PLOTTING A ROUTE TO EFFECTIVE WEB-BASED AVALANCHE EDUCATION TOOLS USING GEOVISUALIZATION PRINCIPLES

by

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ABSTRACT

Interactive web-based avalanche tutorials are becoming increasingly popular in the avalanche community. However, the educational effectiveness of such novel interfaces is uncertain. This study explores properties of web-based interactive interfaces (representation, feedback, and single or multiple viewpoints) and their effect on amateur recreationists’ understanding and identification of avalanche hazards. An experimental exercise, incorporating the Canadian Avalanche Centre’s AVALUATOR booklet and an Flash™-based interface based on its current training modules, was used to examine 172 participants’ responses to surveys measuring avalanche safety knowledge. The performance of a subset of participants on route-finding and hazard identification tasks was also examined. Survey scores increased significantly after the participants read the AVALUATOR booklet but not after the route-finding exercise. Participants correctly identified only 25% of visible hazards present on a single terrain photograph and route-finding worsened on successive attempts. Analysis suggests 2D representations and hazard feedback, delivered through Flash™ pop-ups, negatively impacted performance.

Keywords: INTERACTIVE LEARNING; AVALANCHE EDUCATION; AVALUATOR; VISUALIZATION;

Subject Terms: SCIENCE EDUCATION; VISUALIZATION; GEOGRAPHY – STUDY AND TEACHING – RESEARCH;
DEDICATION

To my mother Georgia Ann Scarlett and in honour of my grammy, Theresa Scarlett. Two amazing, loving, women who always put their needs last. I haven’t forgotten Uncle Miller's old saying and I'm doing my best to find a third option and escape Scarlett curses. Hopefully in doing so I can start making up for the crummy deal life gave you.

To Patrick Burkhart, Bill Chapman, and Lenny Lehman for showing me how awesome science is and that I could do it if I put my mind to it.

govno unutra pojedinac ruka , želja unutra onaj drug , pa vidjeti šta pojedinac napuniti settle brže.

- my uncle Miller Scarlett
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It is impossible to adequately thank my partner-in-crime Stuart Hammond for his support, encouragement, consultation, and saint-like levels of patience.

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Thank you to my Dad for teaching me how to creatively approach and solve problems. And finally thank you to Frances Jellybean, the best puppy-dog (and lab partner) ever. I wouldn’t have made all through all those long nights of work without your company and puppy-kisses.
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<td><strong>Affordances</strong></td>
<td>The properties of objects or interfaces that enable individuals to perform particular actions. This includes both action possibilities that are physically possible, as well as possibilities of which the user is aware.</td>
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<tr>
<td><strong>Cognitive model</strong></td>
<td>An internal mental representation of an object, real phenomenon, concept or set of abstract relationships.</td>
</tr>
<tr>
<td><strong>Completion tasks</strong></td>
<td>Testing technique used in spatial cognition research where test subjects are given a limited amount of data and asked to complete a task. A cued sketch map is a form of completion tasks.</td>
</tr>
<tr>
<td><strong>Cued sketch map</strong></td>
<td>Spatial cognition testing measure that elicits configurational knowledge of spatial relationships. Test subjects are given a potion of a map and asked to identify specific features. This type of graphic test does not use scale.</td>
</tr>
<tr>
<td><strong>Ecological validity</strong></td>
<td>Attribute of a research study, wherein its methods, materials, and setting approximate the real-life situation under investigation.</td>
</tr>
<tr>
<td><strong>Egocentric frames of reference</strong></td>
<td>Perception of objects or environments relative to oneself (i.e.- from a first person viewpoint).</td>
</tr>
<tr>
<td><strong>Exocentric frames of reference</strong></td>
<td>Perception of objects or environments from an external viewpoint (i.e.- third-person viewpoint).</td>
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<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>Geovisualization</td>
<td>An interdisciplinary scientific field of research dealing with the development and use of visual representations of geographic data. Research explores the tools and methods used to explore, interpret, and visualize geographic data as well as how people use, modify, and construct knowledge from interaction with visualizations. The term may also refer to a particular instance of visual geographic representation (e.g. a 3D terrain model, dynamic animation, map).</td>
</tr>
<tr>
<td>Interface</td>
<td>The means by which users/people interact with information, computer systems or other people (e.g., geographic data can be interacted with using a book, map, computer, or a 3D interface). Interfaces enable user inputs and outputs - allowing the users to manipulate a system, and for the system to indicate the outcomes of the users’ manipulation.</td>
</tr>
<tr>
<td>Mixed reality environments</td>
<td>Interface environments that combine real and virtual content. Permutations include predominantly real environments enhanced with virtual content (augmented reality) and mostly virtual environments supplemented with real content (augmented virtuality).</td>
</tr>
<tr>
<td>Open-ended questions</td>
<td>A question that cannot be answered with ‘yes’ or ‘no’. A typical open-ended question requires an opinion or argument be given in response.</td>
</tr>
<tr>
<td>Presence</td>
<td>The experience of a person so immersed in interacting within a virtual environment that he or she is no longer aware, for the moment, that the environment is virtual.</td>
</tr>
<tr>
<td>Recognition tasks</td>
<td>Testing measures using in spatial cognition research that are designed to identify learnt or familiar configurations</td>
</tr>
<tr>
<td>Repeated measures design</td>
<td>A research design in which all experimental subjects participate in all levels or treatment conditions of the experiment. Change due to the experimental treatment is measured through changes in participants across each treatment.</td>
</tr>
<tr>
<td>Reification</td>
<td>Visual representation of intangible or abstract processes and concepts.</td>
</tr>
<tr>
<td>Propositional knowledge</td>
<td>Knowledge stored as declarative sentences, such as propositions or facts.</td>
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<tr>
<td>Scaffolded learning</td>
<td>Structuring educational material according to the level of the individual learner.</td>
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<td>Serious games</td>
<td>Applications, including software and hardware, developed using video game technology and design principles for more than entertainment purposes (e.g. education).</td>
</tr>
<tr>
<td>Virtual environments</td>
<td>A broad term that refers to a wide-range of computer-simulated environment that allows for real-time human interaction within it. A virtual environment may contain entirely virtual content (viewed through goggles) or a less immersive form of mixed reality.</td>
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CHAPTER 1: INTRODUCTION

