity Theory as a conceptual framework, this comparative analysis investigates users' engagement with VR-based mountaineering simulations in New Zealand. Activity Theory facilitates an exploration of the systemic interrelations among the subject (learners), the tools (VR technology), the object (training goals), and the broader community, rules, and division of labour that mediate learning outcomes.

8.2.2.5.1 Tool Integration and Usability: Interaction with Mediating Artefacts

A pronounced divergence is evident in the interaction between users from each country and the VR tool. Participants in New Zealand frequently described their experiences as not only immersive but also psychologically intense, indicating a high degree of fidelity between the simulated environment and the authentic cognitive demands associated with mountaineering. In this context, the VR system operates as a well-integrated mediating artefact, successfully eliciting stress responses analogous to those encountered in real

mountainous scenarios, thereby fulfilling a critical design objective. The reason participants in New Zealand differ from those in Chile regarding the audio component is that the intervention was initially conducted in Chile. The researcher and development team then improved the audio quality after receiving feedback from participants in Chile, as the audio component had been identified as needing improvement. Conver had been identified as needing Chilean participants, acknowledged the immersive audio component, but reported considerable challenges related to visual clarity, interface usability, and language barriers. Many users required onboarding, which suggests a steeper learning curve and limited digital literacy in VR among this demographic. This scenario reflects what Activity Theory identifies as a misalignment between the tool and the subject's cultural-historical context. Incorporating a Spanish-language interface and culturally relevant onboarding processes would serve as mediating artefacts that more effectively align users with the learning activity. These differences demonstrate that the effectiveness of a technological tool cannot be understood in isolation. Rather, its educational value emerges through its interaction with users' socio-cultural contexts, technological familiarity, and environmental realities.

8.2.2.5.2. Contextual Relevance: Aligning Objects with Learners' Environments

In New Zealand, the VR content closely mirrors the environmental hazards typically encountered in authentic alpine contexts, such as cold temperatures, snow, steep terrain, and altitude. This close alignment fosters a strong resonance between the object of the activity (the activity's objectiveness) and the situated reality of the learners, thereby enhancing the transferability of skills. In contrast, Chilean participants expressed a disconnect, noting that the majority of mountainous areas in southern Chile are in

environments. Consequently, simulations predicated on snow navigation appeared unfamiliar and contextually irrelevant to their lived experiences. This situation highlights a contradiction between the intended object (risk preparedness) and the perceived object (contextually meaningless snow navigation). Activity Theory advocates for resolving such contradictions through the redesign of object-oriented activities. In this case, localising simulations to address heat exhaustion, low-altitude navigation, and rockfall risks would realign the tool with the learners' genuine environmental context and activity system.

8.2.2.5.3 Community and Rules: Social Structures that Shape VR Adoption

The socio-institutional environments in New Zealand and Chile have a distinct influence on the adoption of VR technology. In New Zealand, a well-established ecosystem comprising educational institutions, mountaineering federations, and outdoor non-governmental organisations (NGOs) provides a conducive environment for integrating VR into training curricula. The prevailing rules and division of labour within this activity system are broadly supportive of the technology's deployment, reflecting a foundational level of trust, access, and organisational backing. Conversely, Chilean participants identified a lack of infrastructure and cultural readiness as significant barriers to progress. The community exhibits limited exposure to immersive technology, with a greater reliance on more active sponsorship and grassroots advocacy. Although there is palpable interest in technology, the regulatory frameworks governing training institutions and community perceptions are misaligned and receive insufficient attention. This reveals an infrastructural contradiction: while the tool may possess pedagogical merit, its adoption is contingent upon the community's capacity to assimilate it. Without targeted support mechanisms such

as financial assistance, policy advocacy, and the presence of local chamm, the situation remains precarious.

8.2.2.5.4 Division of Labour: Implementation, Access, and Educational Ecosystems

Both New Zealand and Chile concur that VR cannot completely supplant the pull-fill mountaineering experience; instead, it should be incorporated into a blended model that combines simulation with field practice. However, the division of labour in this process varies considerably. This divergence reflects not only contrasting levels of institutional maturity but also broader socio-economic conditions shaping how educational technologies are adopted. In New Zealand, the integration of VR builds on a strong infrastructure of established safety councils, alpine clubs, and university-led training programs, in which digital tools are increasingly viewed as natural complements to face-to-face practice. By contrast, in Chile, the relatively limited penetration of VR technologies, combined with economic barriers and cultural scepticism, means adoption is more dependent on partnerships with external actors. These structural differences highlight how local contexts mediate the division of labour in activity systems, influencing who assumes responsibility for sustaining innovation and how quickly new tools can be embedded into educational practice.

In New Zealand, participants perceive VR as a natural extension of existing educational methodologies. Educational institutions appear prepared to assume responsibility for integration tasks, which include curriculum development, instructional design, and student facilitation. In stark contrast, Chilean participants express a reliance on external entities—such as private firms, governmental agencies, or foreign institutions—to provide necessary

hardware, training, and implementation support. This scenario indicates variability in the capacity for self-sustaining innovation within activity systems, where New Zealand's model appears more internally driven. In contrast, the Chilean context necessitates external intervention for effective integration.

8.2.2.5.5 Synthesis and Broader Implications

From an Activity Theory perspective, both Chile and New Zealand engage in similar overarching training activities—mountain safety preparation—but operate within differently configured systems. The following summarises the key systemic differences.

Table 8.7

The key systemic differences between Chile and New Zealand

Component	New Zealand	Chile
Tool	VR is immersive and well-received	Audio practical; visual/language issues
Object	Matches real environmental risks	Mismatch with local geography
Community	Ready institutions and partnerships	Requires cultural buy-in and funding
Rules	Favourable for tech adoption	Conservative, requires policy support
Division of Labour	Educational institutions take the lead	Relies on external actors (gov, NGOs)

These differences have significant implications for scaling VR training internationally. Successful adoption requires not just exporting tools but also reconstructing entire activity systems to fit local contexts. Designers, funders, and policymakers must attend to the

cultural, institutional, and environmental mediators that shape users' experiences of technology.

8.2.2.5.6 Summary

Activity Theory offers a robust analytical framework for examining how the same technological tool—such as virtual reality (VR)—can yield vastly different educational outcomes when embedded in distinct sociocultural and institutional contexts. By focusing on the systemic interactions between subjects, tools, community, rules, division of labour, and the object of activity, Activity Theory reveals that effective learning is not merely a function of the tool itself, but of how that tool is integrated into the broader activity system in which learning occurs.

In Aotearoa New Zealand, the introduction of VR for mountain safety training has benefited from several enabling factors. These include a relatively high level of digital literacy among the target user group, familiarity with immersive technologies in education, and environmental alignment between the VR scenarios and real-world alpine conditions. Additionally, support from established institutions—such as the New Zealand Alpine Club and the Mountain Safety Council—has created a favourable environment for the uptake and scaling of VR-based learning. These conditions have enabled a smoother integration of VR into existing training paradigms, with fewer systemic contradictions between tools, community expectations, and learning objectives.

In contrast, the Chilean intervention reveals a more fragmented activity system in which the VR tool often clashes with user expectations, contextual constraints, and institutional limitations. Many users, particularly in rural or under-resourced areas, were less familiar

with VR technologies, and the training scenarios often failed to represent the actual conditions of Chile's mountainous terrain—typically dry, low-altitude, and non-snowy. Moreover, a lack of Spanish-language interfaces, limited onboarding support, and economic barriers to access to hardware exposed gaps and contradictions between the design of the VR tool and the linguistic and infrastructural realities of its intended users. Resistance from experienced mountaineers and scepticism within local training communities further complicated the tool's legitimacy as a pedagogical solution.

These comparative insights underscore the importance of moving beyond surface-level localisation, such as translating user interfaces or altering environmental textures. Instead, future interventions should adopt a co-design and co-development approach that actively involves local users, educators, institutions, and communities in shaping the activity system. It means not only adapting the VR content but also reshaping the surrounding social structures—rules, roles, and support mechanisms—to reflect better the lived realities, safety practices, and socio-technical conditions of the learners it aims to serve.

As this comparative analysis demonstrates, the success of VR in mountain safety training is not universal, but contingent. It is shaped by the degree to which the activity system supports or contradicts the introduction of immersive technology. Understanding and responding to these systemic tensions is critical for ensuring that VR becomes a transformative, rather than disruptive, addition to the high-risk training landscape in both countries.

8.3 Design Principles coming from Data Collection

Building on the earlier theoretical foundations, this section explores the practical development and implementation of the VR intervention across two distinct national contexts. Guided by Design-Based Research (McKenney & Reeves, 2012) and Engeström's Activity Theory (1987, 2001), the intervention evolved through iterative, collaborative processes involving climbers, educators, VR developers, and outdoor safety professionals in Chile and New Zealand. Chapters 4 to 7 trace this progression—from initial consultations and design iterations to pre-intervention assessments, implementation, and post-intervention evaluation—revealing how context-specific insights shaped the design and how user feedback informed the continuous refinement of both the tool and its pedagogy.

Chapter 4 details the early development phase, emphasising how input from climbing experts and institutions (e.g., NZAC, FEACH) surfaced key differences in culture, environmental conditions, and technological infrastructure. These insights informed the VR app's features, including simulations of altitude sickness, multilingual accessibility, and realistic environments. For instance, New Zealand's structured safety protocols required formal onboarding, whereas Chile's grassroots training culture called for more flexible, community-oriented features. These findings validated the need to situate technology within users' socio-cultural contexts, aligning with Activity Theory's emphasis on systemic evolution through contradictions and their resolution.

Chapters 5 through 7 present the empirical arc of the intervention. The pre-intervention survey (Chapter 5) revealed that while many participants were experienced climbers,

formal training in high-altitude risk management was limited. They expressed concern about risks such as altitude illness, unpredictable weather, and poor decision-making, while also showing cautious optimism about VR's potential to simulate such scenarios safely. This supports findings in the immersive learning literature highlighting VR's cognitive and emotional impact on the development of situational awareness (Slater & Sanchez-Vives, 2016).

Chapter 6 covers implementation, which was generally well received. Participants praised the immersive audio and scenario realism but noted usability challenges, including discomfort with headset use and inadequate language options. These issues reflect contradictions within the activity system—gaps between tool capabilities and user needs—which Activity Theory identifies as drivers for systemic change. Biometric data and interviews confirmed that while VR strengthened risk perception, it was most effective when combined with real-world practice.

Chapter 7 further develops this analysis, identifying key themes such as the immersive potential of VR, the cognitive and psychological benefits of learning, and the importance of cultural and contextual relevance. These findings reinforce the theoretical framework while generating actionable recommendations for improving the tool, embodying the iterative and reflective spirit of both Design-Based Research and Activity Theory.

The synthesis of theory, consultation, and empirical evaluation illustrates the strength of a design-based, activity-centred approach to educational innovation. Theoretical insights anticipated learning challenges, while real-world use produced feedback loops to refine both theory and design. This research shows VR is most powerful when integrated into

broader pedagogical systems that include institutional support, cultural sensitivity, and hands-on learning. The design process itself became a learning opportunity, revealing tensions and offering strategies for transforming education in high-risk outdoor contexts.

The next section draws from the Chilean and New Zealand intervention studies to present a set of empirically grounded design principles for VR-based mountaineering education. These are not abstract suggestions, but insights rooted in real user experiences. Using feedback from climbers, educators, and safety professionals, and informed by biometric data and iterative testing, the framework is shaped by Design-Based Research (McKenney & Reeves, 2012), Activity Theory (Engeström, 1987, 2001), and constructivist learning models (Hase & Kenyon, 2001; Vygotsky, 1978). It reflects the complex, multi-layered nature of outdoor education.

In both countries, VR was seen as a promising tool for simulating hazardous scenarios and increasing risk awareness. However, participants also identified cultural mismatches, usability limitations, and cognitive overloads that could hinder learning. These real-world insights drove the creation of design principles that extend beyond technology to encompass the full learning ecosystem, including context, accessibility, and pedagogy.

The principles are organised into four themes:

- Cognitive: Supporting decision-making, situational awareness, and psychological readiness.
- Contextual: Ensuring regionally relevant content and dynamic, realistic environments.
- Cultural: Accommodating language diversity, digital literacy, and local practices.

- Pedagogical: Drawing from heutagogy, constructivism, and authentic learning to shape structure and interactivity.

Rather than simply offering immersive visuals, the goal is to foster adaptive expertise—helping climbers build the mental models and reflective skills needed for high-stakes alpine environments. This demands alignment between user needs, learning goals, and design solutions.

The need for such a framework is underscored by ongoing incidents in mountain safety, many of which stem from inadequate decision-making under stress, poor preparation, or lack of formal instruction. Traditional methods—such as lectures, books, and informal mentoring—struggle to replicate the real-world pressures that climbers face. VR fills this gap by enabling emotional and cognitive rehearsal in a safe, controlled environment.

However, immersion alone doesn't guarantee effective learning. Participant feedback underscored that engaging visuals or audio must be paired with thoughtful, learner-centred design. It includes managing cognitive load, enabling reflection, and ensuring cultural relevance.

Participants in both countries praised the realism of scenarios, audio, and branching narratives, but criticised issues such as poor navigation, low visual fidelity, and lack of localisation. These responses validate Activity Theory's assertion that learning outcomes are shaped by interactions among tools, rules, community, and division of labour—and that contradictions in these systems must be addressed for expansive learning (Engeström, 2001).

Accordingly, the ten design principles below serve as both evaluation criteria and practical guidance for future development of VR training in high-risk education:

1. Cognitive development and decision-making
2. Complementarity with real-world training
3. Environmental and hazard realism
4. Interactivity and emotional engagement
5. Sensory limitations and psychological fidelity
6. Immersion and usability
7. Onboarding and user orientation
8. Cultural and regional localisation
9. Accessibility and cost-efficiency
10. Strategic partnerships for sustainable implementation

These principles promote a holistic, inclusive, and pedagogically robust approach to VR design, aiming to develop safer, more prepared climbers while offering a replicable model for other high-risk domains, such as firefighting, emergency medicine, and law enforcement.

The ten design principles were not arbitrarily selected but emerged from the iterative research process, combining both theoretical foundations (Chapter 2) and empirical findings (Chapters 5–7). This reflects the design-based research (DBR) approach (McKenney & Reeves, 2012), where insights from theory and practice are progressively integrated.

The development of the design principles for this study began with a strong theoretical foundation. The integration of Activity Theory (Engeström, 1987, 2001), Experiential Learning Theory (Kolb, 1984), and immersive learning principles (Makransky & Lilleholt, 2018; Slater & Sanchez-Vives, 2016) provided the conceptual lens through which the research was framed. These frameworks collectively underscore the importance of cognitive engagement, situated decision-making, authenticity, and the mediating role of virtual reality (VR) tools in shaping learning outcomes. From these ideas, broad conceptual categories were derived, including cognitive development, VR affordances, pedagogical scaffolding, and contextual or cultural fit.

Building on this theoretical base, empirical insights were generated through the interventions conducted in Chile and New Zealand. Rich qualitative and biometric data—including interviews, observational records, and heart-rate monitoring—were analysed using thematic approaches. Participants consistently highlighted practical needs, such as the value of onboarding tutorials to reduce cognitive load, the importance of language localisation for accessibility, and concerns about usability issues such as blurry visuals and headset discomfort. Importantly, both cohorts viewed VR as a valuable complement to, but not a substitute for, traditional field-based practice. These recurring themes acted as grounded dimensions that could be mapped directly against the theoretical categories, ensuring the findings remained both empirically rooted and theoretically informed.

The iterative process of synthesis then brought these strands together. More than ten potential principles emerged from the data; however, not all were retained in the final framework, as some overlapped or were too narrowly context specific. For example, separate themes relating to “visual fidelity” and “sound design” were combined under the

broader principle of immersion and usability, while considerations around “funding” and “sponsorship” were integrated into a single principle of strategic partnerships for sustainable implementation. This process of consolidation ensured that the final ten principles were comprehensive, coherent, and practical, offering both evaluation criteria for the current intervention and clear guidance for future development of VR training in high-risk education.

8.3.1 Cognitive Development and Decision-Making - Focus on Cognitive and Decision-Making Skills

The findings from both Chilean and New Zealand participants highlight that the most significant contribution of the VR intervention was not its visual realism or sensory immersion, but its capacity to support cognitive skill development in high-risk mountaineering contexts. Participants consistently emphasised the value of engaging with scenarios requiring decision-making under pressure, interpreting environmental cues, and managing cognitive load in uncertain conditions. These responses align with existing literature suggesting that virtual simulations are most effective when they prioritise psychological fidelity—the degree to which a scenario replicates the mental demands of real-world tasks—rather than physical or visual accuracy (Gaba, 2004; Slater & Sanchez-Vives, 2016).

In both national contexts, users noted that while the VR experience lacked some physical realism—such as tactile feedback or terrain variability—the opportunity to rehearse risk-laden decisions in a safe environment was invaluable. For example, New Zealand participants highlighted the cognitive strain associated with real-time route selection in

dynamic weather conditions, which was effectively replicated through branching scenarios and time-sensitive challenges. Similarly, Chilean participants valued the emotional pressure simulated by VR when facing altitude sickness symptoms despite the absence of full-body physical cues.

These findings suggest that the educational value of VR lies in its ability to train the mental processes underpinning safe and effective action in hazardous environments. This supports van Ginkel et al.'s (2020) argument that immersive environments can strengthen critical thinking and adaptive decision-making in complex, high-stakes situations. Rather than attempting to mimic physical sensations, the VR design in this study was most impactful when it engaged learners in scenario-based reasoning, uncertainty navigation, and reflective evaluation of decisions.

Furthermore, the incorporation of guided prompts, pre-briefing materials, and post-scenario debriefs supported metacognitive development by helping learners reflect on their decision-making processes. This was particularly evident in post-intervention interviews, where participants referenced their ability to transfer VR-based learning to real-world cognitive strategies. Such scaffolding aligns with heutagogical and experiential learning theories (Hase & Kenyon, 2001; Kolb, 1984), which prioritise learner autonomy, reflection, and adaptability in unfamiliar or complex conditions.

Overall, the findings confirm that in the context of high-risk outdoor education, cognitive realism—rather than full sensory replication—should guide the design of immersive technologies. Effective VR-based mountaineering education must therefore be oriented toward developing mental models, enhancing situational judgment, and fostering adaptive

expertise. This cognitive orientation emerged as a critical theme across both case studies, reinforcing the importance of designing for decision-making, rather than for physical fidelity alone.

8.3.2 Complementarity with Real-World Training - Complementary, not Replacement

Virtual Reality (VR) should be designed not as a replacement for traditional mountaineering training, but as a preparatory and complementary component within a blended learning framework. This principle is strongly supported by findings across Chapters 5 to 7. Participants in both Chile and New Zealand consistently reported that while VR enhanced their situational awareness and decision-making skills in high-risk scenarios, it could not replicate the physical and kinaesthetic demands of real-world mountaineering. For example, several participants noted that the VR intervention was effective for rehearsing responses to environmental risks, such as sudden weather changes or altitude sickness, but emphasised the importance of field training to physically apply these strategies under realistic conditions.

This feedback reflects a broader theme: VR is most effective when used to develop cognitive readiness and foundational competencies—such as hazard recognition, route planning, and emergency decision-making—that are then reinforced and contextualised through hands-on experience. This finding is consistent with Means et al. (2013), who found that blended learning models integrating digital simulation with physical practice consistently outperform single-mode approaches in fostering learner preparedness. Similarly, Gagnon et al. (2022) emphasise that simulated learning environments reduce

anxiety and enhance perceived competence, especially among novice learners transitioning into hazardous field environments.

The intervention was designed as a VR-only experience; however, findings suggest strong potential for a blended structure in which VR scenario training could be paired with instructor-led outdoor practice, such as instructor-supervised practice in knots, navigation, and avalanche drills. Such a model would allow participants to test and refine their decision-making strategies across both simulated and real-world contexts, ensuring that cognitive preparedness developed in VR is reinforced by the physical and environmental challenges of actual mountaineering. This design aligns with the findings in Chapter 7, in which learners reported increased confidence and reflective capacity after engaging in both simulated and real-world tasks. For example, one participant from New Zealand described how VR-based rehearsal for avalanche rescue could improve their situational judgment when applied during a live mountain training session. Such outcomes validate the theoretical proposition from Engeström's Activity Theory that expansive learning occurs when contradictions between simulated tools and authentic practice are recognised and resolved through iterative experience (Engeström, 2001).

Ultimately, this study reinforces the idea that the pedagogical power of VR lies in its capacity to simulate cognitive complexity and emotional engagement rather than in physical replication. When situated within a blended learning ecosystem, VR makes a meaningful contribution to the development of adaptive expertise, equipping climbers with the critical-thinking and self-regulatory skills necessary to navigate unpredictable, high-stakes environments.

8.3.3 Environmental and Hazard Realism - Realistic and Dynamic Environmental Simulation

To create pedagogically effective VR-based training for high-risk mountaineering environments, it is essential to simulate dynamic environmental conditions and realistic hazard scenarios. The findings from Chapters 5 through 7 underscore that learning outcomes in extreme contexts, such as mountaineering, are significantly shaped by the development of situational awareness and pressure-based decision-making. Participants across both the Chilean and New Zealand cohorts consistently identified the need for greater environmental realism within the VR experience. Specifically, they recommended including elements such as sudden weather changes (e.g., snowstorms, wind gusts), avalanche response modules, route-finding tasks, and altitude acclimatisation scenarios. These enhancements were viewed as critical to fostering user engagement, increasing perceived realism, and preparing climbers for the unpredictability of high-altitude terrain.

These recommendations align with the principles of authentic learning and simulation-based education, which advocate for instructional designs that mirror the real-world conditions in which knowledge will ultimately be applied (Cant & Cooper, 2010; Herrington & Oliver, 2000). The integration of such contextual variables into VR scenarios allows learners to anticipate risks, assess evolving situations, and make decisions under pressure—skills that participants repeatedly highlight as essential for safe mountaineering practice. For instance, pre-intervention survey data revealed widespread concern over cognitive risks such as altitude illness and weather misjudgment, which participants felt were inadequately addressed in traditional training.

Moreover, by embedding environmental complexity into the VR design, learners engage in authentic, scenario-driven experiences that support experiential learning cycles as described by Kolb (1984). This includes progressing through concrete experiences in the simulation, engaging in reflective debriefs, and applying abstract insights to real-world decision-making. Several participants noted that navigating VR scenarios that mimicked real alpine hazards helped them reflect more deeply on past climbing decisions and identify knowledge gaps, thereby promoting adaptive learning.

Incorporating such realistic, high-fidelity elements into VR design not only enhances instructional value but also promotes the transfer of learning from the virtual environment to actual field conditions. As such, environmental and hazard simulation is a critical design principle for developing effective VR interventions in high-risk outdoor education.

8.3.4 Interactivity and Emotional Engagement - Enhance Interactivity and Realism

To enhance the instructional effectiveness of VR-based training in high-risk environments such as alpine mountaineering, learning experiences must extend beyond visual immersion to include interactive, scenario-based tasks with real-time feedback. Findings from Chapters 6 and 7 revealed that participants found the immersive design and audio cues helpful for engagement; however, they noted limitations in interaction, realism, and scenario complexity. Learners in both Chile and New Zealand consistently recommended enhancements such as time-pressured decision-making tasks, accident simulations, and multisensory feedback to better replicate the cognitive demands of real-world climbing.

Real-world accident case studies—cited by participants as particularly impactful—anchor learners in contextually rich, emotionally resonant scenarios that enhance situational

awareness, ethical reasoning, and practical judgment. These narratives encourage reflection on previous mountaineering accidents, fostering transferable learning outcomes through experiential immersion (Shin et al. 2020). Participants also expressed interest in haptic feedback systems that simulate tactile sensations, such as icy terrain or unstable rock faces, which could enhance embodiment and risk perception in the VR environment (Slater & Sanchez-Vives, 2016). Additionally, timed decision-making elements were suggested to better simulate high-pressure scenarios, thereby assessing and reinforcing a user's capacity to act swiftly under stress.

These interactive and contextually grounded features align with research on simulation-based learning, which emphasises the value of active engagement, variability, and real-time feedback in developing deep learning and skill transfer (Cook et al., 2013). In the context of mountaineering, where errors can lead to severe consequences, such features are vital for developing not only cognitive understanding but also the behavioural readiness and resilience necessary for real-world application.

8.3.5 Sensory Limitations and Psychological Fidelity - Address Sensory Limitations Strategically

While Virtual Reality (VR) offers significant potential for experiential learning in high-risk environments, its design must acknowledge inherent limitations—particularly in simulating the physical realities of mountaineering. Despite notable advances, current VR technologies cannot replicate critical somatic sensations such as cold, physical exhaustion, oxygen deprivation, or the bodily strain of prolonged alpine ascents—factors that significantly affect situational awareness and decision-making in real-life mountaineering

(Makransky & Mayer, 2022). This limitation was noted by both Chilean and New Zealand participants, who appreciated the immersive visual and auditory components but highlighted the lack of physical realism, such as the inability to simulate fatigue, altitude sickness, or unstable terrain.

However, rather than viewing this shortfall as a deficit, the study's findings suggest that it provides an opportunity to recalibrate VR design towards cognitive and psychological preparedness. Participants across both countries emphasised the value of VR in simulating cognitive pressure, ambiguity, and emotionally charged decision-making scenarios. For example, time-pressured navigation tasks and simulated emergencies could help learners rehearse risk analysis and prioritisation strategies in a psychologically safe environment. These insights align with simulation-based learning theory, which prioritises psychological fidelity—defined as the degree to which learners engage cognitively and emotionally with the scenario—over complete physical replication (Gaba, 2004).

Instructional enhancements such as structured debriefings, scenario walkthroughs, and prompts for emotional self-regulation were also recommended by participants to support reflective learning and metacognitive awareness. These strategies reinforce the pedagogical aim of VR as a cognitive rehearsal tool—cultivating mental readiness, emotional regulation, and decision-making under stress. The evidence from this study supports the use of VR as a preparatory supplement to field-based training rather than a standalone solution. By recognising its limitations while leveraging its strengths, VR can effectively contribute to holistic training approaches that prepare climbers to respond with clarity and confidence in unpredictable, high-risk situations.

8.3.6 Immersion and Usability - Prioritise Visual and Auditory Immersion with Usability

Dubovi (2022) and Triberti et al. (2025) point out one of the most compelling affordances of Virtual Reality (VR) lies in its capacity to create immersive sensory experiences that elicit emotional engagement and enhance the learner's sense of presence. In the context of high-risk mountaineering education, participants across both Chile and New Zealand consistently noted that realistic environmental sounds—such as wind gusts, snowfalls, and echo effects—significantly heightened their emotional engagement and made the scenarios feel authentic. These auditory cues were often reported to evoke feelings of fear, nervousness, or alertness, which participants associated with real-world mountain experiences. This supports Slater and Sanchez-Vives' (2016) argument that presence in VR is not defined solely by visual fidelity, but by a coherent multisensory experience that convinces the user they are "really there."

However, despite the strong audio immersion, several participants highlighted that visual clarity and interface usability were lacking, thereby diminishing the overall experience. Reports of blurry images, motion blur, and text readability issues were common. These issues often led to frustration or disengagement, interrupting the flow of learning and reducing the effectiveness of the training. Such usability barriers align with Makransky and Mayer's (2022) findings that excessive cognitive load induced by technical flaws—such as unclear visuals or clunky interaction—can hinder cognitive processing and learning in immersive environments.

Addressing these concerns, participants recommended enhancements such as higher screen resolution, clearer UI elements, and headset calibration features. These are not simply

technical upgrades—they are pedagogical necessities. In safety-critical education, such as mountaineering, visual fidelity plays a central role in enabling learners to identify hazards, interpret environmental cues, and engage cognitively with the scenario without distraction. Usability also supports emotional regulation by ensuring users are not overwhelmed or disengaged by interface friction.

In summary, achieving an optimal balance between immersive realism and practical usability is crucial. The findings across Chapters 5–7 underscore that high-quality audiovisual integration, paired with user-centred interface design, enables VR to move beyond surface-level simulation, facilitating deep, emotionally grounded, and cognitively rich learning experiences.

8.3.7 Onboarding and User Orientation - Provide Onboarding and Navigation Support

While immersive technologies like Virtual Reality (VR) offer powerful experiential learning opportunities, their effectiveness depends significantly on the user's familiarity and comfort with the system. Findings from Chapters 5 and 6 of this study highlight that for many participants—particularly those with limited prior experience in VR—technical challenges such as operating controllers, navigating interface menus, and adjusting to spatial feedback posed initial barriers to learning. These challenges often led to frustration and reduced immersion, thereby limiting learners' cognitive capacity for the core training objectives.

Such usability concerns are supported by Mayer's (2009) Cognitive Theory of Multimedia Learning, which suggests that extraneous cognitive load—arising difficulties unrelated to the core content—can hinder meaningful learning. In high-stakes training environments,

such as mountaineering, this misalignment is especially problematic, as learners must direct their cognitive effort toward situational awareness and decision-making, rather than technical navigation.

To address this, participants across both Chilean and New Zealand cohorts recommended more structured onboarding mechanisms, including tutorials, practice sessions, and interactive guidance before the main simulation. These recommendations align with empirical research demonstrating that pre-training improves learning outcomes by allowing learners to automate basic system interactions before engaging with more complex content (de Koning et al., 2012). Moreover, onboarding can help users acclimate to the physiological effects of VR, such as motion sickness or spatial disorientation, thereby increasing both comfort and sustained engagement (Makransky & Mayer, 2022).

Effective onboarding strategies may include guided orientation modules, interactive control demonstrations, voice-over prompts, and low-pressure environments for practising VR interactions. These tools serve as cognitive and operational scaffolds, preparing learners to engage more effectively with content-rich simulations. This approach also aligns with Vygotsky's (1978) concept of the Zone of Proximal Development (ZPD), which emphasises the role of guided support in facilitating learners' progress toward independent competence.

Therefore, embedding thoughtful onboarding practices into VR design not only reduces technical friction but also enhances learner confidence, optimises cognitive readiness, and facilitates a smoother transition into more demanding, scenario-based training.

8.3.8 Cultural and Regional Localisation - Localise Content and Provide Multilingual Support

For VR-based training to be effective, equitable, and widely adopted in high-risk education contexts, it must be both culturally responsive and geographically adaptable. The findings from this study—based on comparative implementation in Chile and New Zealand—revealed substantial regional variation in environmental conditions, climbing practices, language preferences, and digital literacy that significantly shaped user engagement and learning outcomes. These variations underscore the need for instructional designs that reflect the socio-cultural and ecological realities of the learners they serve. As Engeström (1987, 2001) emphasises, activity systems are historically and socially constructed, comprising diverse tools, norms, and community practices. Consequently, the effectiveness of VR as a pedagogical tool hinges on its ability to adapt meaningfully to local contexts, rather than imposing a standardised or universalised learning model.

In Chile, for example, many participants reported that certain VR scenarios—such as alpine snow navigation or crevasse rescue—felt disconnected from their everyday mountaineering experiences, which often occur at lower altitudes and in non-glacial regions. Participants instead emphasised the need for modules focused on relevant risks such as rockfall, sudden weather shifts, navigation errors, or dehydration during ascent. This mismatch between content and context impacted user motivation and perceived relevance, reaffirming that VR scenarios must be situated within the real environmental and cultural frameworks of each user group to promote authenticity and engagement (Herrington & Oliver, 2000).

Language accessibility emerged as another crucial factor influencing cognitive load and learner confidence. Chilean participants frequently had trouble navigating the VR interface and interpreting instructions due to the absence of Spanish-language support. These challenges were compounded for users with limited digital literacy, a finding consistent with prior research on multimedia learning that highlights the impact of language barriers on cognitive processing (Mayer, 2009). Providing multilingual options, intuitive icons, and culturally meaningful visuals can reduce extraneous cognitive load and support inclusive access. This aligns with culturally responsive instructional design frameworks, which emphasise linguistic inclusivity, symbolic representation, and contextual relevance to improve learning outcomes (Gay, 2018).

Finally, embedding culturally grounded visuals, region-specific scenarios, and locally informed design principles transforms VR from a generic simulation into a socially situated learning tool. These elements align with both constructivist learning theory and third-generation Activity Theory, which view learning as an interaction between individuals, their tools, and their community (Vygotsky, 1978; Engeström, 2001). Such adaptations are not superficial but pedagogically vital to ensuring that immersive learning technologies are responsive to the diverse knowledge systems, experiences, and values of their intended users.

8.3.9 Accessibility and Cost-Efficiency - Ensure Accessibility and Cost-Efficiency

One of the most compelling advantages of Virtual Reality (VR) in high-risk training contexts is its ability to democratise access to experiential learning. Traditional mountaineering education often demands participation in remote, physically challenging,

and financially prohibitive environments—constraints that can exclude learners based on geography, income, or institutional support. Findings from this study, particularly in the Chilean context, reveal that many participants lacked access to formal training infrastructures and relied heavily on peer-led instruction or informal learning experiences. VR offers an alternative by providing safe, repeatable, and weather-independent simulations of hazardous alpine conditions, thus broadening access for learners in geographically dispersed and resource-constrained regions (Radianti et al., 2020).

By decoupling training from terrain and season, VR supports frequent, low-risk practice and encourages safe failure—critical for developing decision-making, route-finding, and situational awareness in mountaineering. For instance, participants from both Chile and New Zealand reported that the ability to repeatedly engage with complex scenarios, such as sudden weather shifts or altitude-related disorientation, increased their confidence and preparedness. These immersive scenarios allow users to reflect, adapt, and improve without incurring the physical risks or costs associated with real-world expeditions.

However, the accessibility benefits of VR are offset by substantial initial costs for development, hardware, and instructional design. Creating pedagogically robust and culturally localised VR environments—especially ones incorporating high-fidelity interactivity and real-time feedback—requires significant financial and technical resources (Makransky & Mayer, 2022). This challenge is particularly evident in lower-income educational settings, where access to advanced headsets and VR-ready infrastructure remains limited. Participants in Chile, for example, reported difficulty using the technology due to a lack of prior experience with immersive media and limited institutional resources to support widespread deployment.

To address these barriers, institutions must explore cost-sharing and partnership models, such as collaborations with mountaineering associations, public safety organisations, and educational technology sponsors. Scalable solutions—such as modular VR design or mobile-compatible versions—can also enhance adoption without compromising instructional quality. Moreover, once developed, VR modules offer long-term savings by enabling unlimited reuse and reducing recurring expenses associated with in-person field training (Radianti et al., 2020).

In summary, when designed with strategic deployment, affordability, and contextual equity in mind, VR can serve as a transformative, cost-effective tool for scaling high-quality mountain safety education. It offers a way to shift from exclusive, location-bound learning to inclusive, digitally mediated access that meets learners where they are.

8.3.10 Strategic Partnerships for Sustainable Implementation - Seek Strategic Partnerships and Funding

For VR-based educational interventions to transition from small-scale pilots to sustainable, system-wide innovations, success depends not only on sound instructional design but also on long-term structural support and cross-sector collaboration. Findings from this study underscore that while participants across both Chile and New Zealand valued the immersive and cognitive benefits of the VR training, they also raised concerns about its long-term viability, institutional buy-in, and integration into formal mountaineering education systems. Engeström's (2001) Third-generation Activity Theory emphasises the significance of multilevel, networked activity systems in shaping outcomes, in which sustained innovation arises from the interplay among tools, community, rules, and division

of labour. From this perspective, effective implementation requires a coordinated ecosystem that includes government bodies, outdoor education institutions, industry stakeholders, and academic partners.

Government funding plays a foundational role in embedding VR into national safety and education curricula. Without public investment, immersive learning technologies risk remaining confined to elite institutions or private training centres, exacerbating access inequities (Radianti et al., 2020). Strategic policy support and financial backing are needed for hardware acquisition, content development, and educator training. Participants in the Chilean case study, for instance, identified limited institutional support and lack of access to high-end equipment as major barriers to scalability.

Equally important are partnerships with mountaineering and safety organisations, such as the New Zealand Alpine Club (NZAC), the Mountain Safety Council (MSC), and the Federación de Andinismo de Chile (FEACH). These organisations possess invaluable domain-specific expertise, practitioner networks, and real-world incident data that can inform the design of credible and context-relevant scenarios. Participants in both countries acknowledged the importance of these bodies in setting training standards and acting as trusted intermediaries. Their involvement would also facilitate broader dissemination and cultural legitimacy of VR-based learning.