Introduction

Over the last two decades, wilderness and “out of bounds” areas have become increasingly accessible to amateur skiers, snowboarders, snowmobilers, and other recreational users. Easy access to high-quality, affordable equipment has made it easier than ever to venture into potentially hazardous terrain with little to no formal safety training. Not surprisingly, avalanche fatalities have increased – from an average of 12.5 in the 1990s to 14 per year in the last decade (O’Gorman, Hein, & Leiss, 2003; Stethem et al, 2003; Canadian Avalanche Association, 2006). However, recent ten and five year averages indicate a decreasing trend in fatalities since 2003 (CAC annual report, 2008).

The unprecedented deaths of 29 people, including seven high school students, in Canadian avalanches in 2003 (Canadian Avalanche Centre, 2005) received extensive national media coverage. In response to these tragedies and the public's subsequent interest in safety information, the avalanche community began looking for ways to provide more effective and accessible education material and tools.

Starting in the 1990s the professional avalanche community began to recognize the importance of the human factors in avalanche accidents (Fredston, Fesler and Tremper, 1995; Atkins, 2000; McCammon and Haegeli, 2005b) including factors affecting how recreationists make decisions, as a means to improve education (McCammon, 2000; O’Gorman, Hein, & Leiss, 2003; Tase, 2004; Longland, Haider, Haegeli, & Beardmore, 2005; Haegeli et al, 2006; Haegeli and Haider, 2008). Avalanches result from a complex interplay of terrain, weather conditions, and snowpack properties (McClung and Schaarer, 1993; Fredston and Fesler, 1994; Jamieson, 2002).
Avalanche risk depends on many factors, including wind speed and direction, slope angle and aspect, terrain features, temperature, sun exposure and intensity, and snowpack properties.

Synthesizing terrain, snow, and weather conditions are crucial to understanding risk, yet the variables are dynamic and are influenced by a host of unpredictable factors, making this information largely inaccessible to and inappropriate for amateur recreationists (Fredston and Fesler, 1994; O’Gorman, Hein, & Leiss, 2003; Haegeli et al, 2006). Avalanche experts agree that it is commonly the inability of recreationists to recognize avalanche terrain and obvious indications of snow instability that result in many avalanche accidents (McCammon, 2000, 2002; Ferguson and LaChappelle, 2003; Haegeli et al, 2006).

An empirical starting point for new education tools was research by McCammon (2000). McCammon examined reports of hundreds of avalanche accidents and found that 90% of fatal avalanches were triggered either by the victim or someone in the victim’s party. Furthermore, the fatal avalanches were triggered despite the presence of what many professionals deemed ‘obvious hazards’ (Fredston and Fesler, 1994; McCammon, 2000).

McCammon (2000) found that avalanche training did not reduce the number of hazards that amateur recreationists exposed themselves to in these accidents. He argued that even untrained victims were likely able to recognize particular hazards, which translated into avalanche awareness. The victims’ failure to modify their behaviour in the presence of hazards may indicate that they had little experience in an additional step in minimizing exposure to risk: decision-making – deciding whether the level of avalanche risk is acceptable). McCammon and others hypothesized that poor decision-making, based on the use of faulty heuristics, contributed to the majority of the avalanche accidents they had examined (McCammon, 2002; Ferguson and LaChapelle, 2003).

McCammon (2000, 2002), drawing upon early European work on decision
frameworks\(^1\) concluded that North American recreationists need simple, rule-based frameworks to help them catalog and structure hazard information, allowing for better decision-making. He argued for the importance of opportunities to practice decision-making in the field.

Recommendations by O’Gorman, Hein, & Leiss (2003) and Bhudak (2003) led the Canadian Avalanche Association\(^2\) (CAA) to launch the *Avalanche Decision Framework for Amateur Recreationists Project* (ADFAR). ADFAR seeks to improve risk communication and awareness among amateur recreationists through development of a practical, rule-based decision framework. As part of the ADFAR project, Haegeli (2005) and McCammon and Haegeli (2005, 2006) reviewed decision-making tools available to recreationists when traveling through avalanche terrain. Based on their findings and previous research (McCammon, 2000, 2002; O’Gorman et al., 2003), they developed the *AVALUATOR* decision-making card and booklet (Figure 1). The CAA, through its education body, the Canadian Avalanche Centre (CAC), developed an online safety course to increase the general public’s access to basic avalanche safety material.

McCammon and Haegeli (2005b) state that it is less important for amateur recreationists to have a thorough understanding of snow science, which has traditionally been the focus of advanced avalanche courses, than it is for them to identify obvious hazards visible at the slope scale. They suggest that a significant number of US and Canadian avalanche fatalities could have been prevented had recreationists successfully identified obvious clues of instability and increased avalanche risk (McCammon, 2000, 2002). The *AVALUATOR*, which uses a rule-based decision framework, aims to help recreationists minimize risk during trip planning and slope evaluation (Haegeli, McCammon, Jamieson, Israelson, & Statham, 2006). The card features a ‘trip planner’ on one side and a checklist of seven ‘obvious clues’ on the other. Recreationists use the clues to systematically

\(^1\) See Haegeli and McCammon (2005b) for a review of European decision frameworks including Munter’s Reduction method, Nivo test, Stop-or-Go, and Snowcard.

\(^2\) The Canadian Avalanche Centre provides programs and services for public avalanche safety in Canada; the Canadian Avalanche Association provides services to the professional avalanche operations branch.
catalog hazards during slope evaluation. Using the checklist, recreationists check off the number of clues detected on a given slope. The resulting combination of clues is indexed to a travel recommendation that is based on the prevalence of the hazards in previous accidents.

Figure 1 Avaluator decision support tool. a) Companion booklet. b) Slope evaluation card with ALPTRUE list of obvious clues (Source: Canadian Avalanche Centre with permission; Obvious clues© Ian McCammon with permission).

3 The AVALUATOR is not considered a predictive tool. It is intended to raise users’ awareness of risk.
Users of the AVALUATOR are urged to complete an avalanche safety-training (AST) course that features the AVALUATOR as a core component. However, although the AVALUATOR is intended for recreationists with the recommended basic training, it can easily be purchased online or at outdoor recreation and sporting stores. The accessibility of the AVALUATOR by untrained recreationists may limit the assertion that use of the AVALUATOR would have prevented the majority of past avalanche accidents (e.g., Haegeli et al., 2006). Recognition of the clues is key for the proper use of the Avaluator and this assertion assumes that hazards would have indeed been obvious to victims, i.e. assumes a certain skill level exists among its users. However, the professional community cannot control by whom or how the AVALUATOR is used; nor can it ensure that its users have the base level of skills needed to derive confident risk assessments. Learning to accurately identify terrain hazards and signs of instability takes years of practice (Jamieson, 2000). Klassen (2007) questions the abilities of recreationists with basic training (AST 1 and 2) to adequately assess unfamiliar terrain. If trained recreationists face these difficulties in identifying hazards, what hazards are amateur recreationists with little to no training capable of identifying?