Moreover, strategic collaborations with industry sponsors—such as The North Face, Patagonia, and other outdoor gear companies—could provide essential support through funding, equipment donations, and co-branded safety campaigns. Such partnerships align

with corporate social responsibility initiatives and offer mutual benefits: companies advance their safety reputation while learners and institutions gain access to vital resources.

Universities and research centres play a central role in implementation, serving as both innovation hubs and deployment platforms. VR modules can be integrated into existing curricula in outdoor education, adventure tourism, and emergency response, while applied research continues to refine the technology in response to learner feedback and evolving field requirements. As noted by McKenney and Reeves (2012), this type of embedded, iterative development is essential in Design-Based Research, where educational innovations are shaped and sustained through cycles of use, evaluation, and redesign.

When considered collectively, these relationships establish the foundation for a sustainable and adaptable learning ecosystem. Instead of viewing virtual reality (VR) as just a separate technological tool, this model portrays it as a continuously evolving educational infrastructure. This infrastructure is responsive to the specific needs of its context and supported by a connected network of stakeholders. This approach guarantees that VR-based training is not only innovative but also firmly embedded within institutions and has a positive social impact.

8.3.11 Summary

Together, these design principles represent a holistic, evidence-informed approach to virtual reality (VR) mountaineering education, grounded in the convergence of theory, empirical data, and lived practice across culturally distinct environments. Developed through a Design-Based Research (DBR) framework, these principles are not abstract prescriptions but evolved through iterative testing, consultation with stakeholders, and

direct engagement with end-users in both Chile and New Zealand. They respond to real challenges observed in the field—such as fatal decision-making errors, accessibility limitations, and the underutilisation of immersive technologies in outdoor education—and propose actionable solutions for improving the design, deployment, and pedagogical effectiveness of VR tools in high-risk training contexts.

Rather than focusing solely on the technical novelty of VR, this framework places learner experience, cultural context, and pedagogical intent at the centre of design. The principles advocate for a shift from passive content delivery to dynamic, learner-driven environments where users can engage in situated problem-solving, reflect on their decisions, and transfer knowledge to real-world scenarios. In doing so, they align with key tenets of heutagogy (Hase & Kenyon, 2001), social constructivism (Vygotsky, 1978), and Engeström's (2001) Third-generation Activity Theory, which together emphasise the socio-cultural nature of learning, the importance of scaffolding within zones of proximal development, and the transformative potential of encountering and resolving contradictions within activity systems.

Importantly, these principles also acknowledge the diversity of learners and learning conditions. By explicitly addressing sensory limitations, language barriers, digital literacy disparities, and regional environmental differences (e.g., low-altitude Chilean landscapes vs high-alpine conditions in New Zealand), the framework promotes inclusive and culturally responsive design. This emphasis on multivoicedness (Engeström, 1987) ensures that VR training is not a one-size-fits-all solution, but rather an adaptable tool that can evolve to meet the needs of different communities and climbing cultures.

Moreover, the principles encourage the integration of VR into broader educational ecosystems through blended learning approaches and strategic partnerships. Recognising that VR cannot and should not replace hands-on, field-based instruction, the framework proposes a model in which immersive technologies serve as powerful preparatory tools—enhancing cognitive readiness, building confidence, and enabling repeated rehearsal in safe environments. When combined with traditional instruction, field training, and institutional support from governments, mountaineering organisations, and educational institutions, VR can amplify the reach, accessibility, and effectiveness of mountain safety education.

In summary, the design principles outlined in this chapter provide a robust foundation for the next generation of VR-enhanced outdoor education. They are simultaneously grounded in academic theory and validated through field-based inquiry, offering a blueprint for developing immersive learning environments that are pedagogically sound, contextually grounded, and socially meaningful. As such, they hold potential not only for transforming mountaineering instruction, but also for informing the design of VR interventions in other high-risk domains—such as firefighting, military/police training, and disaster response—where decision-making under uncertainty is critical to safety and survival.

8.4 Comparing Theoretical and Empirical Design Principles

The design of this VR-based mountain safety training intervention was shaped by both theoretical constructs and empirical insights. This section critically reflects on the relationship between the initial theoretical design principles, derived from the literature and conceptual models, and the emergent principles that arose from participants' consultation and engagement, as well as the thematic analysis of participant data.

The theoretical design principles, as outlined in Chapter 2, were primarily informed by Engeström's (2001) Third-Generation Activity Theory, Kolb's Experiential Learning Theory (1984), and immersive learning design literature (e.g., Makransky & Lilleholt, 2018). These theories emphasise the importance of mediated learning within complex social systems, the value of experiential and embodied knowledge, and the need for emotionally engaging, context-rich learning environments. For instance, Activity Theory informed the understanding that learning outcomes are shaped by dynamic interactions among mediating tools, community norms, division of labour, and learner motives. Based on these frameworks, the initial design principles included goals such as simulating authentic high-risk scenarios, embedding learning in realistic activity systems, and fostering cognitive readiness through immersive media.

In contrast, the design principles that emerged from data collection in Chapters 4 through 7 reflected more context-specific, practice-based needs. These empirical insights were shaped by participants' consultation (Chapter 4), pre-intervention surveys (Chapter 5), intervention and post-VR interviews (Chapter 6), and the cross-cultural thematic analysis (Chapter 7). While some of these findings affirmed the theoretical assumptions—such as the value of immersion for cognitive engagement—others revealed unanticipated challenges and user needs. For example, participants in both Chile and New Zealand highlighted the importance of language accessibility, usability support (e.g., tutorials and replay functions), and environmental authenticity (e.g., non-snowy mountain scenarios for Chilean contexts). Practical issues, such as visual clarity and physical discomfort with headsets, as well as overconfidence induced by risk-free simulation environments, also

emerged, prompting a reconsideration of how immersive learning environments should be scaffolded.

Overall, while the theoretical principles provided a strong conceptual foundation, the empirical findings enriched and nuanced the design process by highlighting real-world constraints, cultural differences, and learner feedback that theory alone could not fully anticipate. This comparison highlights the benefits of employing a Design-Based Research (DBR) approach, which enables theory and practice to co-evolve iteratively. It also underscores the importance of educational technologies—especially those designed for high-risk learning environments—to be both theoretically grounded and empirically validated. Table 8.7 below summarises these ideas.

Table 8.8

Comparison of Theoretical and Empirical Design Principles

Dimension	**Theoretical Design Principles**	**Empirical Design Principles (from Data Collection)**
Learning Theory Basis	Based on Activity Theory (Engeström), Experiential Learning (Kolb), and immersive learning literature.	Based on mountaineers' intervention (Ch. 4), participant survey/interviews (Ch. 5–7), and thematic analysis.
Role of VR	A tool to mediate learning within authentic activity systems and simulate complex, high-risk environments.	Valuable for simulating risk, but must be blended with field-based training to address physical and emotional realism.
Immersion	Immersion enhances cognitive and emotional engagement.	Sound was highly immersive, but visuals and headset comfort limited realism for many users.
Decision-Making	VR supports situated decision-making by replicating the complexity of real-world environments.	Users found it helped build cognitive readiness, but some overestimated their preparedness due to the absence of physical stressors.

Cultural & Contextual Fit	Assumed principles would be adaptable across contexts with minor localisation.	Strong need for localisation: Chilean participants requested non-snow environments; language barriers were significant for non-English speakers.
Usability	Emphasis on user interaction and feedback loops within the activity system.	Need for onboarding tutorials, replay options, clearer interface design, and better focus adjustment—especially for novices and glasses wearers.
Feedback Mechanism	Iterative design based on systemic contradictions (Activity Theory).	User discomfort, navigation confusion, and lack of haptic realism revealed key contradictions in the activity system.
Design Process Role	The DBR approach to evolving both theory and practical tools through iteration.	Users' input and participant feedback directly shaped feature requests and identified future development priorities (e.g., more scenarios, first-aid training).

Table 8.7 contrasts theoretical design principles drawn from the literature with empirical principles emerging from the Chilean and New Zealand interventions. The aim is to demonstrate both alignment and divergence: where theory and practice converge, where participant experiences challenge assumptions, and where lived realities extend existing frameworks.

Although ten principles were generated during data analysis, only eight appear in the comparative framework. This decision reflects the need to align principles that could be meaningfully mapped across both theoretical foundations and empirical findings. Two principles—complementarity with real-world training and strategic partnerships for

sustainable implementation—operate at the systemic level and are therefore addressed separately in the Recommendations and Implementation sections.

The eight selected dimensions capture the areas where tensions, contradictions, and opportunities for refinement were most apparent. For example, cognitive development and decision-making maps directly to Kolb's (1984) experiential learning theory while reflecting participants' accounts of decision-making under stress. Similarly, immersion, usability, interactivity, and feedback mechanisms draw on immersive learning literature (Makransky & Lilleholt, 2018; Slater & Sanchez-Vives, 2016) but were shaped by user experiences of sound-based presence, blurry visuals, onboarding challenges, and the demand for replay options.

Cultural and contextual fit proved especially salient in the empirical findings, as Chilean participants emphasised Spanish-language localisation and non-snowy mountain contexts, while New Zealand users highlighted headset accessibility for glasses wearers. Accessibility builds on this, underscoring the need to design inclusively for diverse learners. The final dimension, design process role, reflects the Design-Based Research (DBR) framework underpinning this study, which used contradictions and feedback loops to drive prototype refinement.

Framing the comparison around these eight dimensions ensures both clarity and consistency with earlier categorisations in Chapter 2, where principles were grouped into four domains: cognitive, technological, pedagogical, and systemic. The table thus operates as a synthesis point, showing how abstract theories are confirmed, contested, or extended when tested in real-world training environments.

In summary, the comparative framework does not diminish the importance of the full set of ten principles. Instead, it prioritises those dimensions that most clearly demonstrate the intersection of theory and empirical evidence, while situating systemic principles in later discussions of sustainability and implementation.

8.5 Summary

This chapter examined how theoretical frameworks and empirical user feedback jointly shaped the design and evolution of a virtual reality (VR) intervention for mountaineering safety education. It highlighted the dynamic interplay between what theory prescribes for effective learning design and what participants in Chile and New Zealand reported through their lived experiences.

At its foundation, the intervention drew on established models, including Engeström's (2001) Third-Generation Activity Theory, which situates learning within collective, tool-mediated systems, and Kolb's Experiential Learning Theory (1984), which emphasises learning through immersive, reflective practice. These perspectives, complemented by research on immersive learning (e.g., Makransky & Lilleholt, 2018; Slater & Sanchez-Vives, 2016), informed the design of VR environments intended to be engaging, authentic, and pedagogically meaningful.

Applying Activity Theory revealed how the VR system functioned as a culturally embedded artefact, situated within wider activity systems comprising learners, instructors, institutions, and developers. Contradictions—such as visual discomfort for glasses wearers, language barriers for non-English speakers, or tensions between traditional mountaineering practices and digital tools—were interpreted not as failures but as generative moments for

learning and redesign. These tensions reinforced the importance of viewing VR not as a neutral medium but as a socio-technical tool whose affordances and limitations actively shape learner engagement.

Empirical evidence from interviews, surveys, and biometric data provided a vital counterbalance to theoretical assumptions. Participants emphasised the need for culturally relevant scenarios, onboarding tutorials for novices, improved visual fidelity, and multilingual support. While many described VR as a powerful tool for cognitive rehearsal and risk awareness, they also stressed that it could not replace the embodied realities of mountaineering. Overconfidence in simulated skills was identified as a potential danger if VR were not complemented by physical training.

Rather than undermining theoretical models, these findings extended and refined them. Theories offered direction, but it was the lived feedback of users that translated abstract principles into workable, context-sensitive design features. This iterative movement between conceptual framing and empirical insight exemplifies the strength of a Design-Based Research (DBR) methodology, which emphasises cycles of testing, reflection, and adaptation.

Ultimately, this chapter underscores that effective VR training for high-risk contexts must be both research-informed and responsive to user experience. Theory provides the scaffolding, but practice introduces the variability of culture, learner diversity, and technological limitations that cannot be ignored. Together, they yield design principles that are not only theoretically grounded but also usable, inclusive, and sustainable.

The comparison between theoretical and empirical design principles highlights the adaptive nature of educational innovation: while frameworks set boundaries and expectations, practice pushes these boundaries outward, surfacing new considerations such as accessibility, usability, and localisation. Building on this synthesis, Chapter 9 moves from analysis to implications, examining how contradictions, user feedback, and emergent design principles contribute to advancing VR as part of blended safety education, while situating the study within global debates on immersive learning technologies and their practical adoption.

Chapter 9: Discussion and Conclusion

9.1 Introduction

This chapter provides a critical interpretation of the study findings by connecting the empirical results with the theoretical perspectives introduced earlier in the thesis. Drawing on the design principles synthesised in Chapter 8, the discussion examines how the Virtual Reality (VR) intervention contributed to mountaineering safety education across the two research contexts of Chile and New Zealand. Using a Design-Based Research (DBR) approach informed by Engeström's (2001) Third-Generation Activity Theory, the study explored how immersive learning environments can support the development of cognitive awareness, risk perception, and decision-making in high-risk outdoor environments. By examining the intervention across two culturally and geographically distinct contexts, the research also enables a comparative analysis of how immersive technologies can be adapted to different environmental and educational conditions.

The purpose of this chapter is threefold. First, it offers a critical interpretation of the study's main findings and explicitly addresses the four guiding research questions outlined in Chapter 1. These questions investigated: (1) the key design principles for developing practical VR applications in high-risk educational contexts; (2) the optimal use and evaluation of VR tools to enhance outdoor learning; (3) the comparative influence of VR on climbers' learning experiences versus traditional, real-world training environments; and (4) the impact of VR-based interventions on climbers' decision-making and risk perception in extreme outdoor situations. In answering these questions, the chapter integrates

theoretical foundations from Activity Theory, experiential learning, and immersive technology studies with empirical data derived from participant interviews, pre- and post-intervention evaluations, and thematic analyses conducted across Chapters 5, 6, and 7.

Second, the chapter reflects on the emergent design principles and pedagogical implications discussed in Chapter 8, highlighting how contradictions within and across activity systems served as generative mechanisms for system-level transformation. These reflections underscore the importance of contextual responsiveness, cultural adaptability, and stakeholder collaboration in developing technology-enhanced learning environments for high-stakes fields such as mountaineering.

Third, this chapter addresses the broader implications, limitations, and contributions of the study, outlining how the research contributes to academic discourse in the domains of educational technology, outdoor education, and learning sciences. It also offers practical insights for instructional designers, policymakers, and institutions interested in adopting VR for experiential safety training. In doing so, it highlights both the opportunities and constraints inherent in immersive learning technologies, advocating for a balanced, evidence-informed approach to their integration into formal (e.g., tertiary eco-tourism programmes, university-level outdoor education curricula) and non-formal learning contexts (e.g., mountaineering clubs, community-based training initiatives).

The chapter concludes by presenting a set of recommendations for future research, development, and implementation, including strategies for scaling VR applications, ensuring cultural relevance, and fostering sustainable partnerships between academia, industry, and mountaineering communities. These recommendations aim to support the

ongoing evolution of VR-enhanced learning in high-risk environments, ensuring that such innovations are inclusive, adaptable, locally grounded and capable of producing lasting educational impact.

9.2 Discussion of Key Findings

This section interprets the results of the VR-based mountaineering training intervention implemented in Chile and New Zealand. The discussion draws on the Design-Based Research methodology and Engeström's (2001) Third-Generation Activity Theory to analyse how the immersive training environment functioned as a learning tool within complex outdoor education contexts.

The discussion is structured around the four research questions that guided the investigation and draws upon both theoretical and empirical insights presented in earlier chapters. It begins by revisiting the key design principles that emerged from the iterative development process (RQ1), followed by an exploration of how VR can be most effectively utilised and evaluated within outdoor safety education (RQ2). The chapter then considers how VR influenced climbers' learning experiences, particularly compared with real-world environments (RQ3), and concludes by analysing shifts in learners' risk perception and behavioural responses following the intervention (RQ4).

By engaging deeply with the thematic findings from Chapters 5 through 7 and reflecting upon the broader design implications outlined in Chapter 8, this chapter aims to synthesise theoretical propositions with lived experiences. It critically evaluates the affordances and constraints of immersive simulation in fostering meaningful learning outcomes, while

acknowledging the socio-cultural, technological, and psychological factors that mediate user engagement with VR-based instruction.

The discussion also identifies and interrogates systemic contradictions and tensions uncovered during the research process, such as those between technological expectations and usability, cultural relevance and design generalisation, and immersive fidelity and physical realism. These contradictions are viewed not as failures, but as opportunities for expansive learning and pedagogical innovation.

This section argues that successfully implementing virtual reality (VR) in high-risk educational settings requires more than just advanced technology; it necessitates a comprehensive, context-aware, and learner-centred approach to instructional design. By integrating theory, empirical evidence, and reflective analysis, this discussion offers new insights into how immersive technologies can be utilised to enhance cognitive preparedness, adaptive decision-making, and inclusive learning in extreme outdoor environments.

9.2.1 RQ 1 - What are the Key Design Principles for Developing a VR Application for High-Risk Educational Environments?

Designing effective Virtual Reality (VR) applications for high-risk educational environments, such as mountaineering, emergency response, or firefighting, requires an approach that integrates established learning theories, contextual relevance, and empirical user insights. These environments are characterised by unpredictability, cognitive stress, and high physical and emotional stakes, which demand training tools that go beyond knowledge transmission to foster experiential, embodied, and reflective learning (Herrington & Oliver, 2000; Kolb, 1984). This study, situated within the theoretical

frameworks of Engeström's (2001) Third-Generation Activity Theory and Kolb's Experiential Learning Cycle (1984), identifies several pedagogical and technical principles essential for developing VR applications tailored to high-risk contexts, listed below.

- Psychological fidelity
- Authentic case-based learning and scenario-driven interactivity
- Usability and accessibility
- Scaffolded learning structures
- Cultural responsiveness
- Iterative, user-informed design processes

One foundational design principle is prioritising the cognitive and emotional authenticity of the learning experience rather than attempting to perfectly reproduce physical conditions. (Gaba, 2004; Makransky & Mayer, 2022). This means that while sensory cues (e.g., visual, auditory, and limited haptic feedback) are essential for immersion, the emphasis should be placed on simulating the mental demands of high-risk environments, such as uncertainty, time pressure, incomplete information, and decision-making under stress. In the current intervention, features such as dynamic weather shifts, altitude-related constraints, and scenario-based branching narratives were implemented to mirror the unpredictability and complexity of actual alpine conditions. These affordances aimed to enhance users' situational awareness and adaptive decision-making capacities—two critical competencies in high-altitude mountaineering (Gagnon et al., 2022; McCammon, 2004).

A second key principle is the use of learning scenarios grounded in real accident cases and interactive decision-making tasks. Participants responded positively to learning

experiences rooted in real-world accident cases and critical incidents, which were embedded in the VR environment as narrative anchors (Shin et al., 2020). These scenarios enabled reflective engagement with risk factors, encouraging users to evaluate cause-and-effect relationships, consequences of decisions, and safety protocols. Such authenticity not only supported cognitive realism but also made the training emotionally compelling, leading to greater knowledge of retention and application.

Additionally, usability and accessibility emerged as non-negotiable prerequisites for effective learning. This includes technical elements such as high-resolution visual rendering, clear interface design, smooth navigation controls, and compatibility with diverse hardware platforms. Visual clarity, in particular, was critical for hazard recognition and terrain interpretation. Language accessibility and localisation were also identified as essential design considerations, especially given the multilingual user base in Chile and New Zealand. Participants reported greater comfort and engagement when the interface and instruction were available in their preferred language, affirming the importance of culturally and linguistically responsive design (Gay, 2018).

The integration of scaffolded learning structures was another vital design strategy. These include onboarding tutorials, orientation modules, debriefing tools, and reflective prompts that help users prepare for and make sense of the VR experience (de Koning et al., 2012). In this study, novice VR users particularly benefited from guided pre-training modules, which reduced their cognitive load during task execution, allowing them to focus on the learning content rather than navigating challenges. This aligns with Vygotsky's (1978) Zone of Proximal Development, which posits that learners benefit most when instructional support is provided just beyond their current capabilities.

Cultural responsiveness was a vital consideration in the study. It revealed significant regional differences between Chilean and New Zealand participants regarding familiarity with terrain, institutional support, and instructional preferences. These variations underscored the necessity for flexible, modular VR content that could be customised to address local environmental hazards and cultural norms. For example, VR scenarios tailored for Chile should focus on dry, rocky terrain and low-altitude navigation risks, while those for New Zealand should include snowy landscapes, avalanche risks, and alpine rescue protocols. Utilising culturally relevant visuals, identifying region-specific hazards, and crafting contextually appropriate narratives were found to enhance user motivation, build trust, and facilitate learning transfer.

Finally, iterative, user-informed design processes aligned with the Design-Based Research (DBR) methodology were crucial to refining and validating the application. Through cycles of consultation, observation, and feedback collection across DBR Phases 1 and 2 (as described in Chapter 4), the VR tool was incrementally improved to reflect real-world needs and usability expectations. This responsive, co-constructed approach ensured that the design was not only theoretically sound but also practical and socially situated (McKenney & Reeves, 2012).

The development of VR applications for high-risk education must be grounded in a multidimensional framework that integrates pedagogical theory, technical functionality, and sociocultural relevance. Core design principles include psychological fidelity, authentic scenarios, usability, scaffolding, cultural responsiveness, and iterative development. Together, these principles contribute to immersive learning environments

that are not only engaging but also effective in preparing learners for the demands of extreme and hazardous real-world conditions.

9.2.2 RQ 2 - How can a VR Application be Most Effectively Utilised and Evaluated to Enhance Learning in High-Risk Outdoor Situations?

The effective utilisation and evaluation of Virtual Reality (VR) applications in high-risk outdoor education contexts—such as mountaineering—require an integrated approach that combines pedagogical alignment, immersive fidelity, and context-specific application. Based on the findings presented in Chapters 5 through 8, the utilisation of VR is most impactful when embedded within a blended learning model that supports pre-experience orientation, scenario-based learning, and post-experience debriefing. This a structured learning sequence consisting of preparation, immersive scenario engagement, and reflective debriefing.

Effective utilisation begins with onboarding and pre-training mechanisms, particularly important for novice users or those with low digital literacy (Chapter 6). Orientation modules, including interactive tutorials and familiarisation sessions, reduce cognitive load during simulation and help learners focus on task-based learning (Makransky & Mayer, 2022). By scaffolding users' technical and cognitive preparedness, these mechanisms ensure smoother engagement with complex simulation tasks.

Once learners are situated within the VR environment, the application must present challenges that mirror real-world risk conditions. Scenario-driven interactivity, including time-constrained decision-making, navigation under uncertainty, and reaction to dynamic environmental factors, allows learners to rehearse responses to high-stakes situations

(Gaba, 2004; Chapter 7). Such fidelity to cognitive and emotional demands enhances the transferability of learning outcomes from virtual to real-world settings. Furthermore, incorporating locally grounded hazards and culturally relevant case studies (e.g., avalanche rescue in New Zealand, rockfall or dehydration risks in Chile) increases ecological validity and learner motivation (Gay, 2018).

To ensure that the learning derived from VR is internalised and reflected upon, post-simulation debriefings and feedback mechanisms are vital. These sessions, which may involve group discussions, reflection prompts, or instructor-guided analyses, support learners in abstracting lessons from virtual experience and integrating them into broader knowledge frameworks (Kolb, 1984). Chapters 6 and 8 show that such reflective practices were particularly effective in fostering confidence and clarifying safety protocols.

The effectiveness of the VR-based intervention was evaluated through a mixed-methods approach that combined pre- and post-intervention surveys, biometric data, and qualitative feedback (Chapter 5). Each method offered distinct advantages while also carrying certain limitations, making their integration essential for producing a robust evaluation framework. Pre- and post-intervention surveys provided a clear means of capturing changes in participants' knowledge, confidence, and attitudes toward mountaineering safety. The use of standardised questions enabled measurable comparisons over time, allowing shifts in learning outcomes to be quantified. However, as with all self-reported measures, the surveys were susceptible to biases such as overconfidence, social desirability, or inaccurate recall, limiting their ability to fully represent participants' lived experiences. To address these limitations, biometric data such as heart rate variability were collected as objective indicators of stress, arousal, and cognitive load during the VR sessions. This added a

valuable physiological dimension to the analysis. These multimodal metrics enable researchers and educators to capture both objective improvements in knowledge and skills and subjective shifts in learner confidence and preparedness. The Design-Based Research (DBR) methodology employed in this study provides a robust framework for iterative evaluation, aligning data collection with iterative design cycles (McKenney & Reeves, 2012).

The most effective utilisation and evaluation of VR in high-risk outdoor learning hinges on its integration into broader pedagogical systems, careful adaptation to contextual variables, and ongoing iterative assessment. VR should be viewed not as a stand-alone solution, but as a dynamic and adaptable component within a blended and research-informed educational strategy.

9.2.3 RQ 3 - How can a VR Application Influence Climbers' Learning Experience, Compared to When They are in a Real Environment?

Virtual Reality (VR) has emerged as a powerful pedagogical tool for enhancing climbers' learning experiences, particularly in high-risk mountaineering education, where access to physical environments is limited or potentially hazardous. Unlike traditional field-based training, which requires logistical planning, favourable weather, and physical exertion, VR offers an immersive, repeatable, and psychologically engaging environment where users can develop critical safety skills without incurring real-world risks.

One of the primary benefits of VR in this context is its ability to simulate complex and hazardous conditions in a controlled and repeatable manner. Participants from both Chile and New Zealand reported that VR helped them mentally rehearse responses to unfamiliar

or dangerous scenarios, such as navigating in poor visibility, responding to emergencies, or recognising terrain instability (see Chapter 6, section 6.3.8; Chapter 7, section 7.3.2). These simulations foster anticipatory thinking and risk perception, which are essential components of situational awareness in high-altitude environments (McCammon, 2004; Radianti et al., 2020). This supports Kolb's (1984) experiential learning theory, particularly the stages of reflective observation and abstract conceptualisation, where learners analyse simulated experiences and mentally process their implications for real-world application.

Moreover, VR enables what real environments cannot: the ability to pause, rewind, and reflect on critical decision points. Learners can engage in deliberate practice (Ericsson, 2006), revisiting scenarios until they internalise key decision-making frameworks. This feature of VR enhances metacognitive awareness and self-regulation, fostering a learning process that is less dependent on instructor intervention and more learner-driven (Hase & Kenyon, 2001).

Emotional engagement plays a central role in enhancing the educational value of VR-based training. By embedding narrative-driven accident case studies (see Chapter 7, section 7.3.2), the simulations placed learners in ethically charged scenarios that demanded difficult choices—such as whether to continue a climb in deteriorating weather or how to respond when a teammate exhibited symptoms of altitude sickness. These scenarios required participants to weigh personal ambition against collective safety, foregrounding the ethical dilemmas inherent in mountaineering, where poor judgment or negligence can have life-threatening consequences.

The simulations also elicited powerful emotional responses—stress, empathy, and a sense of responsibility—that deepened learners' sense of presence and urgency. As Slater and Sanchez-Vives (2016) argue, these qualities are critical for immersive learning. Similarly, Gaba (2004) emphasises that psychological fidelity—the ability of a simulation to reproduce the cognitive and emotional demands of real situations—is often more important than physical realism for learning transfer. Participants echoed this point, describing moments of heightened tension despite the absence of physical discomfort: "I knew it wasn't real, but my heart was racing when I heard strong wind noise," reported one user. Another described, "Even without the cold, I still felt nervous and on edge—it felt like the decisions mattered."

From an ethical standpoint, VR provided a safe environment to confront moral dilemmas without real-world consequences. Mistakes made in the simulation—such as misjudging weather or failing to recognise altitude sickness—did not endanger lives, yet they exposed learners to the gravity of decision-making under pressure. This reflective process allowed participants to develop awareness of professional responsibility and the ethical implications of leadership, teamwork, and risk management. One Chilean participant observed: "It showed me how easy it is to make the wrong call, and how serious the outcome could be."

Nevertheless, limitations were clear. VR could not replicate embodied stressors like altitude sickness, physical exhaustion, or extreme cold (Makransky & Mayer, 2022). These factors significantly affect cognitive function and decision-making (Cant & Cooper, 2010). Participants themselves highlighted this gap: "It's good for thinking through decisions, but you don't feel the tiredness or cold that changes everything in the mountains." Thus, VR

should be viewed as a complementary tool that prepares learners cognitively and emotionally before real expeditions, rather than as a replacement for field-based training.

Finally, some participants warned of the risk of overconfidence: “After a few tries, I felt confident—but I know in real life it would be much harder.” This underscores the importance of blended learning models that combine VR with outdoor practice. Such hybrid approaches align with Engeström’s (2001) notion of expansive learning, in which learners traverse multiple activity systems—both digital and embodied—to develop a more holistic understanding of mountaineering safety.

In summary, VR significantly transforms the climbers’ learning experience by enhancing their ability to visualise, interpret, and mentally prepare for complex risk scenarios. While it cannot replace the embodied learning of real-world training, it offers substantial cognitive, emotional, and reflective benefits that are especially valuable for novice climbers or those in geographically remote regions.

For more experienced climbers, VR provides complementary advantages rather than foundational training. Its primary value lies in repetition training and scenario diversification. By allowing users to repeatedly rehearse rare or high-risk situations—such as avalanche response, crevasse rescue, or altitude sickness recognition—VR helps advanced climbers refine decision-making under pressure and strengthen procedural memory. Participants noted that this capacity for safe, repeatable exposure to complex scenarios is rarely available in real-life mountaineering, where environmental unpredictability and physical risk limit training opportunities. As one participant explained,

“In real life, you may never get to practise an avalanche rescue until it’s too late—but here you can run it again and again.”

Additionally, VR enhances preparedness for varied conditions, allowing climbers to anticipate and mentally rehearse strategies for unfamiliar environments. For example, a mountaineer accustomed to New Zealand’s alpine terrain could simulate expeditions in high-altitude Chilean ranges or icy European settings, broadening their adaptive readiness. This ability to visualise and practise diverse scenarios fosters greater flexibility, situational awareness, and resilience, skills that are vital even for seasoned climbers.

When integrated into a blended learning ecosystem, VR thus serves both ends of the experience spectrum: it scaffolds confidence and awareness for novices while offering advanced climbers a tool for deliberate practice, rare-scenario rehearsal, and cognitive readiness. Together, these contributions enhance preparedness, reduce anxiety, and improve overall safety awareness in high-risk mountaineering education.

9.2.4 RQ 4 - How do Climbers’ Responses to Risk Factors in Extreme Outdoor Situations Change after Using a VR Application Design?

The findings of this study indicate that engagement with the VR intervention influenced climbers’ cognitive and affective orientations toward risk; however, these changes must be understood primarily as perceived and internalised shifts rather than empirically verified behavioural changes in real mountaineering contexts. Because participants in both Chile and New Zealand did not undertake subsequent climbing expeditions following the intervention, the study could not directly observe or measure behavioural responses to actual environmental risk factors. Instead, the findings reflect participants' descriptions of

anticipated changes in their awareness, preparedness, and decision-making stemming from their VR experience (Chapters 5, 6, and 7).

Participants consistently reported that the VR scenarios enhanced their awareness of environmental hazards and encouraged more deliberate and reflective thinking about risk management. For example, Chilean and New Zealand participants noted that the altitude sickness simulation prompted them to pay greater attention to physiological signals. These reflections suggest that the VR intervention contributed to the development of more structured cognitive frameworks for interpreting risk. Importantly, these outcomes represent participants' perceptions of learning transfer and preparedness rather than objectively measured changes in real-world behaviour.

This distinction is critical for interpreting the results. Without direct observation of climbers' behaviour in actual outdoor environments, the study cannot establish causal claims regarding behavioural change or improved safety outcomes. Rather, the findings demonstrate that participants perceived the VR experience as valuable in shaping their mental preparedness, situational awareness, and reflective capacity. Such perceptions are themselves significant, as they indicate that learners internalised risk-related concepts and viewed the VR training as relevant to their future practice. This aligns with educational research suggesting that perceived preparedness and cognitive rehearsal are important precursors to behavioural transfer, even when transfer has not yet been empirically observed.

From a pedagogical perspective, the VR intervention functioned as a platform for cognitive rehearsal and affective engagement with mountaineering risks. Participants described

experiencing realistic emotional responses during the simulations, including heightened alertness, uncertainty, and urgency. In line with Gaba's (2004) concept of psychological fidelity, the VR environment reproduced the cognitive and emotional demands of high-risk situations sufficiently to allow learners to mentally rehearse appropriate responses. Although physical stressors such as cold, fatigue, and altitude were absent, the simulation enabled participants to practise hazard recognition, decision sequencing, and self-monitoring in a safe and controlled setting.

Engeström's (2001) Third-Generation Activity Theory provides a valuable framework for understanding these changes. Within this perspective, the VR application functioned as a mediating artefact that reshaped the subject–tool–object relationship by introducing new experiential and cognitive tools for interpreting risk. Through interaction with the VR system, participants engaged in simulated activity systems that enabled them to reconstruct their internalised heuristics, safety awareness, and interpretive frameworks. This process reflects expansive learning, in which learners extend their existing capabilities by integrating new tools and perspectives into their conceptual repertoire (Engeström & Sannino, 2010). Importantly, this expansion occurred at the level of cognitive readiness and perceived preparedness rather than directly observable behavioural performance.

Similarly, simulation-based learning literature emphasises that immersive environments can strengthen learners' anticipatory thinking and emotional preparedness even in the absence of real-world application. Cant and Cooper (2010) describe simulation as a mechanism for developing situational awareness and adaptive thinking through safe, consequence-driven rehearsal. In this study, participants reported that the VR experience allowed them to anticipate potential risks, mentally rehearse safety procedures, and reflect

on appropriate responses. These outcomes align with Makransky and Mayer's (2022) argument that psychological fidelity—rather than physical realism alone—is central to the effectiveness of immersive learning environments.

Therefore, rather than demonstrating verified behavioural change, the findings indicate that the VR intervention facilitated cognitive restructuring and enhanced participants' perceived preparedness. Learners described developing more deliberate, analytical, and anticipatory approaches to risk interpretation, suggesting a shift in their conceptual orientation toward safety and decision-making. This shift represents an important precursor to behavioural change, even though such change was not directly measured in this study.

Accordingly, the VR application can be understood as facilitating perceived learning transfer and cognitive readiness rather than empirically confirmed behavioural transformation. Participants' reflections highlight VR's role as a bridge between theoretical knowledge and anticipated real-world applications, enabling learners to mentally rehearse and internalise safety strategies. Future longitudinal research is needed to examine whether these perceived changes translate into observable behavioural adaptations during actual mountaineering expeditions. Nevertheless, the present findings demonstrate that immersive VR can play a meaningful role in shaping learners' cognitive and affective responses to risk, supporting the development of reflective, risk-aware mindsets essential for safe mountaineering practice.

9.3 Contributions to Knowledge

This research contributes to knowledge in several areas, including immersive learning design, mountain safety education, and the application of activity theory in technology-enhanced training environments. The contributions are outlined below.

- Advancing understanding of VR-assisted training in high-risk outdoor environments

This study provides empirical evidence demonstrating how immersive VR environments can support the development of risk awareness and decision-making skills among mountaineers. While previous research has explored VR applications in medical, aviation, and industrial training, limited research has examined its use within mountaineering or outdoor safety education. By investigating climbers' experiences in simulated hazard scenarios, the study expands current understanding of how immersive environments can facilitate experiential learning in contexts where real-world practice may involve significant physical danger.

- Identifying the psychological and physiological impacts of immersive training

A novel contribution of the study lies in the integration of biometric data with qualitative learning experiences. Heart-rate measurements collected during VR simulations indicate that immersive training environments can evoke measurable physiological responses associated with emotional engagement and perceived realism. These findings contribute to the growing body of research on the role of affective and physiological engagement in

immersive learning environments and highlight VR's potential to simulate aspects of psychological stress found in real alpine environments.

- Developing design principles for VR-supported mountain safety training

The research proposes a set of instructional design principles for VR-assisted safety training in outdoor environments. These principles emphasise scenario-based learning, progressive exposure to risk situations, contextual realism, and the integration of reflective learning processes. The design principles provide a practical framework for educators and developers seeking to implement immersive training systems for outdoor education, emergency response, or other high-risk professions.

- Applying Activity Theory to immersive learning environments

This study contributes theoretically by applying Engeström's Third-Generation Activity Theory to analyse tensions and contradictions within the VR learning ecosystem. The analysis revealed systemic contradictions between technological capabilities, learner expectations, instructional design practices, and real-world environmental conditions. By framing these tensions as drivers of system development and learning transformation, the research demonstrates how Activity Theory can serve as a valuable analytical framework for understanding complex interactions between learners, tools, and learning environments in immersive educational contexts.

- Providing cross-cultural insights into mountain safety training

The comparative analysis between Chilean and New Zealand participants offers new insights into how cultural and environmental contexts influence perceptions of risk,

training practices, and learning needs in mountaineering education. The findings highlight the importance of contextualising safety training approaches to local climbing cultures, terrain conditions, and instructional traditions. This cross-national perspective contributes to the broader literature on global outdoor education and technology-supported learning.

9.4 Conclusion

The research presented in this thesis examined the development and evaluation of a VR-based training intervention designed to support mountaineering safety education. Through a Design-Based Research (DBR) methodology grounded in Engeström's (2001) Third-Generation Activity Theory and Kolb's (1984) Experiential Learning Cycle, this study has generated both theoretical insights and practical design principles for immersive safety training in extreme outdoor environments.

The findings across the research questions reveal that VR can offer pedagogically meaningful, context-sensitive, and scalable training tools when designed with cognitive realism, learner diversity, and situated interactivity in mind. The four research questions provided a structured approach to uncovering how VR could be best utilised in mountaineering safety education. Collectively, the findings suggest that VR can serve as a transformative educational tool, not by replacing physical, embodied experience, but by amplifying cognitive, emotional, and reflective dimensions of learning that are often underdeveloped in traditional outdoor training formats.

The analysis of Research Question 1 established that key design principles must go beyond technical fidelity and instead centre on psychological engagement, usability, cultural relevance, and scenario-driven feedback mechanisms. Participants consistently

emphasised the importance of clear visual design, authentic case studies, multilingual support, and pre-training orientation modules. These elements collectively support a learner-centred approach that accommodates diverse needs across geographical and cultural contexts (see Chapters 5–7). Furthermore, cultural localisation played a pivotal role in enhancing contextual relevance, with participants in Chile expressing a strong preference for scenarios that reflected their regional landscapes and linguistic needs. Pre-training orientation modules, embedded scaffolds, and scenario debriefings were also recommended as essential instructional components, aligning with best practices in simulation-based education (Cant & Cooper, 2010; Makransky & Mayer, 2022).

Research Question 2 examined how VR applications can be most effectively implemented and evaluated in high-risk training environments. The findings confirm that VR is most beneficial when integrated into blended learning ecosystems, complementing rather than supplanting traditional field-based instruction. VR's strength lies in its ability to simulate high-risk scenarios without physical harm, enabling learners to rehearse critical decision-making processes in a safe, repeatable environment. Effective onboarding and debriefing strategies were found to be essential for ensuring educational coherence and psychological safety (Makransky & Mayer, 2022; Chapter 6). Effective use also requires thoughtful onboarding, structured debriefing, and mixed-method evaluation strategies, including qualitative feedback, biometric data, and performance comparisons. These multimodal assessments helped identify not only cognitive gains but also emotional readiness and behavioural adjustments, providing a holistic understanding of the intervention’s impact (see Chapters 6–8).

Research Question 3 investigated the impact of VR on learners' experiences compared with real-world conditions. Participants overwhelmingly reported that VR enhanced their mental preparedness, visualisation skills, and emotional regulation, even though it could not fully simulate the physical rigours of mountaineering. This supports existing scholarship suggesting that high psychological fidelity can compensate for physical limitations in simulation-based education (Gaba, 2004; Slater & Sanchez-Vives, 2016). Also, this aligns with Kolb's (1984) experiential learning model, particularly in how VR supports reflective observation and abstract conceptualisation—two phases that are often constrained in real-world training due to time, safety, or environmental unpredictability. By offering repeatable scenarios, VR encouraged participants to engage in deliberate practice (Ericsson, 2006), a key component in high-stakes decision-making, as well as reflective reasoning, both of which are critical for effective decision-making. While limitations such as altitude sickness, fatigue, and physical exertion were acknowledged, the emotional and cognitive fidelity of the experience was consistently deemed effective (Gaba, 2004; Slater & Sanchez-Vives, 2016).

Research Question 4 examined how VR training influenced participants' perceived readiness and anticipated responses to real-world mountaineering risks. As participants did not engage in outdoor climbing after the intervention, behavioural changes were not directly observed. Instead, the findings are based on post-intervention interviews, in which participants described increased awareness of environmental hazards, more deliberate risk assessment, and greater preparedness to manage potential dangers. These reflections suggest that the VR intervention supported cognitive and affective shifts in participants' understanding of safety and decision-making.

Participants reported becoming more reflective and proactive in anticipating risks, indicating changes in their internalised safety frameworks. This aligns with Engeström's (2001) concept of expansive learning, where mediated tools reshape learners' conceptual understanding and preparedness. The VR application functioned as a mediating artefact, enabling participants to mentally rehearse safety procedures and reconsider their approach to risk. Although behavioural transfer was not empirically verified, participants' reflections indicate enhanced cognitive readiness and perceived preparedness. This is consistent with research on simulation-based learning, which shows that immersive experiences can strengthen situational awareness and anticipatory thinking (Cant & Cooper, 2010; Makransky & Mayer, 2022).

This study contributes to both theoretical understanding and practical application within the field of immersive learning for high-risk outdoor education. Grounded in Engeström's (2001) Third-Generation Activity Theory and Kolb's (1984) Experiential Learning Cycle, the research examined how Virtual Reality (VR) can be designed, implemented, and evaluated to enhance mountaineering safety training across culturally distinct contexts in Chile and New Zealand.

By synthesising user experiences from two geographies with differing cultural, linguistic, and environmental conditions, this study advances a globally relevant yet locally adaptable framework for immersive educational design. The Design-Based Research (DBR) methodology employed in the study ensured iterative cycles of implementation, reflection, and refinement, thereby aligning theoretical insights with practical outcomes (McKenney & Reeves, 2012).

Findings from the four research questions (RQ1–RQ4) collectively demonstrate that VR applications for high-risk learning environments are most effective when grounded in principles of psychological fidelity, usability, cultural responsiveness, and situated interactivity. Participants across both sites reported improved cognitive awareness, emotional preparedness, and behavioural decision-making in simulated high-risk environments.

Moreover, this research reinforces VR's role as a powerful mediating artefact within the learner's activity system, facilitating expansive learning (Engeström & Sannino, 2010). When implemented thoughtfully and supported by appropriate onboarding, scaffolding, and debriefing strategies, VR enables users to progress from passive recipients of knowledge to active, reflective practitioners who internalise safety behaviours and anticipate risk with greater competence.

Importantly, this thesis does not position VR as a replacement for traditional field-based learning. Instead, it advocates for its integration into blended learning models, in which virtual simulations and real-life embodied experience serve as complementary elements in the development of adaptive expertise. The lessons learned from this research provide a flexible, evidence-based design framework that can be applied to other domains, including avalanche rescue, wilderness medicine, maritime safety, and disaster response.

In conclusion, this study validates the use of VR as a pedagogically rich, context-sensitive, and scalable educational tool for mountaineering safety training. It offers a practical blueprint for educators, developers, and policymakers seeking to embed immersive technologies into high-risk education. It invites continued interdisciplinary collaboration

to ensure such innovations remain inclusive, practical, and grounded in the realities of the communities they serve.

9.5 Limitations of the Study

While this study provides meaningful contributions to the development, implementation, and evaluation of virtual reality (VR) applications for high-risk mountaineering education, several limitations must be acknowledged. These limitations define the scope of the study's generalisability and underscore important considerations when interpreting the findings. The key limitations are outlined below:

- Sample Size and Demographic Scope
- Technological Constraints and Hardware Variability
- Language and Cultural Translation
- Duration of the Intervention and Long-Term Effects
- Evaluation Framework Limitations

9.5.1 Sample Size and Demographic Scope

A primary limitation is the relatively small, context-specific participant sample. Although participants were recruited from two culturally and geographically distinct regions—Chile and New Zealand—the total number remained modest due to the logistical complexities of VR deployment, field access, and time constraints. The sample sizes for both the Chilean and New Zealand cohorts were relatively small and purposively selected, which, while appropriate for qualitative and design-based research, limits the statistical generalisability of the findings. The insights gained are rich in context and in-depth. Still, they may not fully capture the diversity of experiences present in the broader mountaineering community

or other high-risk domains, such as firefighting, the military, or medical emergency training. This restricts the statistical generalisability of the findings and limits the representativeness of diverse global climbing populations.

Additionally, participants' backgrounds varied in digital literacy, mountaineering experience, and language proficiency. While these variations enriched the qualitative data, they may have introduced confounding variables that were not fully controlled for. For example, a novice climber with strong digital skills may experience the VR system differently from an experienced climber with limited technological familiarity. Future studies should aim for larger and more stratified samples to explore these variables more rigorously.

9.5.2 Technological Constraints and Hardware Variability

Although all participants used the same headset model (Meta Quest 2), several technical challenges arose during deployment. At times, the devices were tethered to external computers for data capture, and unstable wireless connections occasionally caused lag or disrupted tracking. These issues, while intermittent, affected immersion by reducing visual clarity, motion smoothness, and responsiveness to interactions. As a result, despite uniform hardware across the 20 participants, contextual factors meant that not every user experienced the same level of presence.

Beyond these technical concerns, the intervention faced inherent limitations in replicating the embodied realities of high-altitude mountaineering. The VR system achieved a high degree of visual and auditory fidelity—through alpine landscapes, shifting weather, and spatialised sound—but could not reproduce the physiological stressors central to

mountaineering, such as cold exposure, fatigue, or altitude-induced disorientation. The initial research design considered hybrid solutions, including industrial fans to simulate wind resistance and refrigerated spaces to replicate cold conditions. However, logistical, safety, and resource constraints prevented these enhancements from being implemented.

The absence of such embodied stressors underscored a fundamental limitation of current VR technologies in outdoor education. While participants consistently described strong emotional and cognitive engagement—reporting feelings of urgency, stress, and responsibility—the lack of kinaesthetic and sensory feedback risked producing an incomplete training experience. This gap is particularly significant in mountaineering, where the interplay of cognitive vigilance and physical strain often shapes decision-making. For instance, recognising and responding to altitude sickness in a teammate is not only a matter of theoretical knowledge but also of managing one's own fatigue and disorientation in real time.

A further limitation relates to the physiological measurements used in this study. The Suunto device used to record participants' heart rate was a commercially available wearable rather than medical-grade equipment. The measurements were therefore non-clinical and non-diagnostic and should be interpreted cautiously. Heart-rate data were used as supplementary evidence alongside questionnaires, interviews, and observations rather than as an independent measure of participants' emotional or physiological states.

Also, although the researcher checked the fit of the watch before each measurement, wrist circumference and strap tension were not formally measured or standardised. Individual

differences in wrist anatomy and watch fit may therefore have influenced the optical heart-rate readings and represent an additional limitation of the physiological data.

Consequently, the VR intervention was most effective as a complement to, rather than a replacement for, field-based training. Its primary strength lies in fostering psychological readiness and cognitive rehearsal: helping learners practise vigilance, environmental scanning, and decision-making before encountering the unpredictable, multisensory challenges of expeditions.

From a pedagogical perspective, prioritising psychological fidelity and emotional realism offered clear benefits, yet the absence of physical realism constrained the depth of experiential transfer. As Makransky and Mayer (2022) note, immersive simulations without kinaesthetic or sensory input can struggle to fully prepare learners for embodied demands. While the study demonstrated that VR can successfully rehearse decision-making under pressure, it also highlighted the ongoing need for hybrid or blended approaches that integrate virtual and physical training to maximise authenticity, safety, and skill transfer.

9.5.3 Language and Cultural Translation

The contextual scope of the intervention was limited to two geographical regions—Chile and New Zealand—with significant environmental, cultural, and institutional differences. Although these differences enriched the comparative analysis, they also introduced challenges in standardising the VR experience and interpreting cross-cultural findings. Language barriers, differences in mountaineering practices, and institutional support structures may have influenced participants' responses and the intervention's impact.

Despite efforts to create culturally responsive and linguistically inclusive VR modules, challenges related to language localisation and symbolic representation persisted. In the Chilean context, for example, some users found the interface terminology or narrative cues either overly technical or culturally unfamiliar.

Cultural relevance also extends beyond language. The visual and narrative design of scenarios—such as simulating high-altitude mountain sickness—was perceived by some Chilean participants as less applicable to their local mountaineering environments, which differ from the glaciated alpine terrain found in New Zealand. This highlights the broader challenge of creating simulations that are both universally applicable and maintain local authenticity.

9.5.4 Duration of the Intervention and Long-Term Effects

The study was limited by the short duration of the intervention and the relatively narrow post-training observation period. While immediate changes in risk perception, cognitive load, and emotional response were noted, the long-term applicability and retention of learning, behavioural transfer to real-world environments, and sustained changes in safety practices remain uncertain. Longitudinal studies are required to assess whether improvements in hazard recognition and decision-making persist over time and under real-life stress conditions.

Moreover, repeated exposure and iterative learning were not fully explored in this study. Although some participants expressed interest in returning to the VR scenarios for further practice, the study design's constraints limited the opportunity for multi-session training.

Given that repetition and reflection are central to experiential learning (Kolb, 1984), this represents a significant area for future development.

9.5.5 Evaluation Framework Limitations

This study employed a mixed-methods evaluation framework that combined pre- and post-intervention questionnaires/interviews, observational data, and biometric measures. The intention was to triangulate across subjective, behavioural, and physiological data to produce a more holistic understanding of learning outcomes. While this approach was methodologically sound, several challenges prevented the consistent integration of all data sources.

Technical challenges were a primary factor in limiting data consistency. Biometric sensors did not always synchronise reliably with the VR system, resulting in incomplete datasets. Similarly, tethering VR headsets to external computers for observational recording sometimes introduced lag or disrupted immersion, which compromised both the fidelity of the experience and the quality of the captured data. Time constraints during intervention sessions also limited opportunities for comprehensive debriefs and post-intervention surveys, particularly in field settings where logistical pressures were greater.

Variability also stemmed from participant circumstances. Some participants were unable or unwilling to complete all survey items, while others provided minimal responses due to fatigue following intensive VR sessions. In Chile, language barriers occasionally led to misinterpretations of questionnaire items, which reduced the comparability of data across cohorts. In addition, the risk of social desirability bias was present, as participants may

have overstated positive outcomes to align with perceived researcher expectations (Podsakoff et al., 2003).

Also, even when multiple data types were collected, integration across modalities was inconsistent. For instance, self-reported improvements in vigilance or decision-making could not always be cross-validated against biometric stress markers due to missing or incomplete readings. Similarly, observational video was not consistently available for all sessions, limiting behavioural analysis. As a result, the study relied more heavily on self-reported data than originally planned, with fewer opportunities to validate these accounts against objective measures.

In addition, the reliance on participant perceptions rather than systematically triangulated evidence has several implications. First, findings primarily reflect perceived transfer of learning rather than empirically validated skill acquisition. Second, the absence of comprehensive biometric and behavioural integration reduces the robustness of claims about cognitive or physiological preparedness. Third, this reliance may have led to an overestimation of impact, as subjective accounts do not always equate to actual improvements in field-based performance (Cook & Beckman, 2006).

To address these limitations, future research should prioritise stronger integration of data streams. This includes employing more reliable biometric synchronisation, ensuring mandatory observational capture for all sessions, and developing culturally adapted instruments to minimise misinterpretation. In addition, longitudinal follow-up studies that track participants into real-world expeditions could provide more objective measures of

behavioural transfer and skill acquisition. Such methodological refinements would enhance both the reliability and generalisability of findings.

Additionally, while Activity Theory provided a valuable framework for analysing systemic contradictions and mediating tools, its application in cross-cultural, high-risk education contexts remains methodologically complex. The dynamic interplay between interacting activity systems—such as learners, instructors, institutions, and technologies—cannot be fully captured through a single-case design. More comparative, multi-sited research is needed to explore how activity systems evolve in response to immersive learning interventions.

Moreover, the design-based research (DBR) methodology, while highly appropriate for iterative development and contextual adaptation, introduces inherent methodological limitations related to replication and causal attribution. DBR operates through cyclical processes of design, implementation, evaluation, and refinement, during which multiple design elements, technological features, and contextual factors evolve simultaneously. While this flexibility strengthens ecological validity and enables the development of pedagogically meaningful interventions, it complicates efforts to isolate individual design components as singular determinants of observed learning outcomes. Consequently, the improvements reported in this study should be interpreted as the result of interactions among the VR system, pedagogical scaffolding, learner engagement, and contextual implementation, rather than the effect of any single design feature in isolation.

Furthermore, the relatively short duration of the intervention and evaluation period limits the ability to assess long-term retention, sustained behavioural change, and verified transfer

of learning to real-world mountaineering contexts. As participants did not undertake actual climbing activities following the intervention, the study was unable to empirically observe behavioural transfer or objectively measure performance changes in authentic outdoor environments. Instead, the findings primarily reflect participants' perceived preparedness, cognitive restructuring, and anticipated responses to risk, as reported in post-intervention interviews. While these perceptions provide valuable insight into learners' cognitive and affective development, they do not constitute direct evidence of behavioural transformation. Accordingly, future research should incorporate longitudinal designs, real-world performance measures, and integrated behavioural and physiological data to more robustly evaluate the long-term impact and practical transferability of VR-based mountaineering safety training.

Acknowledging these limitations is not to undermine the study's findings, but rather to frame them within the boundaries of what was methodologically, pragmatically, and practically feasible. Future research can address these limitations by adopting and better integrating mixed-methods approaches, expanding sample diversity, enhancing technological fidelity, and conducting longitudinal follow-ups to track sustained impact.

9.6 Implications

The findings of this study provide insights relevant to several groups, including researchers, instructional designers, outdoor educators, and policy-makers involved in safety training. These implications extend across theoretical, pedagogical, methodological, technological, and institutional dimensions, reflecting the interdisciplinary nature of immersive learning

environments. To structure this discussion, the implications are presented across the following key domains:

- Theoretical Implications
- Pedagogical Implications
- Methodological Implications
- Design Implications
- Institutional and Policy Implications
- Research Implications
- Technological Implications

9.6.1 Theoretical Implications

This research advances the conceptual foundations of immersive learning by extending Engeström's (2001) Third-Generation Activity Theory, Kolb's (1984) Experiential Learning Cycle, and immersive learning design frameworks (Makransky & Lilleholt, 2018; Slater & Sanchez-Vives, 2016) into the emerging domain of virtual mountaineering education. By examining both the affordances and contradictions of VR in the Chilean and New Zealand contexts, the study demonstrates how established theoretical frameworks can be translated into actionable, contextually grounded design principles. Through the iterative cycles of analysis, design, implementation, and reflection characteristic of Design-Based Research (DBR), this study identifies ten interrelated design principles that collectively address cognitive, pedagogical, technological, and systemic dimensions of immersive learning. These principles provide a structured framework for guiding the development, implementation, and evaluation of VR-based training in high-risk

educational environments. Specifically, the design principles identified in this study are as follows:

- Cognitive Development and Decision-Making
- Complementarity with Real-World Training
- Environmental and Hazard Realism
- Interactivity and Emotional Engagement
- Sensory Limitations and Psychological Fidelity
- Immersion and Usability
- Onboarding and User Orientation
- Cultural and Regional Localisation
- Accessibility and Cost-Efficiency
- Strategic Partnerships for Sustainable Implementation

9.6.1.1 Cognitive Development and Decision-Making

At the core of the intervention was the goal of supporting decision-making in complex, high-risk scenarios. Kolb's experiential learning cycle (1984) provided a lens for understanding how learners moved through phases of active engagement, reflection, and experimentation. Empirical evidence from participants confirmed that VR scenarios enhanced vigilance, situational awareness, and reflective thinking. However, contradictions also surfaced: while users felt cognitively prepared, some acknowledged a false sense of confidence in the absence of embodied stressors. This aligns with Engeström's (2001) idea of contradictions as catalysts for expansive learning, showing that

decision-making design in VR must be situated within blended ecosystems that extend beyond the simulation.

9.6.1.2 Complementarity with Real-World Training

The principle that VR should complement, rather than replace, physical training is grounded in both Activity Theory and authentic learning perspectives (Herrington & Oliver, 2000). Empirical data reinforced this, as both Chilean and New Zealand cohorts stressed the irreplaceable value of physical sensations—cold, fatigue, altitude sickness—in shaping mountaineering competence. The theoretical implication is that VR should be theorised as a mediating artefact for cognitive and ethical rehearsal, rather than as a holistic substitute. This reinforces blended learning models in which VR prepares learners mentally, while field practice consolidates embodied competence.

9.6.1.3 Environmental and Hazard Realism

Theories of immersion and presence (Slater & Sanchez-Vives, 2016) emphasise fidelity as a foundation for meaningful learning transfer. Participants valued realistic weather, terrain, and auditory cues but highlighted the absence of physical stressors as a major limitation. This aligns with Gaba's (2004) distinction between physical and psychological fidelity, suggesting that while VR can successfully simulate cognitive and emotional stressors, it cannot yet replicate embodied physiological ones. The implication for design is that realism should prioritise psychological fidelity, while recognising its boundaries.

9.6.1.4 Interactivity and Emotional Engagement

Kolb's emphasis on active experimentation (1984) and research on immersive learning (Makransky & Lilleholt, 2018) both stress the importance of active participation. Empirical findings confirmed that interactivity—navigating terrain, or responding to simulated mountain sickness symptoms—heightened engagement and emotional arousal. Ethical dilemmas embedded in scenarios also foregrounded the moral dimension of decision-making, aligning with heutagogical principles of learner agency (Hase & Kenyon, 2001). This theoretical implication is significant: immersive learning must be designed not only to engage emotionally but also to stimulate ethical reflection and responsibility.

9.6.1.5 Sensory Limitations and Psychological Fidelity

The inability to simulate cold, fatigue, or altitude highlighted a contradiction between theoretical aspirations of "total immersion" and practical technological limits. Yet, participants still reported heightened tension, fear, and focus, affirming Gaba's (2004) argument that psychological fidelity is more critical than physical realism for transfer. This finding extends immersive learning theory by showing that emotional realism can partially compensate for sensory absence, but only when learners are supported to contextualise limitations.

9.6.1.6 Immersion and Usability

Immersion is widely theorised as a driver of presence (Slater & Sanchez-Vives, 2016), yet the study revealed how usability directly conditions immersion. Issues such as blurry visuals, headset discomfort for glasses wearers, and the absence of localisation features constrained users' sense of presence. From a theoretical standpoint, this underscores the

interdependence between technical usability and cognitive immersion, extending Sweller's (2011) cognitive load theory to immersive environments: poorly designed interfaces increase extraneous load, disrupting presence and learning.

9.6.1.7 Onboarding and User Orientation

While onboarding is often treated as a pragmatic design choice, this study positions it as a theoretical necessity tied to scaffolding within Activity Theory and constructivist paradigms. Tutorials, replay functions, and interface guidance were crucial for reducing cognitive load and enabling learners to engage meaningfully with simulations. Without such scaffolds, novices experienced disorientation and anxiety. This expands the theoretical framing of usability into one of pedagogical orientation, showing that VR design must include structured entry points to maximise learning.

9.6.1.8 Cultural and Regional Localisation

Activity Theory's concept of multivoicedness (Engeström, 1987) emphasises that cultural and historical contexts shape tools. Empirical findings strongly reinforced this principle: Chilean participants demanded Spanish-language options and non-snow environments, while New Zealand participants aligned VR with established safety curricula. Theoretically, this shows that localisation is not an optional "add-on" but a core design requirement for immersive learning, ensuring relevance, credibility, and adoption.

9.6.1.9 Accessibility and Cost-Efficiency

The accessibility principle reflects broader discourses in equitable education and aligns with WCAG's (2018) emphasis on inclusive design. Empirical findings highlighted

accessibility barriers—such as glasses fit, headset discomfort, and hardware costs—underscoring the risk of exclusion if VR is not designed inclusively. From a theoretical perspective, accessibility must be foregrounded in immersive learning research as a systemic constraint that shapes not only user experience but also adoption across institutions with unequal resources.

9.6.1.10 Strategic Partnerships for Sustainable Implementation

Finally, Activity Theory's community and division of labour components (Engeström, 2001) frame VR implementation as inherently systemic. The principle of partnerships reflects the reality that sustainability depends on multi-actor ecosystems—government funding, industry sponsorship, and academic collaborations. Empirical data supported this, with Chilean participants stressing reliance on external agencies, and New Zealand participants highlighting institutional readiness. The theoretical implication is that immersive learning cannot be theorised solely at the micro-level of learner–tool interaction but must be embedded within macro-level socio-technical systems.

In summary, the theoretical implications of this study extend beyond individual learning design features, showing how cognitive, cultural, technological, and systemic dimensions intersect in immersive education. By mapping the ten design principles back to Activity Theory, experiential learning, and the literature on immersive learning, this research demonstrates that VR in high-risk education is best understood as a multi-layered system: cognitively engaging, emotionally immersive, culturally situated, and institutionally supported.

9.6.2 Pedagogical Implications

The pedagogical potential of VR in high-risk outdoor education is underscored by participants' enhanced situational awareness, emotional regulation, and cognitive engagement. These outcomes reflect a shift away from traditional, didactic modes of teaching toward constructivist and learner-centred pedagogies, where knowledge is actively constructed through reflection, simulation, and embodied cognition (Herrington, Reeves, & Oliver, 2010). By immersing learners in consequence-driven scenarios, VR moves pedagogy toward authentic, experiential learning, enabling learners to rehearse decision-making, confront ethical dilemmas, and engage emotionally in ways that classroom-based instruction rarely affords.

A central implication for pedagogy is the confirmation of a blended learning model. While VR excels in cognitive rehearsal, risk visualisation, and emotional engagement, it cannot replicate critical embodied experiences such as cold, fatigue, or physical coordination under stress. Consequently, VR should be conceptualised as a preparatory or complementary tool that enhances field readiness rather than a replacement for outdoor experiential learning (Cant & Cooper, 2010; Makransky & Mayer, 2022). This aligns with the idea of scaffolded learning progressions: VR provides a safe, low-risk environment for initial rehearsal, while field-based practice consolidates embodied competence. For novice climbers, this model reduces anxiety and builds confidence before encountering dangerous environments. At the same time, for experienced mountaineers, it supports repetition training, advanced scenario testing, and refinement of decision-making strategies in rare or high-stakes situations.

The findings also highlight the necessity of structured onboarding, scaffolding, and debriefing mechanisms. Learners need clear orientation to the VR interface to reduce cognitive load, guided prompts to scaffold decision-making, and reflective debriefs to consolidate learning. This aligns with Kolb's (1984) experiential learning cycle, which emphasises the whole sequence from concrete experience to reflective observation, abstract conceptualisation, and active experimentation. Without structured debriefing, emotionally intense simulations risk becoming fragmented experiences rather than drivers of more profound insight. Instructors should therefore integrate guided reflection or peer discussion feedback to extend the impact of VR sessions.

Significantly, the pedagogical implications extend across different educational contexts. In formal education (e.g., tertiary eco-tourism programmes, outdoor leadership courses), VR can be embedded within curricula as structured modules that align with assessment frameworks, offering scalable and standardised exposure to high-risk scenarios. In non-formal contexts (e.g., club-based mountaineering training, community safety workshops), VR serves as a flexible and accessible training tool, especially valuable where access to high mountains is limited by geography, cost, or risk. These non-formal uses align with heutagogical principles (Hase & Kenyon, 2001), empowering self-directed learners to explore scenarios at their own pace and reflect critically on their decision-making.

Finally, VR offers unique opportunities to enhance inclusive pedagogies. Lowering entry barriers allows participation by individuals who may face physical, geographic, or economic constraints in accessing real mountaineering environments. However, its pedagogical value depends on addressing accessibility challenges (e.g., headset discomfort, multilingual support, cost barriers). This highlights educators' responsibility to design VR-

enhanced curricula that are not only innovative but also equitable, culturally relevant, and adaptable to learners' diverse needs.

In summary, the pedagogical implications of this study point toward VR as a powerful bridge between theory and practice, capable of fostering reflection, ethical awareness, and decision-making in safe, controlled environments. Yet its most significant value lies in its integration within blended, scaffolded learning pathways that respect the embodied, social, and cultural dimensions of outdoor education.

9.6.3 Methodological Implications

The application of a Design-Based Research (DBR) methodology in this study proved highly effective in supporting the iterative development, testing, and refinement of the VR intervention. By integrating thematic analysis, biometric monitoring, and post-intervention interviews, the study employed a robust mixed-methods approach to provide a comprehensive understanding of participants' subjective learning experiences and their cognitive and behavioural responses. This methodological approach provided valuable insights into the strengths of combining qualitative and quantitative data within immersive learning research. At the same time, the research process highlighted several areas where methodological design and integration could be further strengthened to enhance the validity, depth, and long-term impact of future studies. These methodological considerations are outlined below:

- Integration of Biometric Data
- Longitudinal Follow-Ups
- Enhancing Mixed-Methods Triangulation

- Application of Activity Theory Across Cultures
- Implementation and Pedagogical Integration
- Duration and Iterative Cycles

9.6.3.1 Integration of Biometric Data

One limitation was the inconsistent synchronisation between biometric sensors and the VR system, resulting in incomplete datasets and limited opportunities for triangulation. If this study were to be replicated, greater emphasis would be placed on establishing a robust, reliable biometric data pipeline that integrates heart rate variability, galvanic skin response, and other physiological indicators into a unified, synchronised recording platform. This would enable precise correlations between physiological arousal and decision-making moments in VR simulations. Additionally, real-time visualisation dashboards for researchers could support adaptive adjustments during sessions, ensuring high-quality data capture.

9.6.3.2 Longitudinal Follow-Ups

Another methodological gap was the absence of a longitudinal assessment of learning transfer. The study relied on post-intervention interviews to capture participants' perceived application of VR learning to field contexts. While insightful, these accounts remain subjective. Future research should employ longitudinal designs—tracking climbers into actual expeditions or training courses over months or years—to assess how VR-based learning translates into observable safety behaviours, decision-making accuracy, and reduced accident rates in real-world conditions. Such designs would also allow for

repeated-measures biometric testing, comparing stress regulation in VR with subsequent field performance.

9.6.3.3 Enhancing Mixed-Methods Triangulation

Although a mixed-methods framework was adopted, integration across qualitative and quantitative data streams was not always systematic. For example, self-reported improvements in vigilance were not consistently cross-validated with biometric or behavioural evidence. Future designs should embed protocols for cross-validation, ensuring that each self-report item is linked to corresponding biometric markers and video-coded behaviours. This would produce a richer triangulation and reduce reliance on perception alone.

9.6.3.4 Application of Activity Theory Across Cultures

A significant methodological contribution of this study was the application of Engeström's (2001) Third-Generation Activity Theory in two culturally distinct contexts: Chile and New Zealand. AT provided a robust framework for identifying how cultural norms, linguistic accessibility, and institutional structures shaped the adoption of VR. For instance, scepticism from Chilean mountaineers and reliance on external institutional support contrast with New Zealand's internally driven integration model. This highlighted AT's value in comparative, cross-cultural educational research, as it enabled the systematic analysis of contradictions among local practices, community expectations, and tool affordances. If repeated, the research would strengthen this approach by conducting multi-sited ethnographic mapping alongside AT analysis, to capture local practices more richly before integrating them into VR design.

9.6.3.5 Implementation and Pedagogical Integration

Methodologically, VR must also be studied not just as a discrete tool but as part of a blended learning ecosystem. Future research could integrate structured pedagogical scaffolds (e.g., pre-VR knowledge checks, guided reflection prompts, follow-up field-based drills) into the evaluation framework. This would allow the assessment of pedagogical continuity between VR and physical training, rather than treating them as separate stages.

9.6.3.6 Duration and Iterative Cycles

Finally, the DBR cycles in this study were necessarily constrained by time and resources. With a longer implementation period, multiple iterations could test design refinements (e.g., adding haptic devices, multilingual onboarding, adaptive branching scenarios) across different cohorts. A longer-term DBR approach would allow for progressive iteration in which both technology and pedagogy evolve in tandem, generating richer insights into scalability and sustainability.

In summary, while this study successfully demonstrated the feasibility and promise of VR-based mountaineering education, methodological improvements—such as more reliable biometric integration, longitudinal follow-ups, systematic triangulation, and expanded use of Activity Theory—would deepen the validity, reliability, and transferability of findings. These refinements would not only strengthen future VR research in high-risk education but also provide more robust evidence for policymakers, training organisations, and outdoor communities considering the adoption of immersive learning technologies.

9.6.4 Design Implications

The findings of this study generate a set of empirically grounded design principles that move beyond abstract theoretical constructs to provide practical guidance for the development and implementation of immersive training systems in high-risk educational contexts such as mountaineering. These principles emerged through the iterative interplay between theoretical frameworks—particularly Activity Theory (Engeström, 1987, 2001), Experiential Learning Theory (Kolb, 1984), and immersive learning design models (Makransky & Lilleholt, 2018; Slater & Sanchez-Vives, 2016)—and empirical insights derived from the Chilean and New Zealand interventions. Through this integrative process, the study identifies key considerations that inform how virtual reality environments should be conceptualised, designed, and implemented to support meaningful learning, cognitive development, and contextual relevance. The resulting design principles, outlined below, collectively provide a structured framework for guiding the development of effective and sustainable VR-based training interventions:

- Cognitive Development and Decision-Making
- Complementarity with Real-World Training
- Environmental and Hazard Realism
- Interactivity and Emotional Engagement
- Sensory Limitations and Psychological Fidelity
- Immersion and Usability
- Onboarding and User Orientation
- Cultural and Regional Localisation
- Accessibility and Cost-Efficiency

- Strategic Partnerships for Sustainable Implementation

9.6.4.1 Cognitive Development and Decision-Making

The VR intervention demonstrated strong potential to support cognitive development and enhance risk-related decision-making processes. Participants reported increased awareness of environmental hazards and improved ability to anticipate and evaluate potential risks. These outcomes suggest that immersive simulation environments can facilitate the development of structured cognitive frameworks for interpreting complex and uncertain situations.

From the perspective of Experiential Learning Theory (Kolb, 1984), the VR environment enabled learners to engage in concrete experiences simulating high-risk scenarios, allowing them to actively practise decision-making in a safe, controlled setting. This experiential engagement supported reflective observation, as participants evaluated their actions and outcomes, and abstract conceptualisation, as they refined their understanding of hazard recognition and response strategies. The repeatable nature of VR scenarios further supported active experimentation, enabling learners to test alternative approaches and strengthen adaptive expertise.

Within Engeström's (1987, 2001) Activity Theory framework, the VR system functioned as a mediating tool that reshaped the subject–object relationship by enabling learners to reinterpret risk and safety through simulated experience. This mediation facilitated the internalisation of new cognitive tools, such as improved situational awareness and anticipatory reasoning, thereby supporting expansive learning. As learners engaged with

the VR environment, their conceptualisation of risk evolved from reactive responses to more deliberate and proactive decision-making strategies.

9.6.4.2 Complementarity with Real-World Training

The findings indicate that VR functions most effectively as a complementary tool rather than a replacement for real-world mountaineering training. Participants described the VR experience as valuable for mental rehearsal, hazard familiarisation, and cognitive preparation, while recognising that real-world experience remains essential for developing physical endurance, environmental adaptability, and embodied skill.

Experiential Learning Theory (Kolb, 1984) emphasises that learning occurs through the integration of multiple forms of experience. In this context, VR provides simulated concrete experiences that prepare learners for real-world engagement, while actual climbing provides an authentic embodied experience. Together, these complementary forms of experience support a more complete experiential learning cycle.

9.6.4.3 Environmental and Hazard Realism

Environmental realism emerged as a critical factor in supporting meaningful learning and engagement. Participants emphasised the importance of accurate terrain representation, realistic weather dynamics, and authentic hazard simulation in enhancing their sense of presence and situational awareness.

From the perspective of Experiential Learning Theory (Kolb, 1984), realistic simulation enhances the quality of concrete experience, which serves as the foundation for subsequent reflection and conceptual learning. When learners perceive the environment as authentic,

they are more likely to engage cognitively and emotionally with the learning task, facilitating deeper learning.

Activity Theory further highlights the importance of tool fidelity in mediating learning. The VR system serves as a mediating artefact through which learners engage with the object of learning—mountaineering risk management. Higher levels of environmental realism strengthen the effectiveness of this mediation by reducing contradictions between the simulated and real activity systems, thereby enabling learners to internalise safety practices and hazard interpretation strategies more effectively.