Although the approach to decision-making instituted through the AVALUATOR is an important step to helping recreationists minimize risk, its effectiveness may be limited by users’ ability to identify each of the seven clues that are assumed to allow for a careful and informed decision.

A further problem for the recent safety recommendations of avalanche community is the issue of practice. McCammon (2002) and McCammon and Haegeli (2005) suggest that educational programs should focus on improving recreationists’ decision-making skills. Gaining practice is difficult. Avalanche terrain is a risky environment, which does not afford appropriate feedback on the avalanche system. Loading and snow instability and their relationship to the hazard of a given situation are difficult to comprehend and detect even though visible signs may exist (e.g., scouring, cornices). Additionally, training courses are expensive and generally span a few days. Most recreationists do not have
access to a well-trained travel companion from which they can continue to learn. Left to develop skills on their own, potentially in avalanche terrain, recreationists may expose themselves to danger. Amateur backcountry recreationists need new learning exercises that let them practice route finding and hazard identification in an engaging, effective, and safe environment where mistakes are not fatal.

New computer technologies\(^4\) provide opportunities for developing avalanche education tools that allow amateur recreationists to hone their safety skills before heading out into the mountains. Traditionally, education materials included books, videos, and slideshows in addition to in-field training. More recent applications have begun to exploit computer-based visualizations (e.g.- animations and interactive exercises). There is growing interest in using interactive and advanced visualizations such as 3D models, virtual environments, and educational video games (serious games\(^5\)), with the assumption that they will be more effective than current tools. However, technological options are constrained by pragmatic considerations, including the community’s desire to provide education to the public via easily accessible, free software available over the Internet. Software such as QuickTime\(^\text{TM}\) VR (QTVR), Adobe (Flash\(^\text{TM}\)) animations, Google Earth\(^\text{TM}\), and 3DEM present opportunities for developing and delivering more interactive and engaging education to the general public.

The CAC, Swiss Federal Institute for Snow and Avalanche Research (SLF), US Forest Service, and several US avalanche centres have recently released new educational tools via the web and CD-ROMs. The tools use a wide range of traditional visualizations such as static photographs, maps and illustrations, and more interactive web-videos, Flash\(^\text{TM}\) animations, and terrain models. This study focuses on route-finding exercises (RFEs) contained in each

\(^4\) These technologies include geographic information systems (GIS) and advanced three-dimensional tools such as augmented and virtual reality environments. Although visualizations present highly interactive learning opportunities, this study focuses instead on more conventional, 2D interfaces.

\(^5\) See glossary for definition
of these tools. The RFEs attempt to provide a safe environment (i.e.- at home) in which recreationists can practice their avalanche knowledge.

The CAC’s online avalanche course\(^6\) uses Flash™ software to provide basic safety information, with a focus on rescue skills, through seven learning modules. The course content includes text, illustrations, animations, videos, and interactive exercises. The ‘reducing the risk in the field’ module includes interactive versions of traditional\(^7\) route-finding exercises (RFEs). This module gives participants an opportunity to apply what they have learned about terrain hazards from elsewhere in the tutorial. Participants practice route finding by trying to avoid triggering pop-up hazards on a 2D photograph.

Terrain and route-identification exercises are popular components of both traditional training courses and the CAC’s online tutorial. CAC views both as effective learning tools (Tomm, 2005; CAC, 2008), but the effectiveness of these interactive online training exercises is unknown. No usability or empirical analysis has been conducted into whether any of these web-based exercises actually improves the ability of recreationists\(^8\) to identify hazards or make decisions.

**Research problem**

New computer-based education tools must be effective if they are to be useful. One field of research that includes the study of visual and interactive geographic education tools is *geovisualization* (MacEachren, 1995). Geovisualization combines elements of human-computer interaction (HCI), educational and psychological theory, interface design, geospatial interface research, and geographic information systems (GIS) to investigate how people interact with and learn from visualizations of geographic information (Slocum, Blok, Jiang, Koussoulakou, Montello, Fuhrmann, & Hedley, 2001). Terrain models, animations, static images, and even print-based items such as the

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\(^6\) [http://access.jibc.bc.ca/avalancheFirstResponse/index.htm](http://access.jibc.bc.ca/avalancheFirstResponse/index.htm)

\(^7\) Avalanche training courses generally include pen and paper RFEs.