9.6.4.4 Interactivity and Emotional Engagement

Interactivity was central to participants' engagement. Decision-making, equipment handling, and problem-solving promoted active learning far more effectively than passive video-based methods. This aligns with immersive learning theory, which stresses the role of emotional arousal in knowledge retention. From a design standpoint, this means incorporating multiplayer decision-making, narrative accident case studies, and interactive branching paths that stimulate empathy, stress, and responsibility—qualities central to real mountaineering safety.

9.6.4.5 Sensory Limitations and Psychological Fidelity

Although the VR intervention achieved high levels of visual immersion and user engagement, the absence of embodied physical stressors—such as altitude-related physiological effects, muscular fatigue, wind resistance, and thermal discomfort—limited the extent to which the simulation could fully replicate real mountaineering conditions. Participants from both Chile and New Zealand noted that while the visual and

environmental elements were highly realistic, the absence of physical strain and physiological consequences diminished the perceived authenticity of the risk exposure. These sensory limitations reflect a broader constraint of current VR technologies, which primarily engage visual and auditory modalities while only partially addressing the embodied and physiological dimensions of high-risk environments.

From the perspective of Experiential Learning Theory (Kolb, 1984), the quality and authenticity of concrete experience play a critical role in supporting meaningful learning. While VR provides valuable experiential engagement, the absence of embodied stressors may limit the depth of experiential realism and the extent to which learners fully internalise the physical and emotional consequences of risk. However, the findings suggest that psychological fidelity—the degree to which a simulation replicates the cognitive and emotional demands of real-world situations—can compensate, to some extent, for these sensory limitations. Participants reported heightened alertness, urgency, and emotional engagement in high-risk scenarios, indicating that the VR environment successfully reproduced key psychological dimensions conducive to effective experiential learning.

Similarly, within Engeström's (1987, 2001) Activity Theory framework, these sensory limitations constitute contradictions between the mediating tool (the VR system) and the object of activity (realistic mountaineering preparation). These contradictions highlight the partial misalignment between simulated and real-world activity systems. Rather than undermining the value of VR, such contradictions provide opportunities for iterative refinement and design improvement, consistent with the principles of expansive learning. Enhancing the sensory and psychological realism of VR environments strengthens the subject–tool–object relationship and supports more effective learning mediation.

To address these limitations, design strategies should prioritise enhancing psychological fidelity and multisensory engagement. Practical approaches may include integrating spatialised soundscapes to simulate environmental hazards, haptic feedback systems to replicate physical interaction and impact, and biometrically driven scenario adaptation to dynamically adjust simulation difficulty based on physiological responses such as heart rate. Where feasible, hybrid simulation environments incorporating complementary physical elements—such as wind generation, temperature variation, or physical movement platforms—may further enhance embodied realism. These design approaches do not seek to fully replicate physical reality, which remains technologically challenging, but rather to strengthen cognitive, emotional, and experiential engagement in ways that support meaningful learning and preparedness.

Ultimately, these findings highlight the importance of prioritising psychological fidelity over purely physical realism in immersive learning design. By effectively replicating the cognitive, emotional, and decision-making demands of high-risk environments, VR can provide meaningful experiential learning opportunities, even without full physiological replication. This reinforces VR's role as a valuable preparatory tool that supports cognitive readiness, risk awareness, and reflective learning in high-risk mountaineering education.

9.6.4.6 Immersion and Usability

Findings from both the Chilean and New Zealand cohorts emphasised that usability is a critical prerequisite for effective immersion and learning in VR environments. Participants reported challenges such as visual blurriness, headset discomfort—particularly for glasses-wearers—and unintuitive menu navigation. These usability barriers disrupted engagement

and shifted learners' attention away from the learning task, reducing the overall effectiveness of the immersive experience.

From the perspective of Experiential Learning Theory (Kolb, 1984), usability directly influences the quality of concrete experience by enabling learners to engage fully with the simulation without distraction. When usability is compromised, cognitive resources are diverted toward managing the technology rather than reflecting on the learning experience. Similarly, within Engeström's (1987, 2001) Activity Theory framework, usability issues represent contradictions between the subject (learner) and the mediating tool (VR system), weakening the tool's effectiveness in supporting learning.

These findings highlight the importance of user-centred design in VR-based education. Design considerations should include intuitive navigation, adjustable visual settings, and multilingual interfaces to improve accessibility. Structured onboarding tutorials, replay functions, and scaffolded guidance can further reduce cognitive load and support effective experiential learning. By prioritising usability, VR systems can enhance immersion, learner engagement, and overall educational impact.

9.6.4.7 Onboarding and User Orientation

The iterative refinement from the Chilean to the New Zealand implementation highlighted the critical importance of structured onboarding processes. The introduction of interactive tutorials and enhanced instructional audio clarity resulted in noticeable improvements in participants' usability, confidence, and overall engagement with the VR system. These findings underscore the necessity of incorporating dedicated orientation phases into the design of immersive learning. Such onboarding should include guided tutorials, clear in-

app instructions, and opportunities for formative feedback, enabling learners to develop familiarity with the interface, controls, and learning objectives before engaging in more complex simulation tasks.

9.6.4.8 Cultural and Regional Localisation

The findings of this study highlight that VR learning environments are not culturally neutral, and their effectiveness is shaped by the cultural, linguistic, and environmental contexts in which they are implemented. Participants from Chile and New Zealand expressed different expectations and needs, reflecting their local mountaineering practices. For example, Chilean participants emphasised the importance of including scenarios beyond snow-based environments to reflect the diverse terrain and conditions characteristic of the Andes, while non-English-speaking participants reported difficulty fully engaging with the system due to the lack of language localisation. These findings demonstrate that cultural and linguistic alignment is essential for ensuring relevance, accessibility, and meaningful learner engagement.

From the perspective of Experiential Learning Theory (Kolb, 1984), experiential learning is most effective when learners can relate simulated experiences to their existing knowledge and real-world contexts. When VR scenarios reflect familiar environments and culturally relevant practices, learners are better able to interpret, reflect upon, and internalise the experience. Conversely, a lack of cultural and contextual alignment may weaken the connection between simulated experience and real-world application, limiting the effectiveness of the experiential learning cycle.

Similarly, Engeström's (1987, 2001) Activity Theory emphasises that learning is mediated by tools within culturally situated activity systems. The VR system functions as a mediating artefact whose effectiveness depends on its alignment with the community, rules, and environmental conditions of the learners' activity system. Cultural and regional misalignment may introduce contradictions between the tool and the learner's activity context, reducing usability, engagement, and perceived relevance. Addressing these contradictions requires intentional localisation, including multilingual interfaces, culturally specific environmental simulations, and collaboration with local mountaineering organisations such as Federación de Andinismo de Chile (FEACH) in Chile and the Mountain Safety Council (MSC) in New Zealand.

These findings underscore the importance of designing immersive learning environments that are culturally responsive and contextually grounded. Effective localisation strengthens the relationship between the learner, the technological tool, and the learning object, thereby enhancing experiential engagement, accessibility, and the overall educational effectiveness of VR-based mountaineering training.

9.6.4.9 Accessibility and Cost-Efficiency

The findings indicate that accessibility and cost-efficiency are critical factors influencing the sustainable adoption and scalability of VR-based mountaineering training. Participants emphasised that while high-fidelity VR systems provided rich immersive experiences, the cost and availability of hardware remained significant barriers, particularly for individual learners and smaller organisations. Mobile-based VR solutions, such as Google Cardboard,

were identified as potential alternatives for expanding access, enabling broader participation while maintaining core experiential learning functions.

From the perspective of Experiential Learning Theory (Kolb, 1984), increasing accessibility allows more learners to engage in concrete experiential learning, supporting the development of hazard awareness and decision-making skills. Similarly, within Engeström's (1987, 2001) Activity Theory framework, accessibility strengthens the alignment between the subject and the mediating tool, enabling more effective engagement within the learning activity system. Barriers such as hardware cost, language limitations, or physical discomfort may create contradictions that restrict participation and reduce learning effectiveness.

To support sustainable implementation, future VR designs should adopt scalable and inclusive approaches. This may include offering lightweight, low-cost versions to enable widespread access, alongside high-fidelity systems for institutional training. Accessibility should also be addressed through adjustable interfaces that accommodate users with corrective eyewear, hearing limitations, or language needs. By prioritising both affordability and inclusivity, VR-based training can support equitable access while maintaining meaningful experiential learning outcomes.

9.6.4.10 Strategic Partnerships for Sustainable Implementation

Finally, the study underscores that successful VR interventions cannot be sustained without systemic support. Strategic partnerships with industry (e.g., outdoor brands), government agencies, tourism organisations, and academic institutions are essential for funding, visibility, and integration into broader safety frameworks. Design, therefore, must consider

not only the user interface but also the adoption ecosystem, embedding VR modules into formal curricula (e.g., tertiary outdoor education) and non-formal learning contexts (e.g., club-based training, tourism safety courses).

In summary, the design principles articulated here move beyond general statements about VR's potential, offering practical, empirically grounded guidance for future applications. They stress the balance between psychological fidelity and physical realism, user-centred design and systemic partnerships, localisation and scalability. Together, they point toward VR not as a stand-alone technology but as a strategically embedded component of blended safety education systems that are contextually adaptable, inclusive, and pedagogically robust.

9.6.5 Institutional and Policy Implications

The findings of this study indicate that Virtual Reality (VR) has strong potential for institutional adoption in both formal and non-formal mountaineering education. However, for VR to move beyond experimental interventions and become a sustainable component of educational practice, systemic institutional support and alignment with broader policy frameworks are essential. At the institutional level, VR should be embedded within structured curricula rather than used as an ad hoc supplement. Universities, polytechnics, and outdoor training organisations could integrate VR modules into foundational courses in mountain safety, risk management, and expedition planning, enabling learners to develop hazard awareness and decision-making skills before field-based training. Such integration is consistent with constructivist and experiential learning principles, which emphasise the importance of authentic, context-rich environments for meaningful learning

(Kolb, 1984; Herrington, Reeves, & Oliver, 2010). VR simulations can serve as preparatory tools that complement field experiences, allowing learners to rehearse cognitive and perceptual skills in safe, controlled environments. Similarly, vocational training providers and professional organisations could incorporate VR into continuing professional development pathways, enabling guides, instructors, and first responders to practise decision-making and situational awareness without exposure to real-world risk. Non-formal education providers, such as mountaineering clubs and federations, may also benefit from VR as an accessible entry point for novice climbers who may lack opportunities to experience hazardous alpine environments directly. To support effective implementation, curriculum developers must align VR content with clearly defined learning outcomes and assessment frameworks to ensure that immersive simulations function as legitimate pedagogical tools rather than optional technological enhancements (Makransky & Petersen, 2019).

The successful integration of VR also depends on educators' confidence, competence, and pedagogical readiness. Institutions must therefore invest in professional development initiatives that support instructors in both the technical and pedagogical use of immersive technologies. This includes training educators to facilitate immersive learning experiences, guide reflective practice, and meaningfully integrate VR into blended learning environments. Educators play a critical mediating role within the learning activity system, shaping how learners interpret and use technological tools (Engeström, 1987, 2001). Without appropriate pedagogical support, the educational value of VR may remain underutilised, regardless of technological sophistication. Establishing communities of practice where educators can share immersive scenarios, teaching strategies, and

evaluation approaches may further support sustainable adoption and pedagogical innovation (Wenger, 1998).

At a broader systemic level, policy-makers play an important role in enabling the adoption and sustainability of immersive learning technologies. The inclusion of VR-based safety modules within national outdoor education frameworks and training standards could legitimise immersive learning as a recognised component of safety education. Funding mechanisms, including grants and institutional innovation funds, may support the acquisition of VR hardware, content development, and longitudinal evaluation of learning outcomes. Cross-sector collaboration between academic institutions, mountaineering federations, safety organisations, and industry partners can further support the co-design and dissemination of VR content grounded in real-world practice. Such collaborative approaches align with Design-Based Research principles, which emphasise the importance of partnerships between researchers and practitioners in developing contextually relevant educational innovations (McKenney & Reeves, 2019).

The credibility and long-term sustainability of VR as an educational tool also depend on establishing quality standards and accreditation pathways. Accrediting bodies and professional organisations may develop guidelines to ensure that VR simulations achieve appropriate levels of psychological fidelity, usability, and cultural relevance. Psychological fidelity, defined as the extent to which simulations replicate the cognitive and emotional demands of real-world situations, is particularly important in high-risk domains where decision-making and situational awareness are critical (Gaba, 2004; Slater & Sanchez-Vives, 2016). Aligning VR training with recognised competency frameworks may further enhance its legitimacy and educational value.

Equity and access represent additional considerations for institutional and policy implementation. The cost of VR hardware and content development may create barriers for smaller organisations and under-resourced communities. Strategies such as shared equipment hubs, scalable content platforms, and low-cost mobile-based immersive solutions may help mitigate these disparities and support wider participation. Inclusive design principles, including multilingual interfaces and accessible user interfaces, are essential to ensure that immersive learning technologies support diverse learner populations (Radianti et al., 2020).

Finally, institutions and policy-makers must approach VR as part of a sustainable learning ecosystem rather than a one-time technological intervention. This requires ongoing evaluation, iterative refinement of learning content, and integration with evolving safety practices. Design-Based Research provides a methodological framework for such iterative development, enabling continuous improvement through cycles of implementation, evaluation, and redesign (Reeves, 2006; McKenney & Reeves, 2019). In this sense, the institutional and policy implications of this research extend beyond technological adoption, pointing toward a broader transformation in safety education. VR represents not merely a technological innovation but a pedagogical and systemic shift toward immersive, experiential, and contextually grounded learning, supported by institutional commitment, educator capacity, and policy alignment.

9.7 Research Implications

This study highlights the need for more rigorous, longitudinal, and comparative investigations into the role of virtual reality (VR) in high-risk education, particularly within

mountaineering and outdoor safety contexts. While participants in both Chile and New Zealand reported perceived improvements in vigilance, reflective thinking, and decision-making following the VR intervention, these findings were derived primarily from post-intervention interviews and subjective reflections rather than systematically validated behavioural outcomes. This limitation reflects a broader trend in immersive learning research, where studies often prioritise learner perceptions and engagement over objective measures of behavioural transfer and long-term learning outcomes (Makransky & Petersen, 2019; Radianti et al., 2020). Although such perceptual data are valuable for understanding learner experience and acceptance, they do not fully establish whether immersive simulations lead to durable changes in real-world behaviour, particularly in complex, high-risk environments where cognitive, emotional, and environmental factors interact dynamically.

One of the most important implications of this research is the need for longitudinal studies that examine the persistence and transferability of learning outcomes over extended periods. Experiential learning theory emphasises that meaningful learning involves the integration of experience, reflection, and application over time, rather than as an immediate or isolated event (Kolb, 1984). While participants in this study reported increased awareness of hazards and improved reflective thinking following the VR intervention, it remains unclear whether these cognitive and perceptual shifts are sustained and transferred into real mountaineering practice. Longitudinal research designs that track participants across months or years, including subsequent expeditions and training experiences, would provide stronger evidence regarding the durability of VR-based learning and its influence on real-world safety behaviour. Such approaches would also align with research on transfer of

learning, which highlights the importance of repeated exposure, contextual relevance, and reinforcement in supporting behavioural change (Perkins & Salomon, 1992).

In addition to longitudinal research, there is a clear need for controlled comparative studies that examine differences between VR-trained and non-VR-trained learners under comparable conditions. Experimental or quasi-experimental designs would allow researchers to isolate the effects of immersive learning interventions and assess their impact on hazard recognition, situational awareness, stress regulation, and decision-making performance. The inclusion of objective physiological and behavioural measures, such as heart rate variability, galvanic skin response, eye-tracking, and performance-based assessments, would provide more robust evidence of learning and cognitive engagement. Such multimodal approaches are increasingly recognised as valuable methods for examining immersive learning processes, as they enable researchers to move beyond self-reported perceptions and capture embodied and affective dimensions of learning (Slater & Sanchez-Vives, 2016; Gaba, 2004). Integrating physiological and behavioural data with qualitative insights would strengthen the empirical foundation of VR research and provide clearer evidence regarding its effectiveness as a safety training tool.

This research also highlights the importance of examining cultural and contextual factors that influence the design, adoption, and effectiveness of immersive learning interventions. Participants in Chile and New Zealand emphasised different environmental, institutional, and cultural considerations, reflecting the situated nature of learning and the importance of contextual relevance. Activity Theory provides a useful framework for understanding how technological tools such as VR are embedded within broader socio-cultural activity systems shaped by community practices, institutional structures, and cultural norms

(Engeström, 1987, 2001). Extending research into additional mountaineering contexts, such as the Himalayas, the European Alps, and North America, would provide valuable insights into how immersive learning interventions can be adapted to diverse environmental conditions and cultural traditions. Cross-cultural comparative studies would contribute not only to practical design improvements but also to theoretical understanding of how immersive technologies function within different learning ecologies.

Finally, future research should explore how VR can be systematically integrated into blended learning models that combine immersive simulation with real-world experiential training. While this study demonstrates that VR can support cognitive rehearsal, situational awareness, and reflective learning, it also confirms that immersive simulations cannot fully replicate the physiological demands of mountaineering, such as cold exposure, fatigue, and altitude effects. Rather than replacing traditional field-based training, VR is best understood as a complementary pedagogical tool that enhances preparation, reflection, and experiential learning. Authentic learning theory emphasises the importance of contextualised, meaningful learning experiences that connect simulated and real-world environments (Herrington et al., 2010). Research examining different sequencing models—such as VR preparation prior to field expeditions, or VR-based reflection following real-world experience—could clarify how immersive learning supports skill development, cognitive preparedness, and safety awareness. Such hybrid models may offer particularly effective approaches for supporting experiential learning in high-risk domains.

Overall, these research implications point toward the need for more comprehensive, interdisciplinary, and longitudinal approaches to studying immersive learning in high-risk environments. By integrating longitudinal evaluation, controlled comparative designs,

cross-cultural analysis, and blended learning frameworks, future research can provide stronger empirical evidence and theoretical insight into the role of VR in safety education. Such work will contribute to advancing immersive learning theory, informing educational design practices, and supporting the development of effective training approaches that enhance learning, decision-making, and safety in mountaineering and other high-risk contexts.

9.8 Technological Implications

The findings of this study highlight both the significant promise and the current limitations of virtual reality (VR) technologies in simulating the complex realities of mountaineering environments. While the VR system successfully achieved a high level of visual and auditory fidelity, enabling participants to engage with immersive representations of alpine terrain and hazards, it was unable to replicate key physiological stressors such as cold exposure, altitude-associated hypoxia, and physical fatigue. This limitation reflects a broader challenge in immersive simulation research, where technological fidelity is often constrained by the difficulty of reproducing embodied, multisensory, and physiological experiences that are central to real-world learning in high-risk environments (Slater & Sanchez-Vives, 2016; Gaba, 2004). Psychological fidelity—the extent to which a simulation replicates the cognitive and emotional demands of real-world situations—has been shown to be more critical for learning transfer than purely physical realism, yet physiological realism remains an important frontier for advancing immersive training technologies (Makransky & Petersen, 2019). Future technological developments may therefore benefit from hybrid approaches that combine immersive VR environments with physical augmentation systems, such as environmental simulation chambers, wind-

generation devices, and haptic feedback technologies, to enhance embodied realism and strengthen experiential learning.

In addition to physiological limitations, the study identified several usability challenges related to hardware accessibility and user comfort. Participants reported issues with headset fit, visual clarity—particularly among glasses wearers—and occasional inconsistencies in biometric synchronisation during data collection. These findings align with previous research demonstrating that usability, ergonomics, and accessibility are critical determinants of the effectiveness of immersive learning and user acceptance (Radianti et al., 2020). Poor hardware usability can introduce cognitive load and reduce learner engagement, thereby limiting the educational value of immersive experiences (Makransky, Terkildsen, & Mayer, 2019). Addressing these limitations requires improvements in headset design, including adjustable optical systems, enhanced calibration tools, and more inclusive user interfaces that accommodate diverse learners. Multilingual interfaces and culturally localised content may further support accessibility and broaden the applicability of immersive learning technologies across diverse populations and global contexts.

The integration of artificial intelligence (AI) represents a particularly promising technological direction for enhancing the adaptability, scalability, and pedagogical effectiveness of VR-based mountaineering education. AI-driven systems have the potential to create adaptive learning environments that dynamically respond to learner behaviour, performance, and physiological responses in real time. For example, AI algorithms could monitor learner actions and biometric indicators to adjust scenario difficulty, introduce new hazards, or provide targeted feedback, thereby supporting personalised learning pathways. Holmes, Bialik, and Fadel (2019) posit that adaptive technologies foster deeper

engagement by individualising the learning journey according to a participant's current proficiency. By shifting away from a "one-size-fits-all" model, these tools facilitate more robust knowledge of retention and skill development. This capacity for automated tailoring allows the educational content to remain challenging yet accessible, optimising the learner's path toward expertise in complex domains. AI may also enable automated analysis of behavioural and biometric data to generate personalised feedback and reflective prompts, extending the pedagogical value of immersive learning beyond the simulation itself. Such capabilities align with experiential learning theory, which emphasises the importance of reflection and feedback in supporting learning and behavioural change (Kolb, 1984).

Furthermore, AI technologies have the potential to generate dynamic, unpredictable simulation scenarios that more closely reflect the variability and uncertainty of real mountaineering environments. Unlike static, pre-designed scenarios, AI-driven simulations can generate diverse environmental conditions, hazard events, and decision-making challenges, thereby preventing learners from relying on memorisation and promoting deeper cognitive engagement. This capacity for dynamic scenario generation supports the development of adaptive expertise, which is critical in high-risk environments where conditions are constantly changing (Ericsson, 2006). AI-based analysis of behavioural and physiological patterns may also contribute to predictive modelling of learner stress responses, cognitive load, and risk perception, providing insights that can inform instructional design and targeted interventions.

However, the integration of AI and biometric monitoring technologies within immersive learning environments also raises important ethical and pedagogical considerations. The collection and analysis of biometric and behavioural data require careful attention to issues

of data privacy, informed consent, and transparency. According to Williamson and Eynon (2020), the deployment of advanced learning tools requires a robust commitment to data integrity and "learner autonomy." This involves not only securing the technical infrastructure but also actively auditing the algorithms for hidden biases that could disadvantage certain participants. In a high-stakes training context, such as mountaineering, ensuring that the software treats every user fairly is not just a technical requirement but a core pedagogical obligation. In addition, while AI has the potential to enhance feedback and personalisation, it should complement rather than replace the role of human instructors. Social interaction, mentorship, and guided reflection are central components of experiential learning and cannot be fully replicated through automated systems alone (Vygotsky, 1978; Wenger, 1998). Human instructors play a critical role in contextualising learning experiences, facilitating reflection, and supporting the social dimensions of learning within mountaineering communities.

Overall, the technological implications of this research suggest that VR should be understood not as a static tool but as part of an evolving technological ecosystem integrating immersive simulation, adaptive artificial intelligence, biometric feedback, and user-centred design. Advances in hardware usability, physiological simulation, and AI-driven adaptation have the potential to significantly enhance the realism, accessibility, and educational effectiveness of immersive learning environments. At the same time, technological innovation must be accompanied by careful consideration of ethical, pedagogical, and human factors to ensure that immersive learning technologies support meaningful, equitable, and contextually grounded educational experiences. Continued interdisciplinary collaboration between educational researchers, technologists, and domain

experts will be essential for advancing VR as a sustainable and effective tool for safety education in high-risk environments.

9.9 Recommendations for Future Research

Based on the empirical findings, thematic analysis, and identified technological, pedagogical, and contextual implications of this study, several recommendations are proposed to guide the future design, implementation, and evaluation of virtual reality (VR) training for mountaineering safety and other high-risk educational domains. These recommendations are grounded in Design-Based Research (DBR) and Activity Theory (AT), which emphasise the importance of iterative development, socio-cultural context, and the role of technological tools as mediators of learning (Engeström, 1987, 2001; McKenney & Reeves, 2019). Collectively, these recommendations aim to ensure that VR training systems are pedagogically meaningful, culturally relevant, technologically accessible, and sustainable over time.

9.9.1 Adopt Participatory and Iterative Design Approaches

Future VR development should adopt participatory and co-design methodologies that actively involve climbers, instructors, safety organisations, and institutional stakeholders throughout the design and development process. Rather than being designed solely by researchers or software developers, VR learning environments should be co-created with end users who possess direct experience of mountaineering and safety training. This participatory approach enhances ecological validity by ensuring that VR scenarios reflect authentic hazards, realistic decision-making challenges, and culturally grounded practices.

From an Activity Theory perspective, learning technologies function as mediating artefacts within activity systems shaped by interactions between subjects, tools, community, and institutional rules (Engeström, 1987). When stakeholders are actively involved in design, VR systems are more effectively integrated into existing training practices and are more likely to be accepted by learners and instructors. Design-Based Research further emphasises iterative cycles of design, implementation, and evaluation, allowing technologies to evolve in response to user feedback and contextual needs (McKenney & Reeves, 2019; Reeves, 2006). Future VR development should therefore incorporate structured needs analysis, pilot testing, and iterative refinement to ensure alignment with real-world mountaineering training requirements.

9.9.2 Localise VR Training to Cultural, Environmental, and Linguistic Contexts

VR training should be culturally and environmentally localised to reflect the specific contexts in which mountaineering education occurs. This study demonstrated clear differences between Chilean and New Zealand participants in terms of environmental hazards, training traditions, and linguistic needs. Cultural localisation enhances learner engagement, perceived realism, and trust, which are essential for supporting meaningful learning and behavioural transfer (Gay, 2018).

Activity Theory highlights the importance of multivoicedness, recognising that learning tools must reflect diverse cultural perspectives and community practices (Engeström, 1987). For VR to function effectively as a mediating artefact, it must align with the social and cultural structures of the learning community. This includes incorporating region-specific terrain, environmental hazards, and culturally relevant safety practices. Providing

multilingual interfaces, culturally appropriate content, and alignment with national training frameworks can improve accessibility and adoption across diverse mountaineering communities.

9.9.3 Prioritise Usability, Immersion, and Structured Learner Support

Usability and accessibility should be prioritised to ensure that VR systems support effective learning without introducing unnecessary cognitive barriers. Poor interface design, visual discomfort, or complex navigation can increase extraneous cognitive load, reducing learners' ability to focus on safety decision-making (Mayer, 2009). Developers should implement intuitive controls, ergonomic headset design, and structured onboarding processes to support learner confidence and usability.

Immersion and presence are also critical for supporting experiential learning. Immersive environments enable learners to engage cognitively and emotionally with simulated hazards, improving hazard recognition and situational awareness (Slater & Sanchez-Vives, 2016). These immersive experiences align with Kolb's (1984) experiential learning cycle, allowing learners to engage in concrete experience, reflection, conceptualisation, and experimentation. Structured pre-training orientation and scaffolded learning experiences can further enhance learning effectiveness by reducing cognitive load and supporting gradual skill development.

9.9.4 Integrate VR into Blended Learning and Institutional Training Systems

VR should be integrated into formal and informal mountaineering education systems as part of blended learning models that combine immersive simulation with field-based training. VR provides opportunities for cognitive rehearsal and experiential learning in safe

environments, while field-based training provides embodied physical experience and environmental exposure. Blended learning approaches enhance learning outcomes by integrating digital and experiential learning modalities (Garrison & Vaughan, 2008).

From an Activity Theory perspective, integrating VR into institutional training systems strengthens alignment between technological tools, institutional rules, and community practices (Engeström, 2001). Universities, mountaineering federations, and safety organisations should incorporate VR into curricula, certification programmes, and safety training frameworks. Institutional partnerships can support the scalability, legitimacy, and long-term sustainability of VR-based safety education.

9.9.5 Conduct Longitudinal and Performance-Based Evaluation

Future research should prioritise longitudinal evaluation to assess the long-term impact of VR training on mountaineering safety behaviour. While this study demonstrated improvements in perceived awareness and decision-making, longitudinal studies are needed to determine whether these improvements translate into sustained behavioural change and real-world safety outcomes.

Transfer of learning research emphasises the importance of evaluating whether knowledge acquired in simulated environments is applied in real-world contexts (Perkins & Salomon, 1992). Design-Based Research methodologies support longitudinal evaluation by enabling continuous refinement based on empirical evidence and learner feedback (McKenney & Reeves, 2019). Future studies should combine qualitative feedback with objective performance measures, such as behavioural observation, decision-making accuracy, and biometric indicators, to provide stronger evidence of VR's effectiveness.

9.9.6 Develop Scalable, Accessible, and Sustainable VR Systems

Scalability and accessibility are essential for ensuring that VR training can be widely adopted across diverse educational and institutional contexts. Modular VR architectures allow training content to be adapted to different learner levels and institutional resources. Supporting multiple hardware platforms, including mobile VR systems, can reduce financial barriers and improve accessibility.

Research has emphasised the importance of scalable immersive learning technologies to support widespread adoption and educational equity (Radianti et al., 2020). Inclusive design features, such as multilingual support, adjustable interfaces, and accessibility options, can further enhance participation. Institutional partnerships and funding support can help ensure long-term sustainability and broader implementation.

9.9.7 Extend VR Training to Other High-Risk Educational Domains

The design principles and methodological approaches developed in this research have broader applicability beyond mountaineering safety. Immersive simulation has demonstrated significant effectiveness in high-risk domains such as healthcare, aviation, and emergency response, where experiential learning and decision-making under pressure are critical (Gaba, 2004; Ericsson, 2006).

Applying VR training approaches to avalanche safety, wilderness medicine, maritime safety, and disaster response can improve safety preparedness across multiple sectors. Comparative research across different high-risk domains can further refine immersive learning design principles and support the development of transferable training frameworks.

9.9.8 Summary

Overall, these recommendations emphasise that the effective implementation of VR in mountaineering safety education requires alignment between technological innovation, pedagogical principles, and socio-cultural context. VR should be understood as a mediating artefact within a broader learning activity system, where its impact depends on how it is integrated with learners, instructors, institutional frameworks, and existing training practices (Engeström, 1987, 2001). When designed through participatory and iterative processes, VR can provide immersive environments that support hazard recognition, situational awareness, and decision-making in ways that complement traditional field-based training.

From a Design-Based Research perspective, iterative development and ongoing evaluation are essential to ensure that VR systems remain responsive to learner needs and real-world training requirements (McKenney & Reeves, 2019). Integrating VR within blended learning models allows learners to engage in cognitive rehearsal and reflective learning before applying their knowledge in real-world environments, consistent with experiential learning theory (Kolb, 1984). Cultural localisation, usability, and accessibility further enhance learner engagement and ensure that VR training remains relevant and inclusive.

Longitudinal evaluation is also necessary to determine whether VR training leads to sustained behavioural change and improved safety outcomes. Transfer of learning research highlights the importance of assessing how skills developed in simulated environments are applied in real-world contexts (Perkins & Salomon, 1992). With appropriate design, evaluation, and institutional integration, VR has the potential to become a valuable and

sustainable tool for mountaineering safety education. More broadly, the design principles developed in this study may also be applied to other high-risk domains, supporting experiential learning and improving safety training across diverse educational and professional contexts.

9.10 Overall Conclusion

This thesis set out to investigate the potential of virtual reality (VR) technologies to support mountain safety education and training within high-risk alpine environments. Through a design-based research approach, the study explored how immersive simulations could be used to enhance learners' understanding of environmental hazards, improve decision-making processes, and strengthen preparedness for real-world mountaineering conditions. Drawing on qualitative feedback from participants in Chile and New Zealand, together with biometric indicators of physiological engagement, the research examined both the pedagogical value and the practical limitations of VR-assisted safety training.

The findings indicate that immersive VR environments can provide a meaningful platform for experiential learning in contexts where direct exposure to risk may be impractical or dangerous. Participants reported that simulated scenarios involving weather conditions and altitude-related hazards contributed to stronger situational awareness and deeper emotional engagement with safety concepts. These responses suggest that immersive technologies can support the development of cognitive and affective dimensions of learning that are critical for effective risk management in mountaineering. At the same time, the study highlights that VR cannot fully replicate the physical stressors of alpine environments, such as extreme cold, fatigue, or altitude-related physiological effects. As a result, VR should

be understood not as a replacement for real-world training, but as a complementary learning tool that can enhance traditional outdoor instruction.

The research also demonstrates the importance of instructional design in determining the educational effectiveness of immersive simulations. The design-based research process enabled iterative refinement of the VR training prototype through user feedback and empirical evaluation, resulting in a set of practical design principles for VR-supported mountain safety education. These principles emphasise the importance of contextual realism, progressive exposure to risk scenarios, opportunities for reflection, and alignment with experiential learning processes. In addition, the application of Engeström's Activity Theory provided a useful analytical framework for examining the tensions and contradictions that emerged between learners, technological tools, instructional practices, and environmental contexts. Understanding these systemic dynamics helps explain how immersive technologies can be effectively integrated into broader learning ecosystems.

A further contribution of the study lies in its cross-contextual comparison between mountaineering communities in Chile and New Zealand. While both groups recognised the value of immersive training for developing situational awareness and decision-making skills, differences in cultural practices, environmental conditions, and instructional traditions influenced how VR training was perceived and applied. These findings highlight the importance of designing immersive training systems that are sensitive to local contexts, rather than assuming a universal model of safety education.

Overall, this research demonstrates that VR technologies have significant potential to support mountain safety training when implemented as part of a blended learning approach

that combines immersive simulations with traditional field-based instruction. By enabling learners to encounter hazardous scenarios in a controlled environment, VR can provide valuable opportunities for preparation, reflection, and skill development before engaging in real-world alpine activities. As immersive technologies continue to evolve, their integration into outdoor education programmes may play an increasingly important role in improving safety awareness and decision-making among climbers.

In conclusion, this thesis contributes to the growing field of immersive learning by demonstrating how VR-based training can be designed and applied within the context of mountain safety education. The findings offer both theoretical insights and practical guidance for researchers, educators, and training organisations seeking to harness immersive technologies to support learning in high-risk environments. Ultimately, by bridging immersive simulation with experiential outdoor learning, this research suggests that thoughtfully designed virtual environments can contribute to safer and more effective preparation for the complex challenges of high-altitude mountaineering.

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Appendix A: Ethics Approval-AUTEC

Auckland University of Technology Ethics Committee (AUTEC)

EA1

APPLICATION FOR ETHICS APPROVAL BY AUTEC

Please print this application single sided in greyscale and do not staple. Once this application has been completed and signed, please read the notes at the end of the form for information about submission of the application for review.

NOTES ABOUT COMPLETION

- Ethics review is a community review of the ethical aspects of a research proposal. Responses should use clear everyday language with appropriate definitions being provided should the use of technical or academic jargon be necessary.
- The AUTEC Secretariat and your AUTEC Faculty Representative are able to provide you with assistance and guidance with the completion of this application which may help expedite the granting of ethics approval.
- The information in this application needs to be clearly stated and to contain sufficient details to enable AUTEC to make an informed decision about the ethical quality of the research. Responses that do not provide sufficient information may delay approval because further information will be sought. Overly long responses may also delay approval when unnecessary information hinders clarity.
- AUTEC reserves the right not to consider applications that are incomplete or inadequate. Please do not alter the formatting or numbering of the form in any way or remove any of the help text.
- Comprehensive information about ethics approval and what may be required is available online at http://aut.ac.nz/researchethics
- The information provided in this application will be used for the purposes of granting ethics approval. It may also be provided to the Graduate Research School, the Research and Innovation Office, or the University's insurers for purposes relating to AUT's interests.
- The Form is focussed around AUTEC's ethical principles, which are in accordance with the *Guidelines for the approval of ethics committees* in New Zealand.

To respond to a question, please place your cursor in the space following the question and its notes and begin typing.

A. *Project Information*

1. What is the title of the research?

If you will be using a different title in documents to that being used as your working title, please provide both, clearly indicating which title will be used for what purpose.

Developing a critical Design-Based Research Methodology that Utilises Virtual Reality (VR) Technologies to Enhance Education for Authentic High-Risk (or Extreme) Situations.

2. Is this application for research that is being undertaken in stages? ☒ Yes ☐ No

If the answer is 'Yes' please answer A.2.1 and the following sections, otherwise please answer A.3 and continue from there.

1. Does this application cover all the stages of the research? ☐ Yes ☒ No

If the answer is 'No' please provide details here of which stages are being covered by this application, otherwise please answer A.3 and continue from there.

This study includes 4 stages – 1, 2, 3 and 4. This application is for the first stage. The first stage involves following elements.