\(^8\) We consider web users to be amateur, although untrained, recreationists. Use of the online course suggests that they are interested, or engage, in winter recreation and, by using the course, have received basic safety information.
AVAULATOR can be considered geographic visualizations in that they provide access to and mediate interaction with geographic data.

All too often, organizations approach education tools with a 'launch and leave' mentality, with the assumption that the learning tool will do its job of successfully conveying information (Woods and Fels, 1986; MacEachren, 1995; Klett, 2002; Hedley, 2003). Although web-based education tools provide a multitude of factual and conceptual information through text, high-resolution images, animations, and activities, no research has empirically tested the individual or combined effects of using different features of geovisualization tools in avalanche education.

As a supplement to field-based training (such as AST1), computer-based educational tools provide the benefits of accessibility, low cost, and reduced exposure to risk. Yet they may have drawbacks. A poorly designed geovisualization can inhibit learning (Slocum et al., 2001; Klett, 2002; Montello & Freundschuh, 2005). Interface design, if done poorly, may adversely impact the knowledge of users, potentially leading to more dangerous behaviour in the field. Placing too much trust in untested web-delivered education tools could instill unwarranted confidence in users, as well as a false sense of reassurance in the amateur's level of competence by the professional avalanche community.

Applying principles of geovisualization to the development and testing of a modified version of the CAC’s RFE is a first step towards a formal analysis of the effectiveness of the CAC’s approach to web-based avalanche education. The CAC must establish what people learn from the web-based RFEs and how in order to avoid new yet ineffective learning tools. Beyond an analysis of effectiveness, the use of geovisualization principles may highlight the subtleties of geospatial interface design that must be included if existing online avalanche educational tools are to be effective or improved.

This study draws upon existing research on the use of geovisualizations in other areas of science education, including multimedia visualizations for university-level geology classes (Piburn, Reynolds, McAuliffe, Leedy, Birk, & Johnson, 2005), 3D virtual environments in physics education (Dede, Salzman,
Bowen-Loftin, & Ash, 1998), the use of mixed reality for teaching Earth-Sun relationships (Shelton and Hedley, 2002), and understanding the physical oceanography of Puget Sound (Winn, Windschitl, & Hedley, 2001b). These studies are instructive in assessing the impact of interactive geovisualizations on avalanche education.

Spatial cognitive research suggests that individuals have difficulty visualizing and understanding complex spatial phenomena and physical processes (Kitchin and Blades, 2002). Traditional attempts to assist learners have used two-dimensional approaches such as text and illustrations and digital images and animations (Shelton and Hedley, 2002). However, 2D forms are limited in their ability to convey complex, spatially dynamic phenomena and processes.

Research further suggests that using interactive geovisualizations based on a constructivist educational design are highly effective in educating students about complex, abstract spatial phenomena and concepts (Winn, 1993; Nyerges, Moore, Montejano & Compton, 1998; Winn & Jackson, 1999; Hedley et al., 2001; Shelton and Hedley, 2002; Winn, 2002b). Constructivism is an approach to education whereby the learner takes a more active role in building knowledge. Providing a learner with a book about bridge building is an example of a traditional approach to learning; providing a learner with blocks to build a model of a bridge is a constructivist approach. Unfortunately, designers sometimes confuse genuine interactivity with visually engaging content and features. There is a need to carefully study which aspects of new geospatial interface tools assist in increasing spatial understanding and development of users’ cognitive models.

This research attempts to identify how users interact with and learn from 2D representations in a web-based geovisualization about route finding through avalanche terrain. Several conceptual frameworks exist for exploring how individuals conceptualize and represent space in cognitive models. This study draws on Hedley’s (2003) conceptual framework for the study of cognitive models in interface-mediated geovisualization research. This framework incorporates Portugali’s (1996) theory of internal representational networks