1. **Analysis & Exploration:** I will focus on a detailed review of the literature in relation to identifying design principles for education of mountain safety and risk factors in high altitude mountain ranges, and the principles of VR/MR design, and learning and other theories. I will also conduct initial feasibility interviews with expert climbers from climbing communities in New Zealand and overseas. Using this work, initial design principles will be developed.
2. **Design & Construction:** It will involve designing and building the prototype app based on input from phase 1. This process includes shooting 360 degree videos in the mountains in the South Island, including footage of crevasses, avalanches and different weather conditions in the mountains to help develop the prototype app.
3. **Evaluation and Reflection:** It will be focused on producing and evaluating a prototype MR learning app with key participants. Amendments with full information for the following stages will be provided once it is known.

3. Who is the applicant?

When the research is part of the requirements for a qualification at AUT, then the applicant is always the primary supervisor. Otherwise, the applicant is the researcher primarily responsible for the research, to whom all enquiries and correspondence relating to this application will be addressed.

Dr Claudio Aguayo.

4. Further information about the applicant.

1. In which faculty, directorate, or research centre is the applicant located?

Te Ara Poutama, Faculty of Māori and indigenous Development.

2. What are the applicant's qualifications?

Ph.D.

3. What is the applicant's email address?

An email address at which the applicant can be contacted is essential.

claudio.aguayo@aut.ac.nz

4. At which telephone numbers can the applicant be contacted during the day?

Office: 09-921 9666 ext. 5253

Mobile: 021 02495862

5. Research Instruments

1. Which of the following does the research use:

☒ a written or electronic questionnaire or survey ***☒ focus groups*** ***☒ interviews***

☐ observation ***☒ participant observation*** ***☐ ethnography*** ***☐ photographs***

☒ videos ***☐ other visual recordings*** ***☐ a creative, artistic, or design process***

☐ performance tests

☒ some other research instrument (please specify)

A virtual reality (VR) software application (i.e. an 'app'); and a biometric (heart rate) data collection instrument.

Please attach to this application form all the relevant research protocols. These may include: Indicative questions (for interviews or focus groups); a copy of the finalised questionnaire or survey in the format that it will be presented to participants (for a written or electronic questionnaire or survey); a protocol indicating how the data will be recorded (e.g note-taking and video recording) for focus groups or interviews. The researcher will set a video camera on a tripod to record the interview for video recording. After the researcher tells the participant, the researcher starts recording and ends recording after the interview. The equipment will be set safely and operated by the researcher's assistance. Please note that there are specific confidentiality issues associated with focus groups that need to be addressed; a copy of the observation protocol that will be used (for observations); full information about appropriate protocols and consent processes; protocols for any creative, artistic, or design process; a copy of the protocols for the instruments and the instruments that will be used to record results if you will use some other research instrument.

2. Who will be transcribing or recording the data?

If someone other than the applicant or primary researcher will be transcribing the interview or focus group records or taking the notes, you will need to provide a confidentiality agreement with this Application Form.

The primary researcher – Ki Myung (Jin) Hong.

6. Please provide a brief plain English summary of the research (300 words maximum).

Please provide a simple response to each of these three questions: What are you trying to find out? Who are you wanting to involve? and What would you like them to do for you?

While mountaineers are generally wary of the risk factors in the mountains, there are still fatal accidents happening every year. As a mountaineer, I have encountered several accidents in the mountains myself and I have heard of many unfortunate incidents in the climbing communities. This research will explore ways of enhancing the education of mountain climbers of the very real risks of high-altitude mountain climbing. While the focus is on high-risk mountain climbing, the goal is to extend findings to other high-risk educational areas such as firefighting and policing. The project will utilise learning theory, design-based research (DBR) methodologies along with virtual reality (VR) and mixed reality (MR) technologies to enhance learning in preparation for engagement in high-risk environments. Using a design-based research methodology, I intend to explore and design a learning app that uses these MR and VR technologies to re-create and virtually simulate high altitude environments, therefore, enabling mountaineers to experience and troubleshoot risky obstacles such as altitude sickness, endless crevasses, ice cliffs and frostbites within a safe yet authentically simulated environment. These new technologies enable the mountaineers to learn themselves using the app as a form of technology enhanced self-determined learning tool. This research is informed by the literature and analysis of initially identified design principles for designing MR technologies for mountain safety. The research will draw upon literature applying new pedagogies for non-formal learning, including heutagogy or self-determined learning.

7. Additional Research Information

1. Is this research an intervention study? ☐ Yes ☒ No

An Intervention Study is defined in NEAC's National Ethical Standards for Health and Disability Research and Quality Improvement. as "A study in which an investigator controls and studies an intervention(s) provided to participants for the purpose of adding to knowledge of the health effects of that intervention(s). The term 'intervention study' is often used interchangeably with 'experimental study'. Many intervention studies are clinical trials." (p.247)

2. Is this Health and Disability Research? ☐ Yes ☒ No

Broadly speaking, health and disability research should:

- ***aim to answer a question or solve a problem and therefore generate new knowledge to prevent, identify and treat illness and disease***
- ***have the ultimate purpose of maintaining and improving people's health – in the sense of a state of physical, mental and spiritual wellbeing, rather than simply the absence of disease or infirmity***
- ***support disabled people to be included, participate more, exercise choice and control, and be more independent***
- ***address health and disability disparities***
- ***contribute to whānau ora.***

This description is necessarily broad; we acknowledge that people's health is influenced by a much wider range of social factors than their health care. (NEAC's National Ethical Standards for Health and Disability Research and Quality Improvement. p.28)

3. Does this research involve people in their capacity as consumers of health or disability support services, or in their capacity as relatives or caregivers of consumers of health or disability support services, or as volunteers in clinical trials (including, for the avoidance of doubt, bioequivalence and bioavailability studies)?

☐ Yes ☒ No

B. *The Ethical Principle of Research Adequacy*

AUTEC recognises that different research paradigms may inform the conception and design of projects. It adopts the following minimal criteria of adequacy: the project must have clear research goals; its design must make it possible to meet those goals; and the project should not be trivial but should potentially contribute to the advancement of knowledge to an extent that warrants any cost or risk to participants.

1. Is the applicant the person doing most of the research (the primary researcher)? ☐ Yes ☒ No

If the answer is 'No' please answer B.1.1 and the following sections, otherwise please answer B.2 and continue from there.

1. What is the name of the primary researcher if it is someone other than the applicant?

Ki Myung (Jin) Hong

2. What are the primary researcher's completed qualifications?

Master in Communication Studies

3. What is the primary researcher's email address?

An email address at which the primary researcher can be contacted is essential.

jin.hong@aut.ac.nz

4. At which telephone numbers can the primary researcher be contacted during the day?

021 715 889

2. Is the primary researcher

☒ *an AUT staff member* ☒ *an AUT student*

If the primary researcher is an AUT staff member, please answer B.2.1 and the following sections, otherwise please answer B.3 and continue from there.

1. In which faculty, directorate, or research centre is the primary researcher employed?

If the response to this section is the same as that already given to section A.4.1 above, please skip this section and go to section B.2.2.

N/A

2. In which school or department is the primary researcher employed?

altLAB, AUT leaning Transformation LAB, Office of the Pro Vice Chancellor Learning & Teaching.

3. When the primary researcher is a student:

1. What is their Student ID Number?

0006660

2. In which faculty are they enrolled?

Faculty of Māori and indigenous Development

3. In which school, department, or Research Centre are they enrolled?

Te Ara Poutama

4. What is the primary researcher's experience or expertise in this area of research?

Where the primary researcher is a student at AUT, please identify the applicant's experience or expertise in this area of research as well.

As a digital media team leader of altLAB (AUT leaning Transformation LAB), the primary researcher has had experience exploring and designing new media technologies such as augmented reality (AR), virtual reality (VR) and mixed reality (MR), which places him well for undertaking this research. He also has access to the resources that he will need for the research project. And also, he is a mountaineer/climber and has extensive experience in technical mountain climbing.

5. Who is in charge of data collection?

The primary researcher – Ki Myung (Jin) Hong

6. Who will interact with the participants?

The primary researcher – Ki Myung (Jin) Hong

7. Is this research being undertaken as part of a qualification? ☒ Yes ☐ No

If the answer is 'Yes' please answer B.7.1 and the following sections, otherwise please answer B.8 and continue from there.

1. What is the name of the qualification?

Ph.D

2. In which institution will the qualification be undertaken?

Auckland University of Technology

8. Details of Other Researchers or Investigators

1. Will any other people be involved as researchers, co- investigators, or supervisors? ☒ Yes ☐ No

If the answer is 'Yes' please answer B.8.1.1 and the following sections, otherwise please answer B.8.2 and continue from there.

1. What are the names of any other people involved as researchers, investigators, or supervisors?

Associate Professor Thomas Cochrane and Dr Andrew Withell

2. Where do they work?

The University of Melbourne and Auckland University of Technology, respectively.

3. What will their roles be in the research?

The research supervisors

4. What are their completed qualifications?

Ph.D

2. Will any research organisation or other organisation be involved in the research? ☐ Yes ☒ No

If the answer is 'Yes' please answer B.8.2.1 and the following sections, otherwise please answer B.9 and continue from there.

1. What are the names of the organisations?

Click here to enter text.

2. Where are they located?

Click here to enter text.

3. What will their roles be in the research?

Click here to enter text.

9. Why are you doing this research and what is its aim and background?

Please provide the key outcomes or research questions and an academic rationale with sufficient information, including relevant references, to place the project in perspective and to allow the project's significance to be assessed.

Research Question: How can a design-based research methodology that utilises mixed reality (MR) technologies be utilized to effectively enhance learning for authentic, high-risk situations?

As a mountaineer, I have encountered several accidents in the mountains myself and I have heard of many unfortunate incidents in the climbing communities. CNN reported on 24 May 2016 that avalanches killed 35 climbers on Mount Everest the past two years including 16 in one devastating day in 2014. At least one person has died climbing the mountain in Nepal every year since 1900. "Everest is a mountain of extremes", said Jon Kedrowski, a geographer, and climber who summited Mount Everest in 2012, when 10 climbers died. At altitude, the body can deteriorate quickly. While mountaineers are generally wary of the risk factors in the mountains, there are still fatal accidents happening every year. In addition,

even though most mountain climbers have a great range of general experiences, they often lack specialist knowledge of fast evolving high-altitude problems and situations, which can quickly put them into critical danger. Given the situation, it is vital to develop effective new learning strategies for high- risk environments such as mountaineering. Emergent technologies, such as augmented reality (AR) and mixed reality (MR), along with contemporary learning theories, provide the platform for the design of these new and innovative learning strategies.

Vertual-reality (VR) is a live direct or indirect view of a physical, real-world environment whose elements are augmented (or supplemented) by computer-generated sensory input such as sound, video, graphics or GPS data. Mixed-reality (MR), is the merging of real and virtual worlds to produce new environments and visualisations where physical and digital objects co-exist and interact in real time. Mixed reality are technologies that layer computer-generated enhancements atop an existing reality in order to make it more meaningful through the ability to interact with it through digital means. The key term for VR and MR, is flexibility. It is flexible and can be portable compared to the three-dimensional real physical world and provides a low-risk environment in which to explore high-risk real-world environments. Dunser and Kaufmann (2006) in their article *"Virtual and Augmented Reality as spatial ability training tools"* mentioned that researchers can create environments in which users can act without being exposed to certain dangers that potentially occur in real environments. According to them, "using VR enables researchers to create exactly the same stimulus conditions for all participants or to vary certain environment variables in real-time and thus gives researchers more control over experimental settings" (p. 126). Some people might argue that people can learn effectively from textbooks, however, I believe that VR and MR technologies' strengths are interactivity and flexibility and the ability to simulate real-world environments in a more authentic manner. Some museums use these technologies to enable visitors to use their own mobile devices as an interactive tool through which areas around them receive enhanced layers of information. Visitors discover historical events by exploring various additional content in connection to objects. Another example, VR books provide a deeper understanding of complex subjects. Textbooks don't motivate the student to study science but if teachers use books that include VR content such as 3D models with animations, sound and interaction attract student attention. Vygotsky (1978) insists that the learners can learn beyond the limits of what they can on their own when aided by a more experienced peer within the Zone Of Proximal Development. The role of an educational app could be a virtual more experienced peer, in this case. The app will enable mountaineers to be well prepared about key risk factors before their actual climbing journey, through the use of authentic simulation using VR and MR affordances (i.e. learning possibilities offered by technology).

Along with VR and MR technologies (as above), this research will be underpinned by learning theory such as constructivism, social constructivism, and heutagogy. These foundational learning theories will be applied within a design-based research methodology that will guide the research. In a complex rapidly changing world new technologies influence new

pedagogical approaches in a learning environment. More self- directed and self-determined approaches are needed in rapid development in new teaching methods and new technologies. Other traditional educational learning theories such as Behaviourism and Cognitivism are no longer fully sufficient.

This research addresses a gap in the literature, emphasising the importance of constructivist learning, problem-solving, critical thinking and collaboration in an informal and authentic high-risk learning environment. Designing VR and MR technologies for mountain safety is perfectly situated to integrate these very important pedagogical elements into an interactive learning environment. The app-based on VR and MR technologies and affordances provide the learners the opportunity to discover their own knowledge, through individual learning, reflecting and collaborative learning. There will be a range of benefits of this research. Firstly, it will lead to enhanced, in-depth and critical understandings of how people potentially learn using MR technologies and the processes for utilising MR in authentic educational contexts. Secondly, the research will create new DBR (Design-Based Research) principles and process for education in authentic high-risk situations for academics who are in high-risk training education, and, the research develops how to evaluate learning in these high-risk situations, and how it is conceptualised in this context for academics. Thirdly, this research develops new theories about MR technology and education for learning technology communities. Fourthly, this research will contribute to enhancing the learning outcomes of high altitude mountaineering educational programmes.

10. What are the potential benefits of this research to the participants, the researcher, and the wider community?

The research will potentially contribute to the reduction in accidents and improve safety in extreme environments for climbing communities. It is also the potential benefits for the researcher as a part of PhD study, and it also helps the researcher to understand how a design-based research methodology that utilises Mixed-Reality (MR) Technologies be utilised to effectively enhance learning for authentic, high-risk situations. Also, participants (mountaineers) will benefit from the research such as mountain safety and risk management in high mountain ranges in an authentic safe environment. Also, they will learn how VR help them to enhance their mountain safe training in a safe environment and gain benefits of technololgy enhance learning.

11. What are the theoretical frameworks or methodological approaches being used?

Along with VR and MR technologies (as above), this research will be underpinned by learning theory such as constructivism, social constructivism, and heutagogy. These foundational learning theories will be applied within a design-based research methodology that will guide the research.

Constructivism is one of the modern learning theories and heutagogy is self-determined learning that builds upon constructivism and social constructivism. Constructivism is a learning theory that equates learning with creating meaning from experience (Bednar et al., 1991). Learning is more meaningful to students when they are able to interact with concepts in the learning process. Constructivism states that learning is an active, contextualized process of constructing knowledge rather than acquiring it. Knowledge is constructed based on personal experiences and hypotheses of the environment. Constructivism utilises interactive teaching strategies to create meaningful contexts that help students construct knowledge based on their own experiences. Social constructivists view that learning is meant to be a social process that occurs when individuals take part in social activities. Meaningful learning occurs when individuals are engaged in social activities such as interaction and collaboration. Social Constructivism emphasises the importance of culture and context in the process of knowledge construction. According to Vygotsky (1978), knowledge is constructed through social interaction and is a shared rather than an individual experience. He states that human beings create meaning from an educational experience by learning with others. Vygotsky also views interaction with peers as an effective way of developing skills and strategies within the Zone of Proximal Development. Heutagogy is self-determined learning that builds upon constructivism, social constructivism, and andragogy. According to Hase and Kenyon (2001), Heutagogy is a process of self-determined learning, where learners influence their own learning process and context, involving changes in the role of the teacher and learner. The learners have the primary role in a heutagogical learning environment and are at the centre of the learning process, as opposed to teacher-centred learning. Self-determined learning is more concerned with how people learn, where the learners have the ability to manage their own learning environment to meet their learning needs. It has a focus on what the learners want to learn.

The research will use a design-based research (DBR) methodology. This involves the identification of design principles that are tested through implementation and evaluation of a design prototype app, that is then iteratively redesigned with further evaluation and feedback from users through the generic process for conducting design research in education. Leading to the development of transferable design principles that can be applied to other knowledge contexts. The model below in Figure 1 shows the process of design-based research as Reeves and Amiel (2008) described it. This research will be undertaken in four phases that align with the four stages of the DBR methodology as McKenney and Reeves (2012) described in "*Conducting educational design research"*.

Using the DBR model, the research will be undertaken in four phases that align with the four stages of the DBR methodology as McKenney and Reeves (2012) described in "*Conducting educational design research"*.

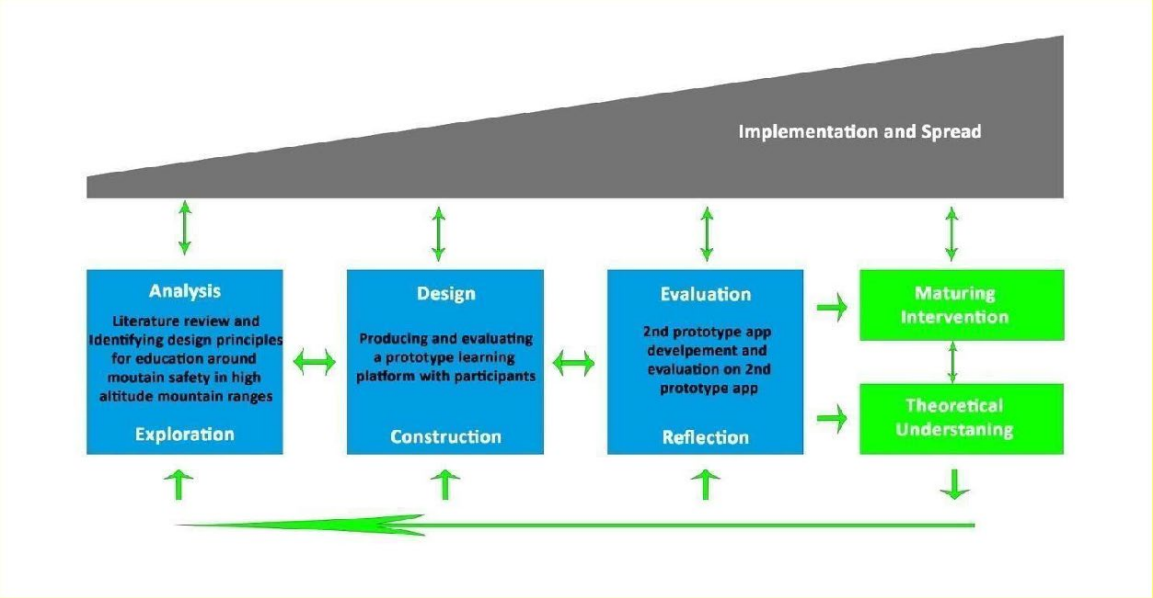


Figure 1. Design-based research stages (based on Reeves and Amiel, 2008).

The DBR stages of this research involve:

1. **Analysis & Exploration:** The first phase will focus on a detailed review of the literature in relation to identifying design principles for education mountain safety and risk factors in high altitude mountain ranges, and the principles of VR/MR design, and learning and other theories. I will also conduct initial feasibility interviews with expert climbers from climbing communities in New Zealand and overseas. Using this work, initial design principles will be developed.
2. **Design & Construction:** The second phase will involve designing and building the prototype app
   based on input from phase 1. This process includes shooting 360 degree videos in the mountains in the South Island, including footage of crevasses, avalanches and different weather conditions in the mountains to help develop the prototype app. I will use the online platform Seekbeak to produce a first stage of the prototype app.

3. **Evaluation and Reflection:** This third phase will be focus on producing and evaluating a prototype
   MR learning app with key participants. The MR learning app will provide an authentic simulated environment, for example, intense wind noise with ice debris or snow by a massive industrial fan and low temperature in an indoor snowfield, ice rink or industrial large freezer. Participants will wear a virtual reality (VR) headset device. They will be supported by paramedics at the scene in case they are under high stress. Also, the research will follow safety protocol and confidentiality

protocols to protect the safety of participants and researchers. As a part of this, all participants need to agree with ethics consent. A very initial mock-up prototype can be viewed at:

https://player.wondavr.com/p/1453c188-4ee0-42b9-8586-f8843edf3b3d?poster=true" (please use Firefox browser to view)

This mock-up demonstrates how a MR learning app can be developed and demonstrated. Key participants (mountain climbers) will use the MR app to enhance their learning and/or provide feedback about four specific mountain climbing scenarios:

- Weather condition identifications
- Crevasse identification
- Avalanches awareness
- Acute Mountain Sickness (AMS)

The impact of the app on learning will be evaluated through pre and post interviews. Biometric feedback (heart rate) will also be utilised via participants wearing a smartwatch. Patterns and themes from the pre and post interviews will be identified. Based on this evaluation, design principles will be refined. The 1st prototype app will be redesigned to further enhance learning opportunities, following this prototype stage. The final part of the third stage involves further theorising and refinement of key design principles.

4. **Theoretical Understanding & Development of Design Principles:** The final phase will mainly focus on developing recommendations and new design principles with the potential to lead to successful safe climbing education applicable in real environments using the app. It will also involve developing theory from the findings that will help other designers and educationalists working in similar high-risk education areas. This phase reflects on findings including the data analysis process and 'maturing intervention and theoretical understanding' as in the figure to produce transferable design principles.

12. How will data be gathered and processed?

Please provide your data collection protocols, describing step by step how you will be interacting with participants when collecting data.

Table 1 below shows how data will be gathered and processed.

Research Phase	Data Gathering	Data Processing
1	Advertising	The researcher will advertise in mountain communities (NZ Apline Club magazine and NZ Apline Club FaceBook) in New Zealand for expression of interest from participants.
2	Invitation	The researcher will invite those who are interested to participate in the research via advertisements and email.
3	Initial contact participants	Participants will be informed of the project details, consent process and the data collection process by the researcher.
4	Data analysis fieldwork 1 (NZ participants)	User testing of the VR learner app will take place at AUT or other locations more convenient to the participants.
	Note: Data analysis will be carried out by the primary researcher in NZ and it is. The data collection is only for the 1st stage.	
	Interview/questionnaire before they use the VR app (30 mins)	Asking about their experience in mountaineering in high altitude and training etc
	Biometric feedback (15 minutes)	It will take around an hour per participant on each stage of development of a prototype VR learning app.
	Focus group discussion (30 minutes)	Participants focus discussion on each stage

The primary researcher will gather data through questionnaires, observations and the use of the prototype app through emails or focus group meetings, and also conduct feasibility interviews with climbers from climbing communities in New Zealand. Participants will be informed of the project details, consent process and the data collection process by the researcher. The research conducts methodological triangulation to measure learning outcomes, using more than one method to gather data such as interviews, questionnaires, and biometric feedback

The researcher will interview participants around half and an hour each and pre and post the use of VR app and it will take place two days before a focus group discussion. If the researcher can't carry on interviewes due to COVID-19, interviews will be carry on online using Team or Zooms. Biometric feedback will take around 30 minutes per participant on each stage of development of a prototype VR learning app. Participants will wear Apple watch to measure heart rate. As a part of biometric feedback, participants' heart rate will be monitored before and after the use of VR app as it is one of great indicators of stress. When there is high heart rate, it indicates stress level increases.

The research will involve designing and producing and evaluating a prototype VR learning app with invited participants. The intervention context of use of the MR learning app will provide an authentic simulated environment, for example, intense wind noise with ice debris or snow by a massive industrial fan and low temperature in an industrial large freezer (between 0 and - 5 degree) for 10 minutes. All participants will be advised of the details of how biometric feedback will be gathered before conducting the research. Participants will wear a virtual reality (VR) Head Mounted Display (HMD) headset. In terms of the side-effects of VR headset use, there is a potential for those using a VR headset to develop nausea or discomfort. If any participant gives advice of any discomfort or nausea the researcher will remove that participant from the study and provide medical support. They will be fully supported by AUT paramedics at the scene in case they are under high stress.

The research will follow safety protocol and confidentiality protocols to protect the safety of participants and researchers. For biometric feedback, participants will be clearly advised about this occurring. The research uses Apple watch to detect heart rate. Qualitative data from pre and post-app interviews will be triangulated with biometric responses before, during and after using the app, and with their feedback from focus group meetings. Participants will receive the questionnaire documents and prototype app through focus group meetings or emails. These Mixed Reality (MR) environments will be captured from authentically staged contexts using a 360° camera, such as Gopro Max, with interactivity added via platforms such as Unity for viewing on smartphones via a Google Cardboard compatible Head Mounted Display (HMD). We will use an established framework developed for designing the mobile VR experiences (Cochrane, 2016; Cochrane, Narayan and Antonczak, 2016).

13. How will the data be analysed?

Please provide the statistical (for quantitative research) or methodological (for qualitative or other research) justification for analysing the data in this way.

The data will be mainly qualitative, using small numbers of participants so the researcher is unlikely to need qualitative analysis software to identify key themes. The researcher is able to categorise participant feedback via thematic coding of emerging themes and creating graphical charts of responses to the survey questions (both quantitative questions and qualitative), and the quantitative data from the biometrics can be analysed via Excel spreadsheets. The researcher will collect data from biometrics - heart rate, to triangulate the subjective feedback from the participants from pre-and post-surveys, focus groups, and their interactions with the app prototype. The research uses Apple watch to detect heart rate. When participants' hear rate goes up during the use of the app, it means they are in tense and stress environment similar to actual real environment. It reflects that virtual environment succefully simulates real environment in safe locations.

Activity theory will be used to make sense of socio-cultural factors and will be utilised in the analysis. Activity theory will help to inform how to analyse data and prepare questions I'm conducting in a focus group.

And it also helps to identify and analyse different cultural aspects between the New Zealand mountaineers cohort.

14. Has any peer review taken place? ☒ Yes ☐ No

If your answer is 'Yes', please specify and provide evidence e.g. a letter of confirmation.

☐ AUT Competitive Grant ☐ External Competitive Research Grant

☐ PGR1 ☒ PGR2 ☒ PGR9 ☐ Independent Peer Review*

Optional exemplars for evidencing peer review are available from the Ministry of Health (HDEC) website (http://ethics.health.govt.nz/) or from the Forms section of the Research Ethics website (http://aut.ac.nz/researchethics)

C. *General Project Details*

1. Likely Research Output

1. What are the likely outputs of this research?

☒ a thesis ☐ a dissertation ☒ a research paper ☒ a journal article

☐ a book ☒ conference paper ☐ a documentary ☐ an exhibition

☐ a film ☐ some other artwork ☒ other academic publications or presentations

☐ Some other output, please specify

Click here to enter text.

2. Research Location and Duration

1. In which countries and cities/localities will the data collection occur?

New Zealand: Wanaka, Mt Cook

1. Exactly where will any face to face data collection occur?

If face to face data collection will occur in participants' homes or similarly private spaces, then a Researcher Safety Protocol needs to be provided with this application.

Workshop places in Wanaka and Mt Cook village in New Zealand

2. In which countries and cities/localities will the data analysis occur?

New Zealand: Auckland

3. When is the data collection scheduled to commence?

When Ethic approval is granted.

3. Research Participants

1. Who are the participants?

This proposed research will conduct NZAC (New Zealand Alpine Club), NZ Mountain Safety Council in New Zealand. The researcher met Peter Cambell, a qualified mountaineering instructor and a senior member from NZAC, and agreed to participate in the research.

Mountain climbers, mountain guides in NZ. They will be invited to take part in the research. There will be

10 New Zealand participants (5 male and 5 female), aged between 25 and 60.

2. How many participants are being recruited for this research?

If you are unsure, please provide an indicative range.

10 participants in New Zealand

3. What criteria will be used to choose who to invite as participants?

The eligible experts should be working in organisations related to climbing industries and mountain guide

communities in high altitude mountains.

1. How will you select participants from those recruited if more people than you need for the study agree to participate?

Select participants should have at least more than 3 years' experience in high altitude mountains.

4. Will any people be excluded from participating in the study? ☐ Yes ☒ No

Exclusion criteria apply only to potential participants who meet the inclusion criteria. An exclusion criterion is any characteristic that ought to disqualify any potential participant from recruitment into the study. Consider exclusion criteria when there are heightened risks due to power differences in the relationship, recent injury, or other characteristics that might place potential participants at unreasonable risk of harms.

If the answer to this question is 'Yes' please answer C.3.4.1 and the following sections, otherwise please answer C.3.5 and continue from there.

1. What criteria will be used to exclude people from the study?

Click here to enter text.

2. Why is this exclusion necessary for this study?

Click here to enter text.

5. Recruitment of participants.

Please describe in detail the recruitment processes that will be used. If you will be recruiting by advertisement or email, please attach a copy to this Application Form

1. How will the initial contact with potential participants occur?

Participants will be recruited through climbing communities via Facebook and Twitter in New Zealand.

The researcher will advertise in mountain communities in New Zealand for expression of interest from participants.

2. How will the contact details of potential participants be collected and by whom?

Through selected guide companies and climbing communities by the primary researcher.

3. How will potential participants be invited to participate?

Expression of their interest.

4. How much time will potential participants have to consider the invitation?

Four weeks.

5. How will potential participants respond to the invitation?

By email and phone calls to arrange.

6. How will potential participants give consent?

In person before the workshop or through email before the workshop.

7. How and when will the inclusion criteria and exclusion criteria given in sections C.3.2 and C.3.3 be applied?

Expression of interest.

8. Will there be any follow up invitations for potential participants?

Yes, after they accept to take part in research, the primary researcher will send them one reminder

before the workshop via group email.

D. *Partnership, Participation and Protection*

1. How does the design and practice of this research implement the principle of Partnership in the interaction between the researcher and other participants?

How are the researcher and the participants working together? How will your research design and practice encourage a mutual respect and benefit and participant autonomy and ownership? How will you ensure that participants and researchers will act honourably and with good faith towards each other? Are the outcomes designed to benefit the participants and/or their social or cultural group? How will the information and knowledge provided by the participants be acknowledged?

The researcher values and respects participants' feedback and experience. Using a qualitative approach highlights the importance we place on participants' experience and perspective as well as the principles of informed consent and ownership of data being collected. The researcher will select the research questions carefully for participants in order to ensure participants are secure to share their knowledge and experience. Also, all research questions will be monitored by a third party. The researcher respects all participants' knowledge and experience without any judgment at all times. As the research process is autonomous, there is no any type of coercion from the researcher to participants, or between participants themselves. The research design ensures that information and knowledge provided by the participants will be acknowledged by collecting data through specific research instruments (survey questionnaires, observation protocols, and focus groups and interviews).

2. How does the design and practice of this research implement the principle of Participation in the interaction between the researcher and other participants?

What is the actual role of participants in your research project? Will participants be asked to inform or influence the nature of the research, its aims, or its methodology? Will participants be involved in conducting the research or is their principal involvement one of sharing information or data? Do participants have a formal role as stakeholders e.g. as the funders and/or beneficiaries of the research? What role will participants have in the research outputs (e.g. will they be asked to approve transcripts or drafts)?

Participants will contribute to help the primary researcher to collect data from their experiences. They will influence the outcome and process of the research as a design-based research methodology will implement participation of participants. This research involves

constant feedback from participants to design a new safety training method in high altitude mountaineering. Participants (mountaineers) will benefit from the research such as mountain safety and risk management in high mountain ranges.

3. How does the design and practice of this research implement the principle of Protection in the interaction between the researcher and other participants?

How are the researcher and the participants protecting each other? How will you actively protect participants from deceit, harm and coercion through the design and practice of your research? How will the privacy of participants and researchers be protected? How will any power imbalances inherent in the relationships between the participants and researchers be managed? How will any cultural or other diversity be respected?

Authentic collaboration between the researcher and participants is a key part of a design-based research. The participants will influence the outcomes and process of the research. During the cycle of collaboration recruit participants feel contribution on redesign of the research and benefit from practice by including them and receive their feedback. The participants are enabled to decline to take part in the research. The data collection process through focus group meetings is designed for a safe and comfortable environment so participants won't have any environmental stress to contribute their extensive knowledge and experience on mountain safety. All participants will have fair opportunities to share their experience. The research will follow safety protocol and confidentiality protocol to protect the privacy of participants and researchers, any cultural or other diversity will be well respected at all times.

E. *Social and Cultural Sensitivity (including the obligations of the Treaty of Waitangi)*

1. What familiarity does the researcher have with the social and cultural context of the participants?

The primary researcher is also in mountain climbing community and a member of NZ Alpine Club. He has been in a NZ climbing community more than 15 years. He is actively involved in a NZ climbing community and has extensive knowledge in social cultural context of the participants in New Zealand.

2. What consultation has occurred?

Research procedures should be appropriate to the participants. Researchers have a responsibility to inform themselves of, and take the steps necessary to respect the values, practices, and beliefs of the cultures and social groups of all participants. This usually requires consultation or discussion with appropriate people or groups to ensure that the language and research approaches being used are relevant and effective. Consultation should begin as early as possible when designing the project and should continue throughout its duration.

All researchers are encouraged to make themselves familiar with Te Ara Tika: Guidelines for Maori Research Ethics: A framework for researchers and ethics committee members which is able to be accessed through the Research Ethics website. Researchers may also find Te Kaahui Maangai a directory of Iwi and Maaori organisations to be helpful. This may be accessed via the Te Puni Kookiri website (http://www.tkm.govt.nz/). As well as these documents, the Health Research Council has published Pacific Health Research Guidelines, and Guidelines on research

involving children. (see http://www.hrc.govt.nz). There are also guidelines by various organisations about researching with other populations that researchers will find helpful.

Before the initial contact to participants, the primary researcher will consult the process and cultural awareness with NZ Alpine Club representatives to make sure research approaches are effective and appropriate.

1. With whom has the consultation occurred?

Please provide written evidence that the consultation has occurred.

Mountaineers in New Zealand.

2. How has this consultation affected the design and practice of this research?

During the consultation and evaluation, it involves the identification of design principles that are tested through implementation and evaluation of a design prototype app, that is then iteratively redesigned with further evaluation and feedback from participants through the generic process for conducting design research in education. The primary researcher revisits and rethinks the design and practice of the research through this process.

3. Does this research target Māori participants? ☐ Yes ☒ No

All researchers are encouraged to make themselves familiar with Te Ara Tika: Guidelines for Maori Research Ethics: A framework for researchers and ethics committee members

If your answer is 'No', please go to section E.4 and continue from there. If you answered 'Yes', please answer the next question.

1. Which iwi or hapu are involved?

Click here to enter text.

4. Does this research target participants of particular cultures or social groups? ☒ Yes ☐ No

AUTEC defines the phrase 'specific cultures or social groups' broadly. In section 2.5 of Applying for Ethics Approval: Guidelines and Procedures it uses the examples of Chinese mothers and paraplegics. This is to identify their distinctiveness, the first as a cultural group, the second as a social group. Other examples of cultural groups may be Korean students, Samoan husbands, Cook Islanders etc., while other examples of social groups may be nurse aides, accountants, rugby players, rough sleepers (homeless people who sleep in public places) etc. Please refer to Section 2.5 of AUTEC's Applying for Ethics Approval: Guidelines and Procedures (accessible in the Ethics Knowledge Base online via http://www.aut.ac.nz/about/ethics) and to the relevant Frequently Asked Questions section in the Ethics Knowledge Base.

If your answer is 'No', please go to section E.5 and continue from there. If you answered 'Yes', please answer the next question.

1. Which cultures or social groups are involved?

Mountain climbing communities in New Zealand.

5. Does this research focus on an area of research that involves Treaty obligations? ☐ Yes ☒ No

All researchers are encouraged to make themselves familiar with Te Ara Tika: Guidelines for Maori Research Ethics: A framework for researchers and ethics committee members.

If your answer is 'No', please go to section E.6 and continue from there. If you answered 'Yes', please answer the next question.

1. Which treaty obligations are involved?

Click here to enter text.

6. Will the findings of this study be of particular interest to specific cultures or social groups? ☒ Yes ☐ No

If the answer is 'Yes' please answer E.6.1 and the following sections, otherwise please answer F.1 and continue from there.

1. To which iwi, hapū, culture or social groups will the findings be of interest?

Mountain climbing communities and outdoor activity communities around the world.

2. How will the findings be made available to these groups?

Posting links to the research outputs in mountain climbing communities and outdoor activity communities through various social media (Facebook, Twitter, etc).

F. *Respect for the Vulnerability of Some Participants*

"Vulnerable persons are those who are relatively (or absolutely) incapable of protecting their own interests. More formally, they may have insufficient power, intelligence, education, resources, strength, or other needed attributes to protect their own interests. Individuals whose willingness to volunteer in a research study may be unduly influenced by the expectation, whether justified or not, of benefits associated with participation, or of a retaliatory response from senior members of a hierarchy in case of refusal to participate may also be considered vulnerable." (Standards and Operational Guidance for Ethics Review of Health-Related Research with Human Participants, World Health Organisation).

1. Will your research involve any of the following groups of participants? ☐ Yes ☒ No

If your research involves any of these groups of participants, please clearly indicate which ones and then answer F.2 and the following section, otherwise please answer G.1 and continue from there.

☐ people unable to give informed consent? ☐ your (or your supervisor's) own students?

☐ preschool children? ☐ children aged between five and sixteen years?

☐ legal minors aged between sixteen and twenty years?

☐ People lacking the mental capacity for consent?

☐ people in a dependent situation (e.g. people with a disability, or residents of a hospital, nursing home or prison or patients highly dependent on medical care)?

☐ ***people who are vulnerable for some other reason (e.g. the elderly, persons who have suffered abuse, persons who are not competent in English, new immigrants)? – please specify***

Click here to enter text.

2. How is respect for the vulnerability of these participants reflected in the design and practice of your research?

Click here to enter text.

3. What consultation has occurred to ensure that this will be effective?

Please provide evidence of the consultation that has occurred.

Click here to enter text.

G. *Informed and Voluntary Consent*

1. How will information about the project be given to potential participants?

A copy of all information that will be given to prospective participants is to be attached to this Application Form. If written information is to be provided to participants, you are advised to use the Information Sheet exemplar. The language in which the information is provided is to be appropriate to the potential participants and translations need to be provided when necessary.

The information document in writing about the research will be sent to participants by email before conducting the questionnaires and focus group meetings.

2. How will the consent of participants be obtained and evidenced?

AUTEC requires consent to be obtained and usually evidenced in writing. A copy of the Consent Form which will be used is to be attached to this application. If this will not be the case, please provide a justification for the alternative approach and details of the alternative consent process. Please note that consent must be obtained from any participant aged 16 years or older. Participants under 16 years of age are unable to give consent, which needs to be given by their parent or legal guardian. AUTEC requires that participants under the age of 16 assent to their participation. When the nature of the research requires it, AUTEC may also require that consent be sought from parents or legal guardians for participants aged between 16 and twenty years. For further information please refer to AUTEC's Applying for Ethics Approval: Guidelines and Procedures.

The researcher will send participants the research consent in writing before processing the questionnaires and focus group meetings.

3. Will any of the participants have difficulty giving informed consent on their own behalf? ☐ Yes ☒ No

Please consider physical condition, cognitive status, age, language, legal status, or other barriers.

If the answer is 'Yes' please answer G.3.1 and the following sections, otherwise please answer G.4 and continue from there.

1. If participants are not competent to give fully informed consent, who will consent on their behalf?

Researchers are advised that the circumstances in which consent is legally able to be given by a person on behalf of another are very constrained. Generally speaking, only parents or legal guardians may give consent on behalf of a legal minor and only a person with an enduring power of attorney may give consent on behalf of an adult who lacks capacity.

Click here to enter text.

2. How will these participants be asked to provide assent to participation?

Whenever consent by another person is possible and legally acceptable, it is still necessary to take the wishes of the participant into account, taking into consideration any limitations they may have in understanding or communicating them.

Click here to enter text.

4. Is there a need for translation or interpreting? ☐ Yes ☒ No

If your answer is 'Yes', please provide copies of any translations with this application and any Confidentiality Agreement required for translators or interpreters.

Click or tap here to enter text.

H. *Respect for Rights of Privacy and Confidentiality*

1. How will the researchers respect the privacy and confidentiality of participants?

Please note that anonymity and confidentiality are different. For AUTEC's purposes, 'Anonymity' means that the researcher is unable to identify who the participant is in any given case. If the participants will be anonymous, please state how, otherwise, if the researcher will know who the participants are, please describe how the participants' privacy issues and the confidentiality of their information will be managed.

All provided information from participants will be confidential and will not be revealed at any circumstance. The researcher follows confidentiality protocol. All information from participants will be secured in a lockable cabinet in WO1022 in AUT and these will be burned after 10 years. Also, the primary researcher will inform participants through email or phone call once all data is destroyed.

2. Will any participants be identifiable in the research outputs or findings? ☐ Yes ☒ No

If your answer is 'Yes", please answer H.2.1, otherwise please answer H.3

1. What level of confidentiality is able to be offered to participants and how will this be managed?

If the research involves small or distinctive groups of participants or procedures such as interviews conducted at the worksite, or focus groups with peers, researchers should identify the level of participant confidentiality that can be offered in the Information Sheet. If participants or groups will be identified, please state why this is appropriate, how this will happen, and how the participants will give consent.

Click here to enter text.

3. What information on the participants will be obtained from third parties?

This includes use of third parties, such as employers or professional organisations, in recruitment.

No information on the participants will be obtained from third parties.

4. How will potential participants' contact details be obtained for the purposes of recruitment?

The primary researcher will obtain potential participants' contact details from participants who respond

express of interest in NZ.

5. What identifiable information on the participants will be given to third parties?

No identifiable information will be given to third parties.

6. Who will have access to the data during the data collection and analysis stages?

The primary researcher and supervisors.

7. Who will have access to the data after the findings have been produced?

The primary researcher and supervisors.

8. Are there any plans for the future use of the data beyond those already described? ☐ Yes ☒ No

The applicant's attention is drawn to the requirements of the Privacy Act 1993 (see Appendix I of AUTEC's Applying for Ethics Approval: Guidelines and Procedures). Information may only be used for the purpose for which it was collected so if there are plans for the future use of the data, then this needs to be explained in the Information Sheets for participants. If you have answered 'Yes' to this question, please answer section H.8.1.1 and continue from there. If you answered 'No' to this question, please go to section H.9 and proceed from there.

1. **If data will be stored in a database, who will have access to that information, how will it be used, for what will it be used, and how have participants consented to this?**

Click here to enter text.

2. **Will any contact details be stored for future use and if so, who will have access to them, how will they be used, for what will they be used, and how have participants consented to this?**

Click here to enter text.

9. Where will the data be stored once the analysis is complete?

Please provide the exact storage location. AUTEC normally requires that the data be stored securely on AUT premises in a location separate from the consent forms. Electronic data should be downloaded to an external storage device (e.g. an external hard drive, a memory stick etc.) and securely stored. If you are proposing an alternative arrangement, please explain why.

The primary supervisor store hard copies of interview and user experience data in his lockable cabinet in WO1022

in AUT city campus. The data will be only accessible by the primary researcher.

1. For how long will the data be stored after completion of analysis?

AUTEC normally requires that the data be stored securely for a minimum of six years, or ten years for health data. If you are proposing an alternative arrangement, please explain why.

The all data will be stored in 10 years.

2. How will the data be destroyed?

If the data will not be destroyed, please explain why, identify how it will be safely maintained, and provide appropriate informed consent protocols.

No sooner than 10 years from the publication of the thesis, all transcripts and field notes will be shredded and

computer files will be deleted.

10. Who will have access to the Consent Forms?

The primary researcher and supervisors.

11. Where will the completed Consent Forms be stored?

Please provide the exact storage location. AUTEC normally requires that the Consent Forms be stored securely on AUT premises in a location separate from the data. If you are proposing an alternative arrangement, please explain why.

The primary supervisor stores the completed Consent Forms in a locked his cabinet in WO1022 in AUT city campus.

The data will be accessible by the primary researcher for 10 years.

1. For how long will the completed Consent Forms be stored?

AUTEC normally requires that the Consent Forms be stored securely for a minimum of six years, or ten years in the case of research involving health data. If you are proposing an alternative arrangement, please explain why.

10 years.

2. How will the Consent Forms be destroyed?

If the Consent Forms will not be destroyed, please explain why.

The researcher will inform participants that the Consent forms will be burned in a secure place after storage.

12. Does your research involve the collection of personally identifiable and sensitive data? ☐ Yes ☒ No

Sensitive data can be used to identify an individual, object or location and has a risk of discrimination, harm or unwanted attention. Sensitive data potentially poses a substantial threat to those who are or who have been involved in it, especially if it is shared inappropriately, or if it falls into the wrong hands. If you have answered 'Yes' please identify what data is being collected

and how it is sensitive and provide a Data Safety Management Protocol (see the Forms section of the Research Ethics website for a guide to drafting one). If the answer is 'No', please answer H.13 and continue from there.

Click here to enter text.

13. Does your project involve the use of previously collected information or biological samples for which there was no explicit consent for this research? ☐ Yes ☒ No

If the answer is 'Yes' please answer H.13.1 and the following sections, otherwise please answer H.14 and continue from there.

1. What previously collected data will be involved?

Click here to enter text.

2. Who collected the data originally?

Click here to enter text.

1. Why was the information originally collected?

Click here to enter text.

2. For what purposes was consent originally given when the information was collected?

Click here to enter text.

3. How will the data be accessed?

Click here to enter text.

14. Does your research involve the collection of information about organisational practices? ☐ Yes ☒ No

AUTEC applies a broad definition to the term 'organisations'. It could include for example, businesses, hospitals or clinics, schools, or sports clubs and teams If the answer is 'Yes' please answer H.14.1, otherwise please answer I.1 and continue from there.

1. How will the authorisation to access the organisation or its staff for research purposes be obtained?

Click here to enter text.

2. Could disclosure of this information potentially disadvantage the oganisation or the participants? ☐ Yes ☐ No

If your answer is 'Yes", please answer H.14.2.1, otherwise please answer H.14.3

1. How will the risks associated with potential disadvantages be managed?

Click here to enter text.

3. Will the participants or anyone else in the oganisation be identified in this information? ☐ Yes ☐ No

If your answer is 'Yes", please answer H.14.3.1, otherwise please answer I.1 and continue from there.

1. How will the potential risks involved be managed?

If the research involves procedures such as interviews conducted at the worksite, or focus groups with peers, researchers should identify the level of participant confidentiality that can be offered in the Information Sheet.

Click here to enter text.

B. *Minimisation of risk*

14. Risks to Participants

Please consider the possibility of moral, physical, psychological or emotional risks to participants, including issues of confidentiality and privacy, from the perspective of the participants, and not only from the perspective of someone familiar with the subject matter and research practices involved. Please clearly state what is likely to be an issue, how probable it is, and how this will be minimised or mitigated (e.g. participants do not need to answer a question that they find embarrassing, or they may terminate an interview, or there may be a qualified counsellor present in the interview, or the findings will be reported in a way that ensures that participants cannot be individually identified, etc.) Possible risks and their mitigation should be fully described in the Information Sheets for participants.

1. How much time will participants be required to give to the project?

The interview will take around an hour and the user experience evaluation will take up to 1 hour at 1st stage,

and final focus group discussion will take an hour. Total it requires 2 hours from participants.

1. The interview/Survey: 30 minutes.
2. User experience evaluation: 1 hour.
3. Focus group discussion: 30 minutes

2. What level of discomfort or embarrassment may participants be likely to experience?

Participants will not have any level of discomfort or embarrassment during the focus group meetings

or interview. However, for use of the app, participants may have possible discomfort such as dizziness with VR.

As VR technologies have been improving, improved immersion makes people feel like their brains and bodies are arguing during what should be a fun experience. The result is sweating, dizziness, headaches, and even nausea. For this case, paramedics will assist participants for any help. AUT Paramedic team agrees that they will be in the scene to observe participants during use of the app.

3. In what ways might participants be at risk in this research?

There is no risk when participants are involved with the survey, interview, app use and the focus group meetings.

4. In what ways are the participants likely to experience risk or discomfort as a result of cultural, employment, financial or similar pressures?

There are no way participants are likely to experience risk or discomfort as a result of cultural, employment

and financial pressures.

5. Will your project involve processes that are potentially disadvantageous to a person or group, such as the collection of information, images etc. which may expose that person/group to discrimination, criticism, or loss of privacy? ☐ Yes ☒ No

If your answer is 'Yes', please detail how these risks will be managed and how participants will be informed about them.

Click here to enter text.

6. Will your research involve collection of information about illegal behaviour(s) which could place the participants at current or future risk of criminal or civil liability or be damaging to their financial standing, employability, professional or personal relationships? ☐ Yes ☒ No

If your answer is 'Yes', please detail how these risks will be managed and how participants will be informed about them.

Click here to enter text.

7. If the participants are likely to experience any significant discomfort, embarrassment, incapacity, or psychological disturbance, please state what consideration you have given to the provision of counselling or post-interview support, at no cost to the participants, should it be required.

Adult research participants in Auckland are able to utilise counselling support from the AUT Counselling Team, otherwise you may have to consider local providers for participants who are located nationwide, or in some particular geographical area or who are children. You may discuss the potential for participant psychological impact or harm with the Head of AUT Counselling, if you require. Please check the relevant Frequently Asked Question on the research ethics website as well and ensure the appropriate wording in included in the Information Sheet when counselling opportunities need to be offered.

It is unlikely that participants will experience any significant discomfort. However, if it happens paramedics

will assist participants for any help. Also, the AUT Counselling team will help them.

8. Will any use of human remains, tissue or body fluids which does not require submission to a Health and Disability Ethics Committee occur in the research? ☐ Yes ☒ No

e.g. finger pricks, urine samples, etc. (please refer to section 13 of AUTEC's Applying for Ethics Approval: Guidelines and Procedures). If your answer is yes, please provide full details of all arrangements, including details of agreements for treatment, how participants will be able to request return of their samples in accordance with right 7 (9) of the Code of Health and Disability Services Consumers' Rights, etc.

Click here to enter text.

9. Will this research involve potentially hazardous substances? ☐ Yes ☒ No

e.g. radioactive material, biological substances (please refer to section 15 of AUTEC's Applying for Ethics Approval: Guidelines and Procedures and the Hazardous Substances and New Organisms Act 1996).

If the answer is 'Yes', please provide full details, including hazardous substance management plan.

Click here to enter text.

15. Risks to Researchers

If this project will involve interviewing participants in private dwellings, undertaking research in unfamiliar cultural contexts either in New Zealand or overseas, doing research in a place to which a travel warning applies, or going into similarly vulnerable situations, then a Researcher Safety protocol should be designed and appended to this application. This should identify simple and effective processes for keeping someone informed of the researcher's whereabouts and provide for appropriate levels of assistance. A guide to drafting one is provided in the forms section of the Research Ethics website.

1. Are the researchers likely to be at risk? ☐ Yes ☒ No

If the answer is 'Yes' please answer I.2.1.1 and then continue, otherwise please answer I.3 and continue from there.

1. In what ways might the researchers be at risk and how will this be managed?

Click here to enter text.

16. Risks to AUT

1. Is AUT or its reputation likely to be at risk because of this research? ☐ Yes ☒ No

If the answer is 'Yes' please answer I.3.1.1 and then continue, otherwise please answer I.3.2 and continue from there.

1. In what ways might AUT be at risk in this research?

Please identify how and detail the processes that will be put in place to minimise any harm.

Click here to enter text.

2. Are AUT staff and/or students likely to encounter physical hazards during this project? ☐ Yes ☒ No

If yes, please provide a hazard management protocol identifying how harm from these hazards will be eliminated or minimised.

Click here to enter text.

C. *Truthfulness and limitation of deception*

14. How will feedback on or a summary of the research findings be disseminated to participants (individuals or groups)?

It is normally courteous to provide participants with a one or two page summary of the findings of the research. Please ensure that this information is included in the Information Sheet.

Complete..

15. Does your research include any deception of the participants, such as non-disclosure of aims or use of control groups, concealment, or covert observations? ☐ Yes ☒ No

Deception of participants in research may involve deception, concealment or covert observation. Deception of participants conflicts with the principle of informed consent, but in some areas of research it may sometimes be justified to withhold information about the purposes and procedures of the research. Researchers must make clear the precise nature and extent of any deception and why it is thought necessary. Emphasis on the need for consent does not mean that covert research can never be approved. Any departure from the standard of properly informed consent must be acceptable when measured against possible benefit to the participants and the importance of the knowledge to be gained as a result of the project or teaching session. This must be addressed in all applications. Please refer to Section 2.4 of AUTEC's Applying for Ethics Approval: Guidelines and Procedures when considering this question.

If the answer is 'Yes' please answer J.2.1 and the following sections, otherwise please answer J.3 and continue from there.

1. Is deception involved?

Click here to enter text.

2. Why is this deception necessary?

Click here to enter text.

3. How will disclosure and informed consent be managed?

Click here to enter text.

16. Will this research involve use of a control group? ☐ Yes ☒ No o

If the answer is 'Yes' please answer J.3.1 and the following sections, otherwise please answer K.1 and continue from there.

1. How will the Control Group be managed?

Click here to enter text.

2. What percentage of participants will be involved in the control group?

Click here to enter text.

3. What information about the use of a control group will be given to the participants and when?

Click here to enter text.

D. *Avoidance of Conflict of Interest*

Researchers have a responsibility to ensure that any conflict between their responsibilities as a researcher and other duties or responsibilities they have towards participants or others is adequately managed. For example, academic staff members who propose to involve their students as participants in research need to ensure that no conflict arises between their roles as teacher and researcher, particularly in view of the dependent relationship between student and teacher, and of the need to preserve integrity in assessment processes. Likewise researchers have a responsibility to ensure that any conflict of interest between participants is adequately managed for example, managers participating in the same research as their staff.

14. What conflicts of interest are likely to arise as a consequence of the researchers' professional, social, financial, or cultural relationships?

There are no conflicts of interest are likely to arise as there is no the researcher's professional, social,

financial, or cultural relationships with participants.

15. What possibly coercive influences or power imbalances are there in the professional, social, financial, or cultural relationships between the researchers and the participants or between participants (e.g. dependent relationships such as teacher/student; parent/child; employer/employee; pastor/congregation etc.)?

There are no coercive influences between the researcher and participants. No power imbalance involved.

16. How will these conflicts of interest, coercive influences or power imbalances be managed through the research's design and practice and how will any adverse effects that may arise from them be mitigated?

There are no conflicts of interest that need to be managed through the research's design and practice.

No power imbalance involved.

17. Does your project involve payments or other financial inducements (including koha, reasonable contribution towards travel expenses or time, or entry into a modest prize draw) to participants? ☒ Yes ☒ No

If the answer is 'Yes' please answer K.4.1 and the following sections, otherwise please answer K.5 and continue from there.

1. What form will the payment, inducement, or koha take?

Koha for participants.

2. Of what value will any payment, gift or koha be?

$50 gift voucher from mountaineering shops.

3. Will potential participants be informed about any payment, gift or koha as part of the recruitment process, and if so, why and how?

Click here to enter text.

18. Have any applications for financial support for this project been (or will be) made to a source external to AUT? ☐ Yes ☒ No

If the answer is 'Yes' please answer K.5.1 and the following sections, otherwise please answer K.6 and continue from there.

1. What financial support for this project is being provided (or will be provided) by a source external to AUT?

Click here to enter text.

2. Who is the external funder?

Click here to enter text.

3. What is the amount of financial support involved?

Click here to enter text.

4. How is/are the funder/s involved in the design and management of the research?

Click here to enter text.

19. Have any applications been (or will be) submitted to an AUT Faculty Research Grants Committee or other AUT funding entity? ☐ Yes ☒ No

If the answer is 'Yes' please answer K.6.1 and the following sections, otherwise please answer K.7 and continue from there.

Click here to enter text.

1. What financial support for this project is being provided (or will be provided) by an AUT Faculty Research Grants Committee or other AUT funding entity?

Click here to enter text.

2. What is the amount of financial support involved?

Click here to enter text.

3. How is/are the funder/s involved in the design and management of the research?

Click here to enter text.

20. Is funding already available, or is it awaiting decision?

Click here to enter text.

21. Do the applicant or the researchers, investigators or research organisations mentioned in Part B of this application have any financial interests in the outcome of this project? ☐ Yes ☒ No

If the response is 'Yes', please provide full details about the financial interests and how any conflicts of interest are being managed, otherwise, please respond to section K.9 and continue from there.

Click here to enter text.

22. Are the participants expected to pay in any way for any services associated with this research? ☐ Yes ☒ No

If the response is 'Yes', please provide full details about the charges and describe how any benefits will balance the burdens involved as well as how any conflicts of interest are being managed. Otherwise please respond to section L.1 and continue from there.

Click here to enter text.

E. *Respect for Property*

Researchers must ensure that processes do not violate or infringe legal or culturally determined property rights. These may include factors such as land and goods, works of art and craft, spiritual treasures and information.

14. Will this research impact upon property owned by someone other than the researcher? ☐ Yes ☒ Noo

If the answer is 'Yes' please answer L.1.1 and the following sections, otherwise please answer L.2 and continue from there.

1. How will this be managed?

Click here to enter text.

15. How do contexts to which copyright or Intellectual Property apply (e.g. research instruments, social media, virtual worlds etc.) affect this research and how will this be managed?

Particular attention should be paid to the legal and ethical dimensions of intellectual property. Care must be taken to acknowledge and reference the ideas of all contributors and others and to obtain any necessary permissions to use the intellectual property of others. Teachers and researchers are referred to AUT's Intellectual Property Policy for further guidance.

There are no specific intellectual property issues associated with research. AUT's standard intellectual property

policy will apply for the app.

F. *References*

Please include any references relating to your responses in this application in the standard format used in your discipline.

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G. *Checklist*

Please ensure all applicable sections of this form have been completed and all appropriate documentation is attached as incomplete applications will not be considered by AUTEC.

Have you discussed this application with your AUTEC Faculty Representative, the Executive Secretary, or the Ethics Coordinator? ☐ ***Yes*** ☐ ***No***

Is this application related to an earlier ethics application? If yes, please provide the application number of the earlier application.	☐ *Yes* ☐ *No*
Are you seeking ethics approval from another ethics committee for this research? If yes, please identify the other committee.	☐ *Yes* ☐ *No*

Section A	*Project information provided*	☐
Section B	*Research Adequacy information provided*	☐
Section C	*Project details provided*	☐
Section D	*Three Principles information provided*	☐
Section E	*Social and Cultural Sensitivity information provided*	☐
Section F	*Vulnerability information provided*	☐
Section G	*Consent information provided*	☐
Section H	*Privacy information provided*	☐
Section I	*Risk information provided*	☐
Section J	*Truthfulness information provided*	☐
Section K	*Conflict of Interest information provided*	☐
Section L	*Respect for Property information provided*	☐
Section M	*References provided*	☐
Section N	*Checklists completed*	☐
Section O.1 and 2	*Applicant and student declarations signed and dated*	☐
Section O.3	*Authorising signature provided*	☐

Spelling and Grammar Check (please note that a high standard of spelling and grammar is required in documents that are issued with AUTEC approval)

Attached Documents (where applicable)

Participant Information Sheet(s)	☐
Consent Form(s)	☐
Questionnaire(s)	☐
Indicative Questions for Interviews or Focus Groups	☐
Observation Protocols	☐
Recording Protocols for Tests	☐
Advertisement(s)	☐
Researcher Safety Protocol	☐
Hazardous Substance Management Plan	☐
Any Confidentiality Agreement(s)	☐
Any translations that are needed	☐
Other Documentation	☐

H. *Declarations*

14. Declaration by Applicant

- ***The information in this application is complete and accurate to the best of my knowledge and belief. I take full responsibility for it.***
- ***In conducting this study, I agree to abide by all applicable laws and regulations, and established ethical standards contained in AUTEC's Applying for Ethics Approval: Guidelines and Procedures, the Auckland University of Technology Code of Conduct for Research, and internationally recognised codes of ethics.***
- ***I accept responsibility for ensuring that management approval for access for this research from any institution or organisation at which it will be conducted will be obtained. When the research is undertaken outside New Zealand, I agree to ensure that all ethical, legal, and locality obligations or requirements for those jurisdictions are met.***
- ***I will continue to comply with AUTEC's Applying for Ethics Approval: Guidelines and Procedures, including its requirements for the submission of annual progress reports, amendments to the research protocols before they are used, and completion reports.***
- ***I understand that brief details of this application may be made publicly available and may also be provided to the Graduate Research School, the Research and Innovation Office, or the University's insurers for purposes relating to AUT's interests.***

Signature ***Date***

15. Declaration by Student Researcher

- ***The information in this application is complete and accurate to the best of my knowledge and belief.***
- ***In conducting this study, I agree to abide by all applicable laws and regulations, and established ethical standards contained in AUTEC's Applying for Ethics Approval: Guidelines and Procedures, the Auckland University of Technology Code of Conduct for Research, and internationally recognised codes of ethics.***
- ***I will continue to comply with AUTEC's Applying for Ethics Approval: Guidelines and Procedures, including its requirements for the submission of annual progress reports, amendments to the research protocols before they are used, and completion reports.***
- ***I understand that brief details of this application may be made publicly available and may also be provided to the Graduate Research School, the Research and Innovation Office, or the University's insurers for purposes relating to AUT's interests.***

Signature ***Date***

16. Authorisation by Head of Faculty/School/Programme/Centre

- ***The information in this application is complete and accurate to the best of my knowledge and belief.***
- ***In authorising this study, I declare that the applicant is adequately qualified to undertake or supervise this research and that to the best of my knowledge and belief adequate resources are available for this research and all appropriate local research governance issues have been addressed.***
- ***I declare that the applicant will ensure that management approval for access for this research from any institution or organisation at which it will be conducted will be obtained. When the research is undertaken outside New Zealand, I declare that the applicant will ensure that all ethical, legal, and locality obligations or requirements for those jurisdictions are met.***
- ***I understand that brief details of this application may be made publicly available and may also be provided to the Graduate Research School, the Research and Innovation Office, or the University's insurers for purposes relating to AUT's interests.***

Signature ***Date***

Notes for submitting the completed application for review by AUTEC

- Please ensure that you are using the current version of this form before submitting your application.
- Please ensure that all questions on the form have been answered and that no part of the form has been deleted.
- Please provide either:
    - one printed, single sided, A4, and signed copy of the application and all related documents. This may be delivered or posted to the AUTEC Secretariat, room WU406, fourth floor, WU Building, City Campus. The internal mail code is D-88. The courier address is 46 Wakefield Street, Auckland 1010. Alternatively, the application may be provided to the Research Ethics Advisor in person at one of the Drop In sessions at any of the four campuses (http://www.aut.ac.nz/researchethics/resources/workshops-and-drop-inns). OR
    - A single .pdf file containing the application and all related documents emailed to ethics@aut.ac.nz. The application and documents must be scanned into a single .pdf file with the EA form at the beginning and the other documents in the order stated in the form. The application must have all the required signatures.
- Applications should be submitted once they have been finalised. For a particular meeting it needs to have been received in the AUTEC Secretariat by 4 pm on the relevant agenda closing day [AUTEC's meeting dates are listed in the website at http://www.aut.ac.nz/researchethics]. As many applications are reviewed under delegated authority, applicants are encouraged to submit their applications once they are ready rather than waiting for the closing date.
- If sending applications by internal mail, please post them at least two days earlier to allow for any delay that may occur.
- Late applications will be placed on the agenda for the following meeting.

MINIMAL RISK CHECKLIST

Your application may be eligible for delegated review if it poses no more than minimal risk of harm to participants. To assist AUTEC's Secretariat to screen the application for assignment to the correct review pathway, please complete the following checklist:

Does the research involve any of the following?

ANONYMOUS SURVEY ASSESSMENT

		Yes	No
1	The collection of anonymous and non-sensitive survey/questionnaire data only. *(If YES is checked, the application may receive an expedited review if the data is from adults and poses no foreseeable risks to participants OR where any foreseeable risk is no more than inconvenience – no further questions on this checklist need be answered.)*	☐	☐

MINIMAL RISK ASSESSMENT

		Yes	No
2	Participants who are unable to give informed consent (including children under 16 years old), or who are particularly vulnerable or in a dependent situation, (e.g. people with learning difficulties, over-researched groups, people in care facilities, or patients highly dependent on medical care)?	☐	☐
3	A reasonable expectation of causing participants physical pain beyond mild discomfort, or that experienced by the participants on an every-day basis, or any emotional discomfort, embarrassment, or psychological or spiritual harm, (e.g. asking participants to recall upsetting events)?	☐	☐
4	Research processes which may elicit information about any participant's involvement in illegal activities, or activities that represent a risk to themselves or others, (e.g. drug use or professional misconduct)?	☐	☐
5	Collection of any human tissue, blood or other samples, or invasive or intrusive physical examination or testing?	☐	☐
6	The administration of any drugs, medicines, supplements, placebo or non-food substances?	☐	☐
7	An intervention of any form of exercise, or other physical regime that is different to the participants' normal activities (e.g. dietary, sleep)?	☐	☐
8	Participants who are being asked to give information of a personal nature about their colleagues, employers, teachers, or coaches (or any other person who is in a power relationship with them), and where the identity of participants or their organisation may be inferred?	☐	☐
9	Any situation which may put the researcher at risk of harm? (E.g. gathering data in private homes)?	☐	☐
10	The use of previously collected biological samples or identifiable personal information for which there was no explicit consent for this research?	☐	☐
11	Any matters of commercially sensitive information?	☐	☐
12	Any financial interest in the outcome of the research by any member(s) of the research team?	☐	☐

13	People who are not giving consent to be part of the study, or the use of any deception, concealment or covert observations in non-public places, including social media?	☐	☐
14	Participants who are in a dependent or unequal relationship with any member(s) of the research team (e.g. where the researcher is a lecturer/ teacher/ health care provider/ coach/ employer/ manager/ or relative etc.) of any of the participants?	☐	☐

Participant Information Sheet in Chile

Project title: Developing a Design-Based Research methodology that utilises Mixed Reality (MR) technologies to enhance education for authentic high-risk (or extreme) situations.

Project Supervisor: Dr. Claudio Aguayo

Researcher: Ki Myung (Jin) Hong

Date Information Sheet Produced:

18/10/2022

Project Title

Developing a Design-Based Research Methodology that Utilises Mixed Reality (MR)Technologies to Enhance Education for Authentic High-Risk (or Extreme) Situations. Click or tap here to enter text.

An Invitation

I am Jin Hong, a Ph.D. student at Te Ara Poutama, Faculty of Māori and Indigenous Development, at Auckland University of Technology (AUT) in New Zealand. I would like to invite you to participate in developing a critical design-based research methodology that utilizes Mixed Reality (MR) technologies to enhance education for authentic high-altitude mountain (extreme) situations.

While mountaineers are generally wary of the risk factors in the mountains, there are still fatal accidents happening every year. As a mountaineer, I have encountered several mountain accidents myself, and I have heard of many unfortunate incidents in the climbing communities. This Ph.D. research will explore ways of enhancing the education of mountain climbers on the very real risks of high-altitude mountain climbing. The project will utilise learning theory and design-based research (DBR) methodologies along with virtual reality (VR) and mixed reality (MR) technologies to enhance learning in preparation for engagement in high-risk environments. In this opportunity, I intend to explore a VR learning app to re-create virtually simulated high-altitude environments. I believe this could enable mountaineers to experience and troubleshoot risky obstacles such as altitude sickness, endless crevasses, ice cliffs, and frostbites within a safe yet

authentically simulated environment. These new technologies can enable mountaineers to learn by themselves using the app as a form of technology-enhanced self-determined learning tool.

It would be highly appreciated if you participate in the research. The research will be conducted between the 9th and 20th of January 2023 at Universidad Andrés Bello, Sede Viña del Mar, in Chile. If you are interested in the research, please email jin.hong@aut.ac.nz. I will provide the information sheet, interview questions, and consent form. You will be contacted by email two weeks after receiving this email to set the date, time, and meeting arrangement (online or in-person). During the period of this research, your consent form, contact details, discussions, and data will be kept confidential. All data will be stored securely and disposed of through the university document destruction. If you have questions regarding the research, please feel free to contact jin.hong@aut.ac.nz

What is the purpose of this research?

There will be a range of benefits of this research. Firstly, it will lead to an enhanced, in-depth, and critical understanding of how people potentially learn using Virtual Reality (VR) technologies and the processes for utilizing VR in authentic educational contexts. Secondly, the research will create new DBR (Design-Based Research) principles and processes for education in authentic high-risk situations for academics who are in high-risk training education. Also, the research develops how to evaluate learning in this risk situation and how it is conceptualized in this context for academics. This research will develop new theories about VR technologies and education for learning technology communities. In addition, it will potentially contribute to the reduction in accidents and improve safety in high-risk environments for climbing communities. Finally, it is a potential benefit for the researcher as a part of the Ph.D. study. It also helps the researcher to understand how a design-based research methodology that utilises Virtual Reality (VR) Technologies be utilized to enhance learning for authentic, high-risk situations effectively.

How was I identified and why am I being invited to participate in this research?

The researcher will advertise to seek interest from expert climbers in mountain communities in New Zealand. The researcher will then formally invite those who have expressed interest to participate in the focus groups and interviews. Contact details will be identified through selected guide companies and climbing communities (such as mountaineering groups) and the personal networks of the primary researcher. Selected participants should have at least five years or more of professional experience in high-altitude mountain climbing contexts, including the professional guiding of novice climbers into high-risk situations. Participants will be recruited via advertisements and emails and also through personal climbing networks in New Zealand.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice), and whether or not you choose to participate will neither advantage nor disadvantage you. You can withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

The research will involve a biometrics set-up and recording (90 min max): A biometric data collection device, e.g., a smartwatch with biometric recording capabilities, will be set up on the participant's wrist. The biometric data collection will run for the duration of the intervention (i.e., pre-intervention survey and VR intervention). All interventions will be conducted in a studio at Universidad Andrés Bello, Viña del Mar in Chile.

1. Pre-intervention survey (30 min): The survey will cover demographic questions, prior experience regarding high altitude mountaineering, and education experience regarding high altitude mountaineering.
2. Intervention (20-30 min): The intervention will include using a VR app prototype for high-altitude mountaineering education. Participants will use a prototype VR app for 20 minutes and experience a VR app and give the researcher feedback during the post-intervention (interview). The intervention will include the following:

a. Video recording: A researcher will set up video cameras with tripods on the left and right sides of the room, so it doesn't interrupt the intervention. The researcher will inform participants when to start recording and stop recording.

b. Step 1: Check that the participant is comfortable in the VR environment; check that the biometric data collection (5 min)

c. Step 2: VR use by the participant

3. Post-intervention Interview (20-30 min): Participants will be interviewed right after using the VR app about their user experience using the app; and the potential of immersive learning technologies for high-altitude mountaineering.

What are the discomforts and risks?

I will not anticipate you will experience any discomfort or risk during the interviews and the using a VR app. However, I will inform you that you can exclude from interviews or intervention (using a VR app) if discomforts and risks occur. I will exclude you from an interview or intervention if it happens immediately.

How will these discomforts and risks be alleviated?

You will be given the questions before the interview. You should not have any discomfort or embarrassment during the interview as you are experts and familiar with the situations and contexts that will be explored and discussed. However, during the interview, if you feel uncomfortable about questions and the atmosphere, you do not have to answer. You may stop and leave the interview at any time. You can exclude it from the research anytime, and we won't ask anything.

What are the benefits?

There will be a range of benefits of this research. Firstly, it will lead to an enhanced, in-depth, and critical understanding of how people potentially learn using Virtual-Reality (VR) technologies and the processes for utilising VR in authentic educational contexts. Secondly, the research will create new DBR (Design-Based Research) principles and processes for education in authentic high-risk situations for academics who are in high-risk training education. Also, the research develops how to evaluate learning in this risk situation and how it is conceptualised in this context for academics. This research will develop new theories about VR technologies and education for learning technology communities. In addition, it will potentially contribute to the reduction in accidents and improve safety in high-risk environments for climbing communities. Finally, it will be a potential benefit for the researcher as a part of the Ph.D. study, and it will also help the researcher to understand how a design-based research methodology that utilises Virtual-Reality (VR) Technologies be utilised to enhance learning for authentic, high-risk situations effectively.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury due to your participation in this study, the researcher will seek first aid response available on campus at the Universidad Andrés Bello (Campus Viña del Mar). An ambulance will be called to assist the participant, if required.

How will my privacy be protected?

During the period of this research, your consent form, contact details, discussions, and data will be kept confidential. All data will be stored securely and disposed of through the AUT document destruction service.

What are the costs of participating in this research?

Participation will take approximately 2 hours of your time. There are no direct financial costs for participating.

What opportunity do I have to consider this invitation?

Please take two weeks to read the information sheet, consent form, and interview questions sent to you by email and consider participating. If you have any questions, please contact me through email: jin.hong@aut.ac.nz or phone at 0064 9 921 9999 ext 5849.

After this time, I will contact you by email to ascertain whether or not you wish to participate in the interview.

Will I receive feedback on the results of this research?

If you would like to receive a summary of the findings, please tick the designated circle and write your contact details on the consent form.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr. Claudio Aguayo claudio.aguayo@aut.ac.nz 0064 9 921 9999 ext 5253. Mob: 0064 021 024 95862

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Ki Myung (Jin) Hong, jin.hong@aut.ac.nz, 0064 9 921 9999 ext 5849, mob: 0064 021 243 3336.

Project Supervisor Contact Details:

Dr. Claudio Aguayo claudio.aguayo@aut.ac.nz 0064 9 921 9999 ext 5253. Mob: 0064 021 024 95862.

Approved by the Auckland University of Technology Ethics Committee on ……AUTEC Reference number ……..

Participant Information Sheet in NZ

Date Information Sheet Produced:

_/_/2022

Project Title

Developing a Design-Based Research Methodology that Utilises Mixed Reality (MR)Technologies to Enhance Education for Authentic High-Risk (or Extreme) Situations. Click or tap here to enter text.

An Invitation

My name is Ki Myung (Hong), and I am a Ph.D. student in Te Ara Poutama, Faculty of Māori and indigenous Development at Auckland University of Technology. I am conducting this study as part of my Ph.D. research. As a digital media team leader of altLAB (AUT Learning Transformation LAB) at Auckland University of Technology and also a mountain climber, I would like to explore and design new media technologies such as virtual reality (VR) and Mixed-Reality (MR) to enhance education for authentic high-risk situations such as mountaineering. I would like to invite you to participate. This information sheet will help you decide to take part.

What is the purpose of this research?

There will be a range of benefits of this research. Firstly, it will lead to an enhanced, in-depth, and critical understanding of how people potentially learn using Virtual Reality (VR) technologies and the processes for utilizing VR in authentic educational contexts. Secondly, the research will create new DBR (Design-Based Research) principles and processes for education in authentic high-risk situations for academics who are in high-risk training education. Also, the research develops how to evaluate learning in this risk situation and how it is conceptualized in this context for academics. This research will develop new theories about VR technologies and education for learning technology communities. In addition, it will potentially contribute to the reduction in accidents and improve safety in high-risk environments for climbing communities. Finally, it is a potential benefit for the researcher as a part of the Ph.D. study. It also helps the researcher to understand how a design-based research methodology that utilises Virtual Reality (VR) Technologies be utilized to enhance learning for authentic, high-risk situations effectively.

How was I identified and why am I being invited to participate in this research?

The researcher will advertise to seek interest from expert climbers in mountain communities in New Zealand. The researcher will then formally invite those who have expressed interest to participate in the focus groups and interviews.

Contact details will be identified through selected guide companies and climbing communities (such as mountaineering groups) and the personal networks of the primary researcher. Selected participants should have at least five years or more of professional experience in high-altitude mountain climbing contexts including the professional guiding of novice climbers into high-risk situations. Participants will be recruited via advertisements and emails and also through personal climbing networks in New Zealand.

How do I agree to participate in this research?

Your participation in this research is voluntary (it is your choice), and whether or not you choose to participate will neither advantage nor disadvantage you. You can withdraw from the study at any time. If you choose to withdraw from the study, then you will be offered the choice between having any data that is identifiable as belonging to you removed or allowing it to continue to be used. However, once the findings have been produced, removal of your data may not be possible.

What will happen in this research?

The research will involve a biometrics set-up and recording (90 min max): A biometric data collection device, e.g., a smartwatch with biometric recording capabilities, will be set up on the participant's wrist. The biometric data collection will run for the duration of the intervention (i.e., pre-intervention survey and VR intervention). All interventions will be conducted in the AUT app lab in the WU building, Auckland in New Zealand and a studio in Universidad Andrés Bello, Viña del Mar in Chile.

1. Pre-intervention survey (30 min): The survey will cover demographic questions, prior experience regarding high altitude mountaineering, and education experience regarding high altitude mountaineering.
2. Intervention (20-30 min): The intervention will include using a VR app prototype for high-altitude mountaineering education. Participants will use a prototype VR app for 20 minutes and experience a VR app and give the researcher feedback during the post-intervention (interview). The intervention will include the following:

a. Video recording: A researcher will set up video cameras with tripods on the left and right sides of the room so it doesn't interrupt the intervention. The researcher will inform participants when to start recording and stop recording.

b. Step 1: Check that the participant is comfortable in the VR environment; check that the biometric data collection (5 min)

c. Step 2: VR use by the participant

3. Post-intervention Interview (20-30 min): Participants will be interviewed right after using the VR app about their user experience using the app; and the potential of immersive learning technologies for high-altitude mountaineering.

What are the discomforts and risks?

I will not anticipate you will experience any discomfort or risk during the interviews and the using a VR app. However, I will inform you that you can exclude from interviews or intervention (using a VR app) if discomforts and risks occur. I will exclude you from an interview or intervention if it happens immediately.

How will these discomforts and risks be alleviated?

You will be given the questions before the interview. You should not have any discomfort or embarrassment during the interview as you are experts and familiar with the situations and contexts that will be explored and discussed. However, during the interview, if you feel uncomfortable about questions and the atmosphere, you do not have to answer. You may stop and leave the interview at any time. You can exclude it from the research anytime, and we won't ask anything.

AUT Student Counselling and Mental Health are able to offer three free sessions of confidential counselling support for adult participants in an AUT research project. These sessions are only available for issues that have arisen directly as a result of participation in the research and are not for other general counselling needs. To access these services, you will need to:

· drop into our centre at WB203 City Campus, email counselling@aut.ac.nz or call 921 9998.

· let the receptionist know that you are a research participant, and provide the title of my research and my name and contact details as given in this Information Sheet.

You can find out more information about AUT counsellors and counselling on https://www.aut.ac.nz/student-life/student-support/counselling-and-mental-health

What are the benefits?

There will be a range of benefits of this research. Firstly, it will lead to an enhanced, in-depth, and critical understanding of how people potentially learn using Virtual-Reality (VR) technologies and the processes for utilising VR in authentic educational contexts. Secondly, the research will create new DBR (Design-Based Research) principles and processes for education in authentic high-risk situations for academics who are in high-risk training education. Also, the research develops how to evaluate learning in this risk situation and how it is conceptualised in this context for academics. This research will develop new theories about VR technologies and education for learning technology communities. In addition, it will potentially contribute to the reduction in accidents and improve safety in high-risk environments for climbing communities. Finally, it will be a potential benefit for the researcher as a part of the Ph.D. study, and it will also help the researcher to understand how a design-based research methodology that utilises Virtual-Reality (VR) Technologies be utilised to enhance learning for authentic, high-risk situations effectively.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury due to your participation in this study, rehabilitation and compensation for injury by accident will be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

During the period of this research, your consent form, contact details, discussions, and data will be kept confidential. All data will be stored securely and disposed of through the AUT document destruction service.

What are the costs of participating in this research?

Participation will take approximately 2 hours of your time. There are no direct financial costs for participating.

What opportunity do I have to consider this invitation?

Please take two weeks to read the information sheet, consent form, and the interview questions sent to you by email and consider participating. If you have any questions, please contact me through email: jin.hong@aut.ac.nz or phone at 0064 9 921 9999 ext 5849.

After this time, I will contact you by email to ascertain whether or not you wish to participate in the interview.

Will I receive feedback on the results of this research?

If you would like to receive a summary of the findings, please tick the designated circle and write your contact details on the consent form.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, Dr. Claudio Aguayo claudio.aguayo@aut.ac.nz 0064 9 921 9999 ext 5253. Mob: 0064 021 024 95862

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC, *ethics@aut.ac.nz* , 921 9999 ext 6038.

Whom do I contact for further information about this research?

Please keep this Information Sheet and a copy of the Consent Form for your future reference. You are also able to contact the research team as follows:

Researcher Contact Details:

Ki Myung (Jin) Hong, jin.hong@aut.ac.nz, 0064 9 921 9999 ext 5849, mob: 0064 021 243 3336.

Project Supervisor Contact Details:

Dr. Claudio Aguayo claudio.aguayo@aut.ac.nz 0064 9 921 9999 ext 5253. Mob: 0064 021 024 95862.

Approved by the Auckland University of Technology Ethics Committee on ……AUTEC Reference number ……..

Appendix D: Consent Form

Consent Form

Project title: Developing a Design-Based Research methodology that utilises Mixed Reality (MR) technologies to enhance education for authentic high-risk (or extreme) situations.

Project Supervisor: Dr. Claudio Aguayo

Researcher: Ki Myung(Jin) Hong

- I have read and understood the information provided about this research project in the Information Sheet dated dd _ /_ 2023
- I have had an opportunity to ask questions and to have them answered.
- I understand that the study involves stages: 1) using 1st prototype App and evaluation.
- I understand that notes will be taken during the interviews
- I understand that the use of the VR app will be video recorded and transcribed.
- I understand that taking part in this study is voluntary (my choice) and that I may withdraw from the study at any time without being disadvantaged in any way.
- I understand that if I withdraw from the study then I will be offered the choice between having any data that is identifiable as belonging to me removed or allowing it to continue to be used. However, once the findings have been produced, the removal of my data may not be possible.
- I agree to take part in this research.
- I wish to receive a summary of the research findings (please tick one): Yes◯ No◯

Participant's signature:

.....

Participant's name:

.....

Participant's Contact Details (if appropriate):

……..

……..

……..

……..

Date:

Approved by the Auckland University of Technology Ethics Committee on type the date on which the final approval was granted AUTEC Reference number type the AUTEC reference number

Note: The Participant should retain a copy of this form.

Appendix E: Invitation to Participate in The Research Study for Chile

Invitation to participate in a research project in Chile

Project title: Developing a Design-Based Research methodology that utilises Mixed Reality (MR) technologies to enhance education for authentic high-risk (or extreme) situations.

Project Supervisor: Dr. Claudio Aguayo

Researcher: Ki Myung (Jin) Hong

Dear *[Participant Full Name],*

I am Jin Hong, a Ph.D. student at Te Ara Poutama, Faculty of Māori and Indigenous Development, at Auckland University of Technology (AUT) in New Zealand. I would like to invite you to participate in developing a critical design-based research methodology that utilizes Mixed Reality (MR) technologies to enhance education for authentic high-altitude mountain (extreme) situations.

While mountaineers are generally wary of the risk factors in the mountains, there are still fatal accidents happening every year. As a mountaineer, I have encountered several mountain accidents myself, and I have heard of many unfortunate incidents in the climbing communities. This Ph.D. research will explore ways of enhancing the education of mountain climbers on the very real risks of high-altitude mountain climbing. The project will utilise learning theory and design-based research (DBR) methodologies along with virtual reality (VR) and mixed reality (MR) technologies to enhance learning in preparation for engagement in high-risk environments. In this opportunity, I intend to explore a VR learning app to re-create virtually simulated high-altitude environments. I believe this could enable mountaineers to experience and troubleshoot risky obstacles such as altitude sickness, endless crevasses, ice cliffs, and frostbites within a safe yet authentically simulated environment. These new technologies can enable mountaineers to learn by themselves using the app as a form of technology-enhanced self-determined learning tool.

It would be highly appreciated if you participate in the research. The research will be conducted between November 2022 and January 2023 at Universidad Andrés Bello, Sede Viña del Mar in Chile. If you are interested in the research, please email jin.hong@aut.ac.nz. I will provide the information sheet, interview questions, and consent form. You will be contacted by email after two weeks from receiving this email to set the

date, time, and meeting arrangement (online or in-person). During the period of this research, your consent form, contact details, discussions, and data will be kept confidential. All data will be stored securely and disposed of through the university document destruction. If you have questions regarding the research, please feel free to contact jin.hong@aut.ac.nz

Thanks for participating.

Approved by the Auckland University of Technology Ethics Committee on ……

AUTEC Reference number ……..

Appendix F: Invitation to Participate in The Research Study for New Zealand

Advertisement Letter

Invitation to participate in a research project in New Zealand

Project title: Developing a Design-Based Research methodology that utilises Mixed Reality (MR) technologies to enhance education for authentic high-risk (or extreme) situations.

Project Supervisor: Dr. Claudio Aguayo

Researcher: Ki Myung (Jin) Hong

Dear *[Participant Full Name],*

I am Jin Hong, a Ph.D. student at Auckland University of Technology (AUT), Te Ara Poutama, Faculty of Māori and Indigenous Development. I would like to invite you to participate in developing a critical design-based research methodology that utilizes Mixed Reality (MR) technologies to enhance education for authentic high-altitude mountain (extreme) situations.

While mountaineers are generally wary of the risk factors in the mountains, there are still fatal accidents happening every year. As a mountaineer, I have encountered several mountain accidents myself, and I have heard of many unfortunate incidents in the climbing communities. This Ph.D. research will explore ways of enhancing the education of mountain climbers on the very real risks of high-altitude mountain climbing. The project will utilise learning theory and design-based research (DBR) methodologies along with virtual reality (VR) and mixed reality (MR) technologies to enhance learning in preparation for engagement in high-risk environments. In this opportunity, I intend to explore a VR learning app to re-create virtually simulated high-altitude environments. I believe this could enable mountaineers to experience and troubleshoot risky obstacles such as altitude sickness, endless crevasses, ice cliffs, and frostbites within a safe yet authentically simulated environment. These new technologies can enable mountaineers to learn by themselves using the app as a form of technology-enhanced self-determined learning tool.

It would be highly appreciated if you participate in the research. The research will be conducted between January and March 2023 at AUT in Auckland. If you are interested in the research, please email jin.hong@aut.ac.nz. I will provide the information sheet,

interview questions, and consent form. You will be contacted by email after two weeks from receiving this email to set the date, time, and meeting arrangement (online or in-person). During the period of this research, your consent form, contact details, discussions, and data will be kept confidential. All data will be stored securely and disposed of through the university document destruction. If you have questions regarding the research, please feel free to contact jin.hong@aut.ac.nz

Thanks for participating.

Approved by the Auckland University of Technology Ethics Committee on ……

AUTEC Reference number ……..

Appendix G: Demographic and Experience Survey

Demographic and experience survey

Developing a Design-Based Research Methodology that utilises Mixed-Reality (MR) technologies for authentic high-risk (or Extreme) situations.

Please take a few minutes to read through these questions. Your thoughts will help us identify which functionalities to include in a Virtual-Reality app that can help potentially contribute to the reduction in accidents and improve safety in extreme mountain environments. Our research team welcomes your feedback. Your responses will be kept confidential. Thank you for your participation.

Participant responses

1. Welcome / Introduction

   While mountaineers are generally wary of the risk factors in the mountains, there are still fatal accidents happening every year. In addition, even though most mountain climbers have a great range of experiences, they often have less experience in high-altitude mountain ranges due to financial difficulties and difficult accessibility. Given the situation, is vital to develop effective new learning strategies for high-risk environments such as mountaineering. I envision that there will be a range of benefits from this research. Firstly, it will lead to an enhanced, in-depth, and critical understanding of how people potentially learn using VR technologies and the processes for utilising VR in authentic educational contexts. Secondly, I will create new DBR (Design-Based Research) principles and processes for education in authentic high-risk situations. Thirdly, we develop how to evaluate learning in this risk situation and how it is conceptualised in this context. Fourthly, this research develops new theories about VR technology and education. In addition, it will potentially contribute to the reduction in accidents and improve safety in extreme environments.

2. What is your age?

3. Gender?

4. How long have you been climbing?

5. Where do you normally climb?

6. Do you consider yourself in the below categories?

a. Beginner
b. Intermediate
c. Advanced
d. Professional
e. Others

7. Have you been involved in any mountain climbing training? If you have, please select one of Those methods below.

a. From outdoor institutions or training schools
b. Training by local mountain clubs
c. Training with mountain climbing partners

8. Do you have qualifications for mountaineering?

9. Have you climbed high-altitude mountains (above 3000m)?

10. Do you have formal training in high-altitude mountains? If you have, please describe it.

11. Have you experienced an accident in the mountains? If you had, please describe (the cause and solution).

12. Which factors most contribute to accidents? And also, please describe the details.

a. Mountaineers' mistake
b. Natural force
c. Gear failures
d. Others

13. What are the most common mistakes mountaineers make in high mountain ranges (above 3000m)?

14. What are the most common risk factors in high mountain ranges (above 3000m)?

15. Have you used a VR headset before?

16. How much experience do you have with a VR?
a. 0
b. 1-5
c. 5-10
d. 10-20
e. 20+

17. What do you think about VR technology-assisted mountain safety education?

18. What are the disadvantages of using VR technology-assisted mountain safety education?

19. What are the benefits we could achieve using VR technology-assisted mountain safety education?

20. Thank you and close.

Post - Intervention Interview

Developing a Design-Based Research Methodology that utilises Mixed-Reality (MR) technologies for authentic high-risk (or Extreme) situations.

Please take a few minutes to read through these questions. Your thoughts will help us identify which functionalities to include in a Virtual-Reality app that can help potentially contribute to the reduction in accidents and improve safety in extreme mountain environments. Our research team welcomes your feedback. Your responses will be kept confidential. Thank you for your participation.

Section A: Participant Feedback

1. Could you please state your general experience and functionality using this app?

   (What else? DBR)

2. What do you think about VR technology-assisted mountain safety?
   (why? tell me more etc.)

3. What are the disadvantages of VR technology-assisted mountain safety?
   (Why? What other disadvantages?)

4. What benefits could we achieve with this new technology tool for mountaineers?
   (Why do you think so?)

5. What risk factors and prevention in high mountain ranges do you think we need to include in the App?
(Why?)

6. What do you think is the difference between this new technology approach and traditional mountaineering pieces of training in high-risk mountain ranges?

7. What challenges do you anticipate from this VR App training tool in Chile/NZ/Other areas?

8. What broader support do you think we will require to make this solution successful?
(Why?)

9. Do you have any comments?

Appendix I: Participants' Heart Rate Measurement

Table 5. 18. Heart rate measurement - Chile.

Heart rate	Pre-intervention (bpm)	Post-intervention (bpm)	Variation (bpm)
Leonardo	69	98	+29
Rene	62	98	+36
Victor	60	100	+40
Mabel	64	106	+42
Caroliuz	69	111	+42
Alonso	64	109	+45
Chris	51	101	+50
Manual	50	112	+62
Ana	62	126	+64
Elizabeth	Missing	Missing	N/A

Table 5. 33. Heart rate measurement - New Zealand.

Heart rate	Pre-intervention (bpm)	Post-intervention (bpm)	Variation (bpm)
Josh	51	61	+10
Matthew	64	76	+12
Jeremy	70	83	+12
Alfredas	72	84	+12
Sukhwan	75	90	+15
Robin	74	92	+18
Chun	82	102	+20
Yadi	68	96	+28
Sarah	70	100	+30

Margarx	Missing (watch freezing)	Missing	N/A

Appendix J: Theme Codebook

Level			Theme
1	**2**	**3**	
1.000			**Mountain Safety and Education**
	1.05		Environmental factors:
		1.051	Altitude - Mountain Altitude Sickness
		1.052	Cold: hyperthermia and frostbite
		1.053	Weather close-in: Whiteout, strong wind and snowing
		1.054	Avalanche
		1.055	Navigation
	1.10		Physiological factors
		1.101	Cognitive dysfunction
	1.15		Psychological factors
		1.151	Motivation and goals
	1.20		Climbing tools
	1.25		Fitness

	1.30		First Aid
2.000			**Learning theories**
	2.05		Constructivism and Social constructivism
	2.10		Heutagogy
	2.15		Authentic learning
	2.20		Simulation-based learning
3.000			**Tools**
	3.05		Virtual Reality (VR)
		3.055	Like it
		3.060	Disadvantage
		3.065	Useful/benefits
		3.070	Easy to use/functionalities
		3.075	Accessibility/Affordability
		3.080	Safe environment
		3.085	Finance/cost-effective
		3.090	Government/Community/Institution support
		3.095	Languages

		3.100	Culture
		3.105	Practicality
		3.110	Flexibility
		3.115	Geography
4.000			**Design-Based Research (DBR)**
	4.05		Involve the learner in designing their own learning content and process as a partner.
	4.10		Make the curriculum flexible so that new questions and understanding can be explored as new neuronal pathways are explored.
	4.15		Individualise learning as much as possible.
	4.20		Provide flexible or negotiated assessments.
	4.25		Enable the learner to contextualise concepts, knowledge, and new understanding.
	4.30		Provide numerous resources and let the learner explore
	4.35		Differentiate between knowledge and skill acquisition (competencies) and deep learning
	4.40		ecognise the importance of informal learning and that we need only to enable it rather than control it.
	4.45		Have confidence in the learner.
	4.50		Recognise that teaching can become a block to learning.
	4.55		Provide blended learning

Appendix K: Chile Theme Codebook

Participant ID	Theme Code	Question / Answer	Sequence #
Moderator	3.070	**Q1.** Could you please state your general experience and functionality using this app?	01
Manuel	3.070	I think that at least the audio part is really well done. I knew that it was a simulation, but the audio part really gets the job done to involve you in that scenario. And of the visual part, it's blurry. It's blurry because you need to focus using edgers, so it's blurry.	02
Manuel	3.095	Even I had a little bit of a problem with my hearing. Yes, definitely. We will have an international version, like Spanish, English, French, Italian.	03
Chris	3.055	The experience is nice in terms of, as I said, the setting, wind conditions, the menus are easy to understand.	04

Chris	3.070	And those words. Maybe some pre-training for understanding how to use the controls, the buttons. They work fine, but I needed some training, some help from you, in order to make them work.	05
Anita	3.055	Good, I feel good. It was very rare to be there.	06
Anita	3.070	I think that could be better in the application, maybe? If I can move a little bit more. Yes. But yeah, it feels good.	07
Carolina	3.055	In general it's a good experience	08

Carolina	2.15	In general terms, it is quite real, you can feel the wind noise, the environment of the mountains with the snow, it's like being in the mountains And I thought it was a good experience, that it really reflects the situation in a certain way	09
Victor	3.065	I think it's really good to educate the students of Alta Montaña Before going and being there. It's like an activity in Alta Montaña, a charity, an expedition. Of course, it's a really good initiative so that the person is not in a situation where the weather gets worse and a partner gets busy It's like saying, I'm in the situation, I already lived it, you have to act this way It's like doing the practice, something like that. So yes, I found the image very good, the instructions, everything, a good experience.	10.1
Victor	2.15	I think it's really good to educate the students of Alta Montaña Before going and being there. It's like an activity in Alta Montaña, a charity, an expedition. Of course, it's a really good initiative so that the person is not in a situation where the weather gets worse and a partner gets busy It's like saying, I'm in the situation, I already lived it, you have to act this way It's like doing the practice, something like that. So yes, I found the image very good, the instructions, everything, a good experience.	10.2

Victor	4.30	It's a good experience, it's very good to practice before a high expedition, to make some decisions And it's a good way to educate for climbers.	11
Leonardo	2.15	I think it's very good because the vision that I'm looking at, it's very clear the scenario. I understand immediately what is my condition in the place.	12
Rene		No comment	13
Elizabeth	2.15	The experience was good, something different. It's all... all good, all right. It's different. I didn't get nervous. It will be good to put more nervous in some situation, make it more dangerous. And... Give her... an idea of how to prepare. It takes you out of the theoretical. It takes you a little more to the practical. That's what I like.	14

		I really like it, because... it's different from the books, from the texts. It gets a little closer to reality. And get... out of the theory.	
Mabel	3.070	I would say that it was clear for me to understand that it was like different levels. For me that was kind of clear.	15
Mabel	3.070	I would like to repeat the radio information. Because I'm used to always repeat twice information. I want to hear it, if I can, two times. So, for me, that information, I can answer it better. Yeah, that was the most kind of a stressing situation.	16
Alonso	3.055	In my general experience, I found it innovative. I would have liked to know, or remember more about the mountains, since I don't remember. my experience was good, I didn't feel uncomfortable.	17
Moderator	3.055	**Q2.** What do you think about VR technology-assisted mountain safety?	18

Manuel	3.100	Yes, yes, yes. I think it would be nice to like the courses of the WAFA, I don't know if you know, Wilderness First Aid course. The W-A-F-A, Wilderness Advanced First Aid. Advanced First Aid, yeah. Like for that course, because there are many techniques that are teached like a PowerPoint and not always you have like the, you know. For example, I do a first aid course in summer. So, if they teach me a technique that is meant for wintery places, I can't do that because the season isn't right.So, I think that's like an advantage that could be used.	19
Manuel	3.100	Yes, I think that's the main idea. I think in Chile it would be very helpful to have this technology, because we are 80% mountains. Safety Federation. Here in Chile, there is a news that says that 83% of accidents occur in very low altitudes in the mountains. That's a good point. The majority of accidents occur in low altitude mountains, not in snowy places. And it is because of the lack of education of the people. Because of the pandemic, many people started to climb mountains. And none of them had a skill or studied.	20
Chris	1.151	Safety education is always useful. Now for those guys who like climbing, ascending to those meters, in the understanding that they are going beyond 3,000 meters of sea level, they are quite prepared for that.	21.1

		But this sort of training or question and answer survey makes you realize that you have to be aware of any condition. Don't forget that. Most people tend to be, as I wrote before, overconfident. I know the mountain. I know how to do anything. Not always.	
Chris	3.065	Safety education is always useful. Now for those guys who like climbing, ascending to those meters, in the understanding that they are going beyond 3,000 meters of sea level, they are quite prepared for that. But this sort of training or question and answer survey makes you realize that you have to be aware of any condition. Don't forget that. Most people tend to be, as I wrote before, overconfident. I know the mountain. I know how to do anything. Not always.	21.2
Anita	4.25	It's nice to grab the walkie-talkie and make choices. I like that. Like, choose your own adventure. Something like that. I imagine when I walk with the thing in my head, I was imagining that it's going to make me some questions, and going to be like that, that I make a choice and then the scene changes and go high, and then maybe I did or not	22

Carolina	3.080	I think it brings a person closer to the real situation, not 100% real, but 90% or 80% of what could happen it's good to educate and really train a person before they live the real situation I insist, it's not going to reflect the real situation at the moment, but at least it brings them closer So I think it could be useful for a mountain training school If you attend and use this device, you could live the situation in a good way	23.1
Carolina	2.15	I think it brings a person closer to the real situation, not 100% real, but 90% or 80% of what could happen it's good to educate and really train a person before they live the real situation I insist, it's not going to reflect the real situation at the moment, but at least it brings them closer So I think it could be useful for a mountain training school If you attend and use this device, you could live the situation in a good way	23.2
Victor	4.35	I think it's a good initiative. I think the most important thing... I'm trying to practice as I said before, it's like the theory, to enhance the theory because when they teach you in the classroom, they teach you the theory and you imagine it, but here, they are teaching you the theory while you are living. It's like theory and practice at the same time so it's very good for the human brain, it stores the actions, it memorizes the actions. The reptilian brain It's virtual reality, so it's not going to emulate or be comparable to reality. It's like a memory aid, more efficient compared to a simple theory delivered in a classroom.	24

Leonardo	3.070	I think it's better to test for more extreme situations.	25
Rene	3.070	From what I saw... that it works, it works. The only thing is that... the situation... Well, I think it's because of the application, more than anything. But it can lead to a more stressful situation.	26
Elizabeth	3.065	Yes. It will help a lot for preparation.	27
Mabel	3.065	Because some common experience, you can prepare it here, but those are so specific and special, that I think to be exposed of that previously and to make decisions, maybe it will help. Yes, it will help, because you can answer on specific medical situations, that you have to remember them, you have to repeat them to remember them better. So, for example, the information that you gave me previously, this VR experience, about this kind of reaction is this high, and you have to remember all that information. If you read it, okay, you have that information, but if you have the experience of answering the questions, like you're in this situation, blah, blah, blah, I think it's more interactive, and it is always a better way to keep that information in your mind.	28

Alonso	3.065	Good for preparation	29
Moderator	3.060	**Q3.** What are the disadvantages of VR technology-assisted mountain safety?	30
Manuel	2.15	I think that because I knew that it was a simulation, I wasn't getting like that nervous. I wasn't feeling that danger sense. And because of that, I think that it is like complementary to mountain safety teaching, but like not essential. Because in a mountain rescue environment, you have to prove your knowledge in real life situations. When you know that your life is at risk.you cannot include all of the things. Right? You can just give the basic principle and you modeling it. But in the real world there's more and more. Lots of more.	31
Chris	3.060	Maybe the level of specificity. Because climbers, at least most of them, should be fully aware of any conditions and be prepared how to cope with these kind of risks and also accidents.	32
Anita	3.105	I think it's like more advantage than disadvantage, but maybe a disadvantage can be that it doesn't involve physically, it can be different if I'm in a machine that makes me physically involved. if you teach students about how to use a rope or harness, right? This one, it's a bit hard.	33

Carolina	2.15	It could be very obvious, but it's not the same. I mean, it's really not the same. Although the images are the same I know that I'm living a situation that is not real. Without a doubt it's not the same But it's close,	34
Victor	3.070	Of course It's necessary to complement the visual with the sensations Like, for example, the X-frame movie theater that has heat, wind, splash of water. It moves, of course In this case it was necessary to complement with, for example Maybe in a place where there is a small slope to be able to walk a little in a place to give the option of being able to walk a little In a path, for example, to make it a little more real.	35
Victor	2.15	When you make a decision, let's say, being rested. It's not the same as when you make a decision being exhausted. When you are exhausted, the patience is less and the anguish is greater. So it's not the same to really feel that you've been walking five, seven hours, your body doesn't resist you anymore and it's also a complex situation. But, here I'm resting, well, standing I don't feel cold, I'm not supposed to be tired,of course, I can take the liberty of deciding with my brain a little calmer. Do you understand me? So when you're tired, when you're hungry, obviously the time to make decisions changes and that, virtual reality can't reflect it perfectly well.	36
Leonardo	2.15	I think that this situation is very basic. It's very basic. But I think that it's good to teach what's the real situation. When I stay in the mountain, and I feel something, or I stay in the rescue situations, you can't have the time to look around you.	37

		I'm very relaxed today, but in this situation, I think it's good to put this thing inside the cooler.	
Rene	2.15	The main disadvantage would be the lack of equipment. And, for someone who has done mountains it's the lack of reality.	38
Elizabeth	3.105	Using equipment is hard.	39
Mabel	4.25	Those kinds of things, like all the natural things that can interrupt the communication. Maybe, because I didn't see someone, you put me in the area, but I didn't understand the actual situation. Because you said to me, there is someone feeling sick, because of the VR, I can see someone, he is acting like you said, he is acting weird, and I see someone acting weird, and probably I would react in a more alarmed way, you know? Like, what is going on? And maybe I can't answer. It's like a no visual, right? Yes. You only can hear it. Yes, I just imagine that someone is, but if I saw just a black thing moving.	40
Alonso	3.075	Access to this tool. Affordable. Access to this one and affordable.	41

Moderator	3.000	**Q4.** What benefits could we achieve with this new technology tool for mountaineers?	42
Manuel	3.105	I think that the organisation teaches mountain safety can have like more people involved. In the course, you can have more. Because in the mountain course, there is always like 10 people, or at least here in Chile. Restricted number.	43
Chris	2.20	I would certainly say this is a pre-training before going up. Yes. Like every simulation, you try to replicate the environment with risky situations, with accidents, conditions, people getting dizzy or with a blurred vision. This is exactly what you can go through in a real setting. Lack of oxygen. It's quite different, isn't it? If you get done pre-training before you go climbing, then you have very fast knowledge, good information. So at least when you go, you have pre-equipment knowledge, so you can judge and make good decisions. Be aware this might happen. So take proper actions to avoid these kinds of conditions.	44.1
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		Lack of oxygen. It's quite different, isn't it? If you get done pre-training before you go climbing, then you have very fast knowledge, good information. So at least when you go, you have pre-equipment knowledge, so you can judge and make good decisions. Be aware this might happen. So take proper actions to avoid these kinds of conditions.	
Chris	4.45	You could learn by using the app. That's right, yeah.	45
Anita	3.110	First, you don't need to be in the mountains to train some factors, like mental factors or decision-making. I think for decision-making factors or training, it's very, very effective. Decision-making process is good using this tool because you don't have to be in the mountains.	46
Carolina		No answer	47
Victor		No answer	48
Leonardo	3.065	I think they have a real benefit, a very good benefit. For example, this situation today, it's very good for initials, Mountaineers. Okay. For example, in the basic course, or the basic information. Novice climber.	49
Rene	3.080	Get experience. Get experience in an accident without having to actually happen so they can	50.1

		learn. Because one thing is that they teach you in the courses but when you live it it's very different. Have experience with accident without actually happening so they can learn. You can control situation.	
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Elizabeth	4.20	I can take you to different places. You know the equipment and the environment in which you are. And if you are new, we put you in a new situation in different scenarios with different equipment and with different conditions.	51
Mabel	4.30	Not like textbook, yes, the people are more involved in the situation. It's more perceptive information. Because you are actually doing it, even listening, but you have to click and you see the environment, so you're more engaged in the learning.	52

Alonso	4.15	Education. Education purpose, right? To the new climbers and the old climbers.	53
Moderator	1.000	**Q5.** What risk factors and prevention in high mountain ranges do you think we need to include in the App?	54
Manuel	1.30	I think that the major point that you can add more techniques in first aid. Because in the acute mountain sickness, during the VR, set the symptoms. But I was doubting a little bit because there are two major points that anyone takes into account in this diagnosis, I think. That it's heart rate and respiration rate. In the VR, they didn't say that when it's in an emergency situation, the first thing that one has to do is take the vital signs. Because of that, I was doubting if that was a pulmonary edema or an AMS or something like that. Because in the first aid course that I took, the vital signs were essential to a diagnosis.	55
Chris	1.20	It would be nice to add some training regarding how to wear the gear. How to use the gears. Yes. Yeah. For instance, how to use the radio. And then also how to dressing when you go high mountain. This kind of stuff, right? First of all, the kind of gear you're going to need, depending on the kind of climbing you're intending to perform.	56

Anita	1.054	Like maybe more scenes with other risky scenes. Okay, like avalanche, landslide	57
Carolina		No answer	58
Vicotor		No answer	59
Leonardo	1.20	How to use the tools. So if your client partner falls into crevasse, how to rescue so the tools include using an ice axe.	60
Leonardo	1.054	Weather forecast	61
Rene	1.054	I think we need to focus on the most typical things or what we can find more than these storms, for example, air heal, low visibility landslides an avalanches typical things	62
Elizabeth	1.20	No answer	63
Mabel	1.30	I would like to learn more about first aid.	64
Alonso	1.20	The use of gear	65
Alonso	1.054	Avalanche awareness	66
Alonso	1.053	Weather pattern.	67
Alonso	1.20	And there was self-rescue. If you're falling into a cliff or crevasse, how to rescue yourself?	68

		How to recover. Yeah, so... Tools. Technics. I think if possible as well, a bit of, like, given this VR button, have a bit of movement. Yes. So, like trying to replicate a scenario.	
Moderator	**2.000**	**Q6.** What do you think is the difference between this new technology approach and traditional mountaineering pieces of training in high-risk mountain ranges?	69
Manuel	3.070	I think there are, in a face-to-face situation, you don't have alternatives to select. And the sole fact that there were alternatives, someone that hasn't studied that much can remember, in my classes, I remember that this was the way to go. And in a face-to-face situation, one has to practice and study much more. So face-to-face study in that situation, I think it's better. But if some way you manage to make someone answer these questions in real life without an alternative, I think that's much better. Okay.	70
Chris	3.075	Accessibility. You can access this experience through a cell phone or a computer, maybe. You can be anywhere and access this. Secondly, it might not be affordable in a live situation. For instance, a club. The timing. If you have to work, you will be given a few hours per week and go to this club for getting a couple of hours of training. But at home, you can do it anytime.	71

		Replicating an experience that you can't have in person. Because of the time, because of the money, or maybe because of the mountain, because it's too far from you.	
Anita	3.080	Yeah, experience. Maybe being here in this experience, you know that you are in a virtual experience and you are not in the stress of doing the decision-making with the stress. It's very different to being at home. But that I think it's the advantage to do this thing at home because you don't have the stress and you can think with calm to make decision and you repeat, repeat, repeat. You can improve your decision-making in the mountain. But if you are traditional, the mountain is hard because stress and then decision-making process is going to be harder	72
Carolina	2.20	This experience is a little more real less adrenaline and the mountaineer wants to live the adrenaline even when there are risks and intricacies, that would be the biggest difference for me. If it can somehow enough to indicate key parts to improve on, it's used in conjunction with that. The difference between both things is probably the climbers prefer the real experience and don't stay sitting in a classroom and hear some person about what can happen. But this app is more realistic so it's closer to reality while the climbers hope Ok.	73
Victor	3.060	Although this is a useful technology one can predict things. A person who climbs a	74

		mountain will always want to live the experience. It's so similar with the reality But there is no feelings about... Sense, no sense of reality.	
Leonardo	4.15	I think the traditional training is better because you're staying in the environment. We have so many people here that go to the mountains and never take the cars. And in this case, this is very good. And this tool is, people say, wow, I want to do it. I want to learn with this tool. Maybe people can say, okay, I want to learn because this is very attractive to me. People like the technology. Traditionally, the real approach to the real mountain, you can feel the real environment. But this tool can be very good for inexperienced climbers. Or for experienced climbers, also for new situations.	75.1
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		can say, okay, I want to learn because this is very attractive to me. People like the technology. Traditionally, the real approach to the real mountain, you can feel the real environment. But this tool can be very good for inexperienced climbers. Or for experienced climbers, also for new situations.	
Rene	4.40	I think that when you have a VR and visualize the situation, you can see something more objective more than imagining the situation because when you imagine the situation you have more answers. Traditional is more subjective it's more subjective because in the sense that you do everything so practical that if they put you in a situation and then you come to the practice to do what would you do in that situation.	76
Elizabeth		No answer	77
Mabel	3.075	The main difference I would say, this would be cheaper. Yeah, this one, VR. It's more accessible. Accessible, safer. You hear you have all the experiences controlled. Accessibility is quite important and time-saving	78.1

Mabel	3.080	The main difference I would say, this would be cheaper. Yeah, this one, VR. It's more accessible. Accessible, safer. You hear you have all the experiences controlled. Accessibility is quite important and time-saving	78.2
Mabel	4.40	The main difference I would say, this would be cheaper. Yeah, this one, VR. It's more accessible. Accessible, safer. You hear you have all the experiences controlled. Accessibility is quite important and time-saving	78.3
Alonso	2.15	The place. Place. The feelings and sensations	79.1
Alonso	3.080	The risk, yeah. Because if you're using this one, no risk	79.2
Alonso	3.085	Affordability. If you go to mountain training, expensive.	79.3
Moderator	4.000	**Q7.** What challenges do you anticipate from this VR App training tool in Chile/NZ/Other areas?	80

Manuel	3.095	Definitely, language, Spanish	81
Manuel	3.115	I think that if you want to bring this technology to Chile, it has to adapt to the environment here in Chile. The simulation was in a snowy, wintery place but there is a half of Chile, the north half of Chile, where we don't see snow. So we see snow at the top of the mountain only because I'm from the north of Chile. I think adjusting the environment to the different climates of the country is a vital thing to do in teaching mountain safety. Here in Chile, there is a news that says that 83% of accidents occur in very low altitudes in the mountains. The majority of accidents occur in low altitude mountains, not in snowy places. And it is because of the lack of education of the people. Because of the pandemic, many people started to climb mountains. And none of them had a skill or studied. It would be very easy to teach them with this technology. Please don't take photos in a dead end. That's for the safety of everyone. I think the tourism agencies will be very happy to take part in this.	82
Chris	1.20	Definitely, language, Spanish, yeah.	83

Chris	3.100	Or a cultural challenge. In the case of Chile, an environment with snow is not quite popular. But in summertime, everyone wants to go climbing. Climbing? But not winter climbing. Winter may be harsh near the mountains. So, you won't get access to the mountains even if you want to or can. You won't be allowed to enter. Yeah, especially Andes is quite high mountain. Yeah, I got that point. I've been not allowed to access some sectors during wintertime. Because of landslides. That's the major risk.	84.1
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Anita	3.085	Probably the first thing that is expensive technology. Yes. Then, yeah, I imagine that if this technology comes to Chile, probably it must be like universities or specific programs.	85.1

		Like a national thing, we don't have like a very promoted mountain culture and that could be challenging if I want, for example, to ask for money for the government. I don't know if the probabilities to get it are very big.	
Anita	3.100	Probably the first thing that is expensive technology. Yes. Then, yeah, I imagine that if this technology comes to Chile, probably it must be like universities or specific programs. Like a national thing, we don't have like a very promoted mountain culture and that could be challenging if I want, for example, to ask for money for the government. I don't know if the probabilities to get it are very big.	85.2
Carolina		No anwser	86
Victor		No anwser	87
Leonardo	3.075	Maybe challenge is that this tool is expensive	88
Rene	3.075	That would be like a mountain in Chile. And the other, well, in regions, is the lack of accessibility. For example, a rescue in Torres del Paine will be done in three days, if you don't have a helicopte	89
Mabel	3.075	I would say like the key to get this in the right places is to contact locally.	90

		They probably won't get into the, they won't look for a VR experience. They would like to go to the mountain, you know. So, but if you go for the, like here, universities or specific places that give, workshops or activities to educate people, like in clubs or universities, they will use them, but not individual people.	
Alonso	3.075	The access, how we can reach to the kids, for example, or the most people as possible. And then, so accessibility and reach to many people, and then reach to kids? Reach to kids, organizations, universities. Reach to organizations,	91
Moderator	4.05	**Q8.** What broader support do you think we will require to make this solution successful?	92
Manuel	3.085	I think lately, it has grown the interest in the mountains. And because of that, there have been new organizations. Like CEM, C-E-M. Center of... Centro de Investigacion en Montaña? No. It's CEM? Centro de Investigacion en Montaña. Centro de Estudio en Montaña. Our research center of... Of a mountain. Yes, C-E-M. I think maybe they will be also interested. The agencies of tourism, I think that's another point. The jobs of the mountain guides are to guide people with no experience.	93
Chris		No answer	94

Anita	3.090	Fund, fund, you need to fund. Yes, yes. Then, yeah, then different organizations, institutions that have real interest in this like federations, clubs, mountain organizations, associations.Now in Chile there are some associations, the FEACH, which is the National Federation of Mountaineers, that maybe they could be interested in this. That mixed with the good resources, money, funds, could work.	95
Carolina		No answer	96
Victor	3.085	The government too, some companies, some innovation companies, some competitive funds, because it is necessary to make some innovation in some sport, for example... Snowboard. For example, for snowboard, in association with the innovation companies and the mountain clubs, they come and support the project with using the feedback, making the feedback, and some other resources.	97
Leonardo	3.085	Take the real situations and put inside the software, for example. Real cases. When I teach, time by time, we are talking about the real situations. These days, these situations, these people, these are the conditions. And this is a very, very good help to the training.	98
Rene	3.090	I think it's a prototype. To make it as real as possible, for different scenarios. To include as many students as mountaineers already prepared.	99

		To target large companies. Patagonia could also do something similar with climbing, because Patagonia climbs a lot. Something like that. Something like that, put a brand that needs advertising and that has a lot of money. So they don't have to be thinking that the person can go to finance, they can sign directly. They could benefit. I think that the brand wants an experience. Or different companies. it's for students. It's more important for students. And to find economic support in mountain trails.	
Elizabeth	3.090	And several educational centers of mountain security. As a first aid course, they integrate the VR and at the same time they buy the app to do the course. So you not only have the physical material, digital, but also the reality of the story. Because a VR can be used in water rescue courses, rafting, for example. In education, for example, they do a lot of work with teenagers. I can show you a real situation in Avalanche. Then I would look for educational centers. Educational centers for companions. Yes. And before that, I would look for funding from the university. And that's it. Several stores might be interested.	100

		And mountain education centers will buy the application to do this course. There are a couple in Santiago. I think it would be interesting to use the app for the course. But the science behind the situation, we need more education on that. So, anyone can actually teach about the science behind it. So, it's a learning pedagogy. New learning pedagogy	
Mabel	3.090	we will need time. Yeah, and also government initiative. College government fund as well. Again. Government, your government. Yes. Yeah, the fund as well. Yeah, we... Our club can apply funds to the sport ministry.	101
Alonso	3.090	Technology and contents. Learning contents. And also, maybe provide this tool for the community in a good price. It can be, then everyone can afford it. Yeah. Technology.	102
Moderator	4.000	**Q9.** Do you have any comments?	103
Manuel		No answer	104
Chris	3.080	Sometimes when I get a new kind of app, it's a bit daunting how to use this one. And sometimes the technology makes you a bit phobia.	105

		You're not happy about the technology. Oh my God, this is not going to work. I'm not going to use it. Most people are not used to using this kind of equipment. This kind of tools. VR in your cell phone. Or wearing these goggles. And we've seen so many fails on YouTube of people using VR. I've seen grandmas wearing these goggles. And running in the kitchen because a dinosaur is chasing them. It's funny. Very funny. People tend to fall or get dizzy. Yeah, that's a very common symptom, common happening when you use VR. When you get a full view and you start moving. Yeah, and they fall and crash into something. That's why we've got a safe line. So actually there is a rule of thumb. Pole by pole. It's a very safe area you need to create. So there's nothing there.	
Anita		No answer	106
Carolina		No answer	107

Victor	4.55	my risk was not to get hurt. My risk, I mean, my biggest fear was not that I was going to fall, or I don't know. My biggest risk was how my body was going to behave. Because the training already showed that. I climbed a lot of hills, my heart capacity, my physical capacity, it could be that, but I didn't know if I was going to get a headache, I didn't know if I was going to puke, I didn't know if I was going to want to throw up, I didn't know if I was going to faint. I think those were my biggest fears. And more than measuring how I was going to see the mountain visually, I would have liked a technological system to help me measure that, to make the decisions. For example, I haven't reached the peak yet. I'm a little afraid, not how I'm going to see the mountain, but how my body is going to feel. I don't think the virtual reality is going to achieve that yet. Maybe another technology, a hyperbolic camera, maybe. I don't know. The challenge of the mountain is something mental. Something physical.	108
Leonardo		No answer	109
Rene		No answer	110
Elizabeth		No answer	111
Mabel		No answer	112

Alonso	2.15	Innovative? It's innovative, yes, and if the community research this, it will be great. Great results. Okay. Community environments.	113

Appendix L: NZ Theme Codebook

Participant ID	Theme Code	Question / Answer	Sequence #
Moderator	3.070	**Q1.** Could you please state your general experience and functionality using this app?	01
Robin	3.055	It's it's very It's interesting. Mhmm. But I like the I can't see quite clear in there. That's the problem because of my glasses. Okay. Yeah. I think probably the headset headset can adjust that Mhmm.	02.1
Robin	3.070	It's it's very It's interesting. Mhmm. But I like the I can't see quite clear in there. That's the problem because of my glasses. Okay. Yeah. I think probably the headset headset can adjust that Mhmm.	02.2
Robin	2.15	Yeah. Just that that that that's Yeah. When when I like look around and Mhmm. It's really got that like a feel a little scary. Mhmm. It's like a big it's like you imagine yourself is in that situation Mhmm. Authentic. Like change the scenery or something like the snow comes in. Yeah. Okay. Can get the sounds as well to make it more vivid. Yeah. It's it's quite nice.	03

Robin	3.070	I think it's like as English is not my first language, so I sometimes maybe missed the the question or like a hint. So like to listen it. Oh, yeah. If if you go to the function like a replay it again.	04
Suckwhan	3.070	It would be nice if it was a little easier.	05
Yadi	3.070	It's quite fun. In terms of the virtual reality and the way I can, the interactive options, functions.	06
Chun	2.15	It's very real. Very real? Yeah, and I feel a little bit nervous in the beginning. Okay. Because I suddenly been put into the mountain. Oh, because you suddenly into mountain. Sound is good. Wind? Wind? Yes. And also, the guy talk to me. Oh, okay. Base camp. Base camp.	07

		It's like Himalaya. It's quite authentic environment.	
Sarah	2.20	It was good to get the visual and audio Stimulation? I guess for me it was more like visual stimulus was important to me So I did a lot of looking around For example, the wide out part, looking around And then I saw like a tent there So just collecting information And the controls were quite easy to use There were a few bugs But the general concept was good	08.1
Sarah	3.070	It was good to get the visual and audio Stimulation? I guess for me it was more like visual stimulus was important to me So I did a lot of looking around For example, the wide out part, looking around And then I saw like a tent there So just collecting information And the controls were quite easy to use There were a few bugs But the general concept was good	08.2
Matthew	3.070	I couldn't feel any coldness or whatever, so it was just more of an audio-visual experience. I think all the communication that I was hearing was quite clear	09

Jeremy	3.070	I think there could be a lot of cool applications for it. I think it's, the immersion is really necessary. But it's also hard to do, maybe, you know, there's only a certain limit at which you can replicate the real thing	10.1
Jeremy	2.15	I think there could be a lot of cool applications for it. I think it's, the immersion is really necessary. But it's also hard to do, maybe, you know, there's only a certain limit at which you can replicate the real thing	10.2
Alfredas	3.065	Good, something new. Well, I can compare with watching videos or reading some books, but this is more interactive. So, it's more like you get involved in it, like more being in action, and without any harm to yourself, which is good. And less harm. Basically, harmful environment.	11.1
Alfredas	2.10	Good, something new. Well, I can compare with watching videos or reading some books, but this is more interactive. So, it's more like you get involved in it, like more being in action, and without any harm to yourself, which is good. And less harm. Basically, harmful environment.	11.2

Margax	3.065	It's hard to say, but I actually learned today reading through the altitude sickness. Yeah. So, yeah, it was quite informative.	12
Josh	2.20	Well, it's a good opportunity to immerse yourself in a simulated alpine environment and make decisions as if you were there. So when we make decisions, we take what we are seeing alongside the information that's given to us.	13
Moderator	3.055	**Q2.** What do you think about VR technology-assisted mountain safety?	14
Robin	3.065	Gonna Yeah. Definitely gonna help. That's right. So this is trend	15
Suckwhan			16
Yadi	2.15	If it's more developed, then I think it will be better just to learn mountain. Mountain risks, safety, in the book. You would benefit. So I think it's more interactive way to learn. So if it's developed in advance, right? Advanced	17

		skill, right? Then it would benefit for mountain safety. I mean, is to get access information or what is to learn? I think easier to learn. Because you feel like you are in that environment. So it's more engaging. You feel like you are in the environment, right? In authentic environment.	
Chun	2.15	I think yes. Because, yeah. It's much better than just use traditional ways to answer the questions. The environment is responding to the situation in an authentic environment is very critical to me. So, the environment responds to an authentic situation? Yeah. Situation.	18
Sarah	3.065	I think it would be quite useful especially for beginners because they are not ready to get into those harsh and dangerous environments yet So safety is one Also just getting experience Just getting to experience what more experienced mountaineers do Yes So climbing progression, I think it would be good for that as well Okay That's just good Yeah, because I've never done a 3000m plus trip before So I don't even know what it's like up there I've only seen mountains like photos I don't know what it's like up there	19.1
Sarah	3.080	I think it would be quite useful especially for beginners because they are not ready to get into those harsh and dangerous environments yet So safety is one Also just getting experience Just getting to experience what more experienced mountaineers do Yes So climbing progression, I think it would be good for that as well Okay That's just good Yeah, because I've never done	19.2

		a 3000m plus trip before So I don't even know what it's like up there I've only seen mountains like photos I don't know what it's like up there	
Sarah	3.065	VR is a good thing You can keep it to yourself And until you're familiar with the scenarios. But then Traditional training You have to When you set up the anchor You have to keep it Until you're confident I know how to set up the anchor But then you have a time limitation When I was training a long time ago It was the same thing 20 people training Your turn only once You watch and do it once You don't know if you're doing it right And that's it Unless you go climbing with a climbing partner	20.1
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Matthew	3.065	In terms of those specific questions, to a person who is quite experienced, they would probably be quite straightforward answers, but to a person who, like me, doesn't really know, I guess it could be useful.	21
Matthew	4.15	I think a tailored approach would… One for beginners and one for more experienced people. I think that would be… And then, correspondingly, you'd probably want a	22

		manageable condition that a beginner would be comfortable with, and then a more experienced person would be comfortable. So, for example, where they're changing rapidly, maybe an experienced person would be used to that. So, create a manageable condition for beginners and then… Yeah, and I guess… As a beginner, I didn't really know what the answers were, so obviously, it just had to be tailored, I think.	
Alfredas		No answer	23
Jeremy	3.065	I think it could be really helpful. I like the idea of, like, practicing, so maybe not even just, like, the knowledge aspect, but practicing certain, you know, emergency scenarios in a safe environment before doing it in a potentially dangerous environment. Yes. So, you know, the thought of sort of getting it ingrained into your muscle memory before doing it. Visualizations of it, so, you know, the mountains and the snow and the wind. I thought it was helpful	24.1
Jeremy	2.20	I think it could be really helpful. I like the idea of, like, practicing, so maybe not even just, like, the knowledge aspect, but practicing certain, you know, emergency scenarios in a safe environment before doing	24.2

		it in a potentially dangerous environment. Yes. So, you know, the thought of sort of getting it ingrained into your muscle memory before doing it. Visualizations of it, so, you know, the mountains and the snow and the wind. I thought it was helpful	
Margax		No answer	25
Josh	4.30	OK, yeah, yeah, 3D rendering, yeah. You could also use it for case studies on previous accidents. So you can put people in a similar scenario and see what decisions they make. Oh, OK, yeah, yeah. And you can use that to teach people. Say, we're going to give you a scenario that's a real life one. Let's see what decisions you make.	26
Moderator	3.060	**Q3.** What are the disadvantages of VR technology-assisted mountain safety?	27
Robin	3.060	People maybe if it's like a beginner, they probably overlook something. They thought they know everything. But it's actually in this environment you cannot include all of the things. Right? You can just give the basic principle and you modeling it. But in the real world there's more and more. Lots of more. Things there.	28

Robin	3.060	The problem with the you're using VR is that you've got limited space. Mhmm. Yeah. So if you've got that, you have to move. Right? Maybe. Yeah. In the like a theme park is actually you sit inside something. Or you kind of in a in a protected space.	29
Sukwhan		No answer	30
Yadi	2.15	Quite limited now. Like you cannot feel the cold weather. So it's not real experience. And in that situation, you might be scared or more nervous.	31
Yadi	3.070	The VR set is too heavy. VR set is too heavy. Discomfort. Not hygienic enough? Hygiene. Many people use. Dirty. Disgusting. Smelly.	32
Chun	3.070	I think the only thing is like in the beginning, I don't know how to use the devices. But I just use maybe one minute to get used to it. So, usability. It's more interactive, okay. Because I cannot say A, B, C, D. It's easier for me. If a user can communicate. Communicate within the app	33
Sarah	2.15	I think because it's safe You don't Get the full experience And the full experience You need to consider things like Fatigue Weather Cold, you might be hungry You might actually be experiencing Altitude sickness That's going to	34

		impact judgment That's right I guess this is something you could introduce But weather Weather is very dynamic You've got to consider that when you're outside So that Can't be reproduced in VR	
Matthew	2.15	I mean, the obvious one is, like I said at the start, I'm not feeling all of those sort of things. That's right. It's not really authentic, right? But at the same time, if this is just to provide a very much significantly cheaper alternative, yeah, it makes sense.	35
Matthew	3.060	In terms of disadvantages, I mean, I was writing down on the piece of paper before that it might not be the same sort of experience for an older person because maybe their eyes are a bit different from the whole thing. People might get distracted by the way VR works versus maybe like a rapid response in that specific situation. Yeah, distracting people. Yeah. So, I mean, I know that this is the developer's side of things, but the bugs that could be… Yeah, the bugs, yeah.	36
Alfredas		No answer	37
Jeremy	2.15	There is certain, you know, there's a lot of, like, the physical situation, a lot of the physical aspects of the situation that you can't recreate. So, you can't, even if you know about, like, high altitude mountain sickness,	38

		it's a much different thing whenever you actually are feeling it. And so, I think even that, that, let's say, also, like, the wind noise, I think, was helpful. But, you know, you're not in the cold. You maybe don't feel the thinness of the air. So, those are probably some of the disadvantages.	
Margax		No answer	39
Josh	3.060	I said that one of the disadvantages is that you're limited to the availability of the technology. Yeah. So what we noticed is when we were doing community fire safety events, we had maybe four or five VR headsets available, but we often had 20 people that wanted to come for Enduro training. So it limits you to your group size that you can take. Yes. So it is more of a one-on-one tool or more of a small group setting training than a large group. So it's, you know, you can have an audience watch on the big screen, like you have, that is one way around it. But yeah, it's limited to, it has capacity limits in terms of VR, because as you know, you require some close supervision.	40
Moderator	3.000	**Q4.** What benefits could we achieve with this new technology tool for mountaineers?	41

Robin	3.065	The benefit Mhmm. You know, you use like a little bit taste of the Mhmm. Or not make for you, it's Mhmm. For it can be used for other things as well. Yeah. So like a little bit taste of it Mhmm. And then, yeah, it's like some of the like a snow mountains are not easy to access.	42
Suckwhan		No answer	43
Yadi	3.065	People don't have the equipment or financial ability. They couldn't. Don't need equipment. Financially benefit them	44
Yadi	3.065	Without. And then experience. Also worth of accessibility. You don't have to travel so long	45
Chun	4.05	This kind of thing, because it's a very authentic situation. So, when I share this with other people, I have more information to share. Because I can tell not just the questions and answers. Okay. But I can also share the situation and also the experience. Yeah. So, I can share the knowledge in context. Oh. Okay.	46
Sarah		No answer	47

Matthew	2.20	So, you know, because as you know, people cannot really go to Himalaya to experience, isn't it? I think if you have like multiple people using it at the same time, that could be like a group scenario. Okay. Or maybe, let's say, you're actually training with your partner. Yeah. And then there's a scenario there. Yeah. Yeah. At the same time, I think like when you're sort of immersed in this new environment, your response could actually be different compared with just normal. So, that sort of maybe does indicate or show that if you're not making the right decisions, it sort of does provide a bit of a sort of resemblance to that more intense environment. So, I guess to summarize that, all of the sort of visual, audio-visual, that can sort of be sufficient to simulate a similar response, even though I'm not cold or wrapped up in jackets or anything.	48
Alfredas		No answer	49
Jeremy	2.20	sort of what I am envisioning, or like after doing that, I think it sort of stems my, you know, like creative juices to think about how you can apply it. I can see things like, so, sort of having to be in an emergency situation and repeat like exactly what you would do. Repetition.	50

		Be a really like helpful thing for this. So, again, I sort of am thinking about it in terms of muscle memory. Muscle memory. you know, a sort of immersive environment allows you to sort of get that practice. And then when you're in the real thing, you just automatically instinctually know what to do.	
Margax		No answer	51
Josh	3.065	Well, I think it allows us to train regardless of weather conditions, to conduct, I guess what we would call dry training. Yeah. And it allows us to rehearse our, I guess, more risky climbs. Yeah. By familiarizing ourself, we know that we've got 3D mapping tools. We know that we're able to emulate real world environments. Yeah, for sure. And you've even got the ability to put real world graphics on there as well. Yeah. So when they go to do their first ascent, they've already seen a lot of the landscape that they're walking into. Yeah, I think there's definitely around familiarity, around rehearsals, and around dry training and safety awareness. It's accessibility, isn't it? Because you don't have to go to the mountains to train.	52

Moderator	1.000	**Q5.** What risk factors and prevention in high mountain ranges do you think we need to include in the App?	53
Robin	1.053	Weather change.	54
Robin	1.054	Avalanch	55
Suckwhan	1.20	Wearing a mask. If you do things like pre-masks. There is that. There is a way to handle the oxygen supplement oxygen in Wolsinaru. Because when you go up, your face is like that. So it doesn't work well, so there is the operation method and then the calculation.	56
Yadi	1.25	Because physical ability is important too. So how to develop your physics. Oh, good. Oh, that's good. Fitness. Yeah, fitness. Fitness pool. Fitness pool. Climbing mountain. High mountain, higher altitude. Because the fitness is more important. Because you have to really get fit. Because you go over 6,000 meters.	57
Chun	1.054	And then I'm going to put avalanche risk	58
Chun	1.20	how to use tools.	59

Chun	1.053	And then how to read the weather patterns.	60
Chun	1.20	And then also how to do self-rescue when you're pulling the crevasse.	61
Chun	1.055	Navigation. Navigation	62
Chun	1.101	Want to come back. Tired. Yeah. It can be part of it. Part of the situation you covered. So, it's a decision-making process. So, when you're tired, you need to retreat, right? So, decision-making process.	63
Sarah	1.101	I think it's Mostly things that The biggest factor would be The human judgment Human judgment It's a decision making process And memorizing steps Yes, definitely So the human judgment Is more like a decision-making process Or a learning process Because I think that's The most important thing What do you think about the difference Between this immersive technology Using this immersive technology For training And just In-person training	64
Matthew	4.05	Well, one of the questions that you asked in this thing was, what's the most common sort of injuries and stuff? So, you'd want to probably target those first if possible, just because that's most likely what you're going to encounter. So, there could maybe be assistance, like a vibration or something. Vibration. Sort of maybe teach the person so that there is feedback. So, there's feedback.	65

		So, it's like the person is a virtual instructor or virtual partner while the instructor actually is in the real environment. So, the virtual person is actually just communicated by just voice, right? Yeah, because that's probably what their walkie-talkie is for. That's right. So, you'd just be hearing them, nothing else. I think if possible as well, a bit of, like, given this VR button, have a bit of movement. Yes. So, like trying to replicate a scenario. And I think because this is a controlled environment, I think you could definitely implement, like, a time. Once you've, let's say, achieved a certain competency, then you can allow people to time themselves and see how they're performing. Oh, okay. So, it's not like feedback, it's about, what is it called? It's like a target. So, okay, you meet this target, so you pass this one, kind of. Yeah, yeah. So, and then it sort of gradually increases in intensity. So, you could, like, you know, create a scenario and then just to get people used to the VR. Ah, yes.	
Alfredas	1.055	Route selection. Yeah, yeah. Navigation	66

Jeremy	1.054	Maybe something that has to deal with like snow. I don't know. Like avalanche. Yeah.	67
Jeremy	1.055	if you like go into a crevasse or something like. Navigation for crevasse.	68
Jeremy	1.053	Maybe like seeing weather patterns. Yeah. And I could see it.	69
Margax	1.053	Oh, weather, weather. Weather pattern. Yes, weather	70
Josh	1.054	You might use an avalanche buddy tool. Yeah. You may practice using and locating somebody under the snow. And another feature you might want to look at is a route selection test. So you can, you get shown some terrain and you get offered a choice in paths. Yeah. And you choose.	71
Moderator	**2.000**	**Q6.** What do you think is the difference between this new technology approach and traditional mountaineering pieces of training in high-risk mountain ranges?	72
Robin	3.085	This is like a save money. It's like a finance game. Finance but saving money. Yeah. But	73

		even you use this for training, you still need that. It's a real world training.	
Suckwhan	2.20	In fact, this is something that needs to be done on site, but since you can't do everything on site, you should try it out indoors first to get a taste	74
Yadi	4.15	Save human resources. because am I able to use for big class? Like for... Yeah. Able to use large class instead of one-on-one, right? Yeah.	75
Chun	2.20	Because I think it's in a designed environment or controlled environment. The instructor can guide me in depth. You mean just via apps? Yeah. So, because it's a controlled environment, right? Safe and controlled environment, right? Yeah. Safe and controlled environment. And also, we'll have the high quality outcome from the program. Because to learn all the experience in real time, it can take years. Learn. So, we can learn faster. Learn faster. Yeah. In an efficient way. Yeah. Efficient, yes.	76
Sarah		No answer	77
Matthew	4.05	The most that I've done is with Alpine guides. So we went to Plateau Hut. And so we did a bit of crevasse rescue there.	78

		That's only just under supervision. When I was doing that, it took me a lot of time to process. And what I needed for me was a lot of repetition. And with that repetition, I also needed that physical understanding. I think the key difference would be, assuming VR cannot replicate the intricacies, that would be the biggest difference for me. If it can somehow enough to indicate key parts to improve on, it's used in conjunction with that. So I think those key parts would be the difference. What VR would help with, that's probably a really key part. And to maybe even specify that this is not to teach you how a carabiner feels when you unhook it from your part.	
Alfredas	2.10	This is more interesting, yeah. And it's kind of hands-on. It's not fully hands-on. It's still virtual reality, but you are in action. So, at least for myself, it's way easier to understand something when I do it by myself, not just listening for instructors. It's a lot more active learning, isn't it? Exactly	79
Jeremy	3.075	Well, probably the main one is that, you know, at least right now, it's you have a controller versus like actually working with gear, equipment, you know, ropes, all of that stuff. So that's probably, I would say one of the biggest differences is that, yeah, you just are, it's harder to work with those actual physical things if you're in a virtual environment	80

		because then you can't really see where your hands are. I guess they're the same in the sense that they are both conducted in a safer environment, but I guess VR has the advantage of being able to, again, in some senses transport you to the places that you might actually be experiencing certain things. So that's probably a difference. Yeah. And I mean, both are, I guess both are in and of themselves like interactive. It's just maybe how accessible, like we were talking about earlier, how accessible are they? VR is probably a lot more accessible to a lot more people now. Whereas, I mean, even, I guess it depends, right? Like I guess if you live by a lot of mountains, maybe there are a lot more guides or places where they would teach you.	

Margax	3.080	I really like the idea of safety, especially when you're a beginner. Learning with VR, there's more safety. Actually, maybe. Safety environment. And probably very good for very beginners. People are not sure, like, oh, should I get it? Because when you do the practical, you're so stressed. You want to get things right that you might miss some information. But with VR, you're more relaxed. Yes, that's right. Especially if you're a beginner, if you go to a snow mountain for the first time, and you've never used a crampon ice axe. Some people have never been on snow before. So, yeah, it's scary. It's overwhelming. Too much information. They cannot digest.	81
Josh	4.55	VR training and the traditional one? For example, you go, you know, snow craft course. I don't think VR could replace hands-on experience. But it can serve in preparation. Yeah, preparation, yeah. At all levels, I think. Yeah. So it's like, it's building foundation skills. Yeah.	82
Moderator	4.000	**Q7.** What challenges do you anticipate from this VR App training tool in Chile/NZ/Other areas?	83

Robin	3.070	Of course, the language. And especially you read that Mhmm. Text. Yeah. That's quite a lot of reading. Mhmm. Yeah. If it's not familiar in this area.	84
Suckwhan	3.090	If those people do this briefly during their training in advance, it would be helpful to them. In fact, the Alpine Club is where each person takes responsibility for themselves, so it doesn't matter, but it would be much better if those who get paid to do it had their clients experience it in advance.	85
Yadi	3.070	Language first. Also, do they have the resources to use the technology? Yeah, social economic challenge, right? Especially Chile. Even New Zealand, for example, if you go to rural area... They don't have this. Yeah, are they able to access the VR set, right? Yeah, so it's mainly because in Chile, there's a social and economic challenge. Also, lots of people don't accept technology. So culture, right? Stereotype. Culture, stereotype.	86
Yadi	3.075	Also, do they have the resources to use the technology? Yeah, social economic challenge, right? Especially Chile. Even New Zealand, for example, if you go to rural area... They don't have this. Yeah, are they able to access the VR set, right? Yeah, so it's mainly because in Chile, there's a social and economic challenge.	87

		Also, lots of people don't accept technology. So culture, right? Stereotype. Culture, stereotype.	
Chun	3.070	Well, it can be language, I guess. Point out language. It can be language. But I think it's good and bad because let's say you go to the base camp. I think most people speak English. That's right. So, it can be... Because I think it's a controlled environment. Well, I think initially if you go to other countries, people don't speak English. I guess that's a challenge. And also... I had a VR experience. And also, I use computer every day. But if someone doesn't actually use computer every day in other jobs, they may take more time to get used to the devices. So, maybe initially, they will struggle with using it.	88
Chun	3.075	And also... I had a VR experience. I use computer every day. But if someone doesn't actually use computer every day in other jobs, they may take more time to get used to the devices. So, maybe initially, they will struggle with using it.	89
Sarah		No answer	90
Matthew	3.070	Probably trying to replicate the type of weather that occurs in New Zealand. Not sure about the cost, but... The cost, yeah.	91

Alfredas	3.060	From climbers, skepticism, I would guess. Yeah. That's the one. Especially from older climbers, I guess. Like younger climbers are keen to try things, so it would be okay. What else? It's very conservative, isn't it? Yeah, exactly.	92
Jeremy	3.075	Maybe the biggest challenge that I can think of immediately is probably just that you have to spend a lot of money in order to get the program to, you know, like maybe just the development aspect of it. And I guess in my mind, I'm also thinking of like how you can design the app or the experience to be like as immersive as possible, you know, because I thought the app was really good. But I also think, like I said, that there's only a certain level that I've seen with VR so far of how much it can sort of be like real life. The second challenge, I mean, besides the folks who are going to climb like Mount Cook, like you and all your friends, I don't know how many other folks are doing that here. So maybe it's just a, if you're talking about in New Zealand specifically or I'm even just thinking in the North Island, like, I just wonder how many people have that interest to do it. So like adoption might be a bit hard.	93
Margax		No answer	94
Josh	3.075	I think cost is an obvious limitation. Yes. Because you're providing a product that the market hasn't needed before. Mm-hmm,	95

		that's right. Or hasn't required to achieve mountain training. So you're looking at supplementing or enhancing training. And that's always gonna be a hard sell to clubs that, or people that are running on a tighter course. So it will require a significant amount of capital, I think.	
Moderator	4.05	**Q8.** What broader support do you think we will require to make this solution successful?	96
Robin	3.075	At the moment Support. App is easy be downloaded by everybody. Mhmm. But it's not everybody has this.	97
Robin	3.085	Headset	98
Robin	3.085	For the universities Mhmm. Or like a institution Mhmm. They they put us like a Yeah. Several Yeah. To share among students. Government to support this kind of project. They got the like the fundings to get that and then loan to schools.	99
Suckwhan	3.085	In reality, this is something that big companies have to pay for, but there are limits to what schools can do. This is something that requires funding. It can be done by the government or by companies. There are limits to what universities can do.	100
Yadi	3.090	Government support. Government and the university. University could have a course for people who want to become a mountain. Course. I mean, this solution, I mean, using VR technology, immersive technology. Yeah, so	101

		you mean the university offer the course to use in this VR training. And also individual sponsors. like North Face. Yeah. Or Patagonia.	
Chun	2.15	We need experienced climbers to set up authentic scenarios. Experienced? Yeah. Climbers need to set up authentic environment, right? And we need the specialists to guide, to explain the situation. I mean, the climbers know how to climb, how to deal with the situation. But the science behind the situation, we need more education on that. So, anyone can actually teach about the science behind it. So, it's a learning pedagogy. New learning pedagogy the government provides training for free?	102
Sarah	3.075	I think It could work with NZAC Like Post-snowcraft Revision material That's what usually happens You go to these instruction courses And then life happens And you forget everything I like the post-snowcraft Revision kind of Revision kind of Program So Recap what you learned And the practice And the repetition	103
Matthew	3.090	Well, I think, firstly, you would need, for it to be very successful, you would need sort of almost like backing of guides. And they are like your speakers. Yes.	104

		It's like for communities, like in clubs, or in terms of market safety. I think, yeah, it could be integrated.	
Alfredas	3.090	Funding, probably. From government agency or corporate? At this level, I guess government. Later, if you have a really good product, probably Alpine Guide Club would be interested in it.	105
Jeremy		No answer	106
Margax	3.090	Yeah, government. From my view, government agency provide fund. And then community get involved and distribute equally.	107
Josh	3.090	That's right, yeah. It's all about accessibility, isn't it? Then, what broad support do we need for, you know, make this project successful? I mean, you know, in terms of government or communities or institutions or individual? I think you need partnership with the right... The right organisation. So that's looking at Mountain Safety Council, New Zealand Alpine Clubs, Alpine Guides, just anyone that offers formal training, you're looking at pitching it to them to deliver that training.	108
Moderator	4.000	**Q9.** Do you have any comments?	109
Robin		No answer	110
Suckwhan	2.15	The most important thing is to feel the touch in the most realistic situations. The most important thing is always the realism.	111
Yadi		No answer	112

Chun	4.55	Getting lost. Yeah. So, it's navigation. I think it will be very good. Because I think there are two ways. One is that because people want to climb, so they take this program or use these devices. But the other way is that because people know the devices, they can easily access the program, like the hardware or software. So, they take the program first, and then they want to go to climbing. Okay. So, easy access. Yeah, easy access. So, I think this will benefit both.	113
Sarah			114
Matthew			115
Alfredas			116
Jeremy			117
Margax			118
Josh	2.15	you would either look at using real world graphics or something very close to, which is going to be, what's the word? Anything that would use a lot of space to create something like that.	119