The IRN processing model (Figure 2) allows researchers to link a person’s externalized geographical representations (e.g., mapping, navigation, orientation, identification abilities) to an internalized cognitive model (e.g., understanding and perception of spatial objects and relationships). Furthermore, the IRN model explores how the individual’s cognitive model changes dynamically as new experiences are assimilated into existing spatial knowledge. Cumulative experiences in the world can affect how a person constructs a dynamically stable understanding of how a phenomenon works. This understanding is dynamic in that it is constantly updated by new experiences, such as new stimuli. As people encounter spatial stimuli, whether through real or simulated environments, the new stimuli are assimilated into their existing cognitive model (Hedley, 2003). Although the process is dynamic, stability emerges through the process of assimilation; understanding stabilizes as it is proven, through both reflection and practice, to be correct. During the design of geovisualizations, these stimuli can be moderated and controlled by features of the interface such as feedback, representation, control devices, content, and symbol systems (Woods and Fels, 1986; Hedley, 2003; Montello and Freundschuh, 2005).

This research focuses on how users’ cognitive models of terrain hazards and safe routes of avalanche terrain evolve when learning from a 2D experimental route-finding exercise. I specifically explore how visual feedback mechanisms and access to single or multiple views of a terrain affect cognitive representations and knowledge construction.

Case study background

This study uses a testing website that implements features of the existing CAC online avalanche course (Figure 3a) and a modified route-finding exercise (Figure 3b). The CAC’s course uses traditional 2D terrain photographs in combination with Flash™ animation technology. The RFE uses Flash™ rollovers to deliver visual feedback through a combination of polygons and text pop-ups. These pop-up polygons serve to reify the intangible concept of a hazard and attempts to link the concept of hazard to features on the terrain (e.g. gullies, cliffs, slopes greater than 30°). If the exercise is effective then the concept of ‘hazard’ becomes ‘real’ for users as they are able, through the polygon and text-based feedback, to associate the concept of hazard with specific terrain features while attempting to draw a route on a 2D photograph of avalanche terrain.

This study modifies the CAC exercise by incorporating elements of the AVALUATOR booklet and decision card into its testing website (Figure 3). The AVALUATOR approaches risk management through four steps: i) trip planning, ii) recognizing avalanche terrain, iii) slope evaluation, and iv) good travel habits (Haegeli et al, 2006).

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10 Adobe Flash™ software consists of applications for creating animations, embedding videos, and developing interfaces that add interactivity to web pages (www.adobe.com).
While the AVALUATOR is currently not directly included in the CAC online safety course, the CAC is hoping to add an Avaluator module to the course in the future. Anticipating CAC’s future website plans, the present testing materials (website and experimental RFE) incorporates the basic features of the AVALUATOR.

Figure 3 Screenshots from Canadian Avalanche Centre’s online avalanche course. a) Beginning of the 'reducing risk in the field' module. b) Flash™ based route-finding exercise. A red polygon identifies hazard from a wind-loaded slopes (Source: Canadian Avalanche Centre; Image © Canadian Mountain Holidays).
Objectives

This research is a pilot attempt\textsuperscript{11} to formally evaluate interactive avalanche education tools. It employs geovisualization principles to explore the effect of 2D web-based visualizations in promoting learning, transmitting specific avalanche facts and concepts, and identifying terrain hazards. The study:

1. examines the effect of:
   a. the AVALUATOR booklet on user comprehension of specific avalanche facts and concepts;
   b. an interactive route-finding exercise on user comprehension of specific avalanche facts and concepts.

2. analyses participants’ ability to:
   a. identify terrain hazards;
   b. plot a safe route through avalanche terrain;

3. explores the effect of using interactive visual feedback on participants’ ability to plot a safe route; and

4. explores the effect of using single or multiple viewpoints on users’ ability to perform spatial tasks and identify terrain hazards.

After reviewing the literature on avalanche education and presenting an organizing model (IRN) for understanding geovisualizations, I outline the website design, results of participants who used the website, and discuss these outcomes using geovisualization principles.

\textsuperscript{11} The study was initially more ambitious, seeking to contrast the effect of manipulatable and 3-D images on users’ ability to perform spatial tasks. Unfortunately, experimenter error prevented the analysis of much of the data. Although objective 1 includes a full complement of participants (129), the analyses of objectives 2 and 3 are focused on a subset of the total test population.
CHAPTER 2: LITERATURE REVIEW

Introduction

This chapter reviews geovisualization principles, interface design, spatial cognition, as they relate to avalanche education. I then provide an overview of the status of avalanche education and a review of selected previous avalanche education interfaces.

Geovisualization

Advances in computer technology since the 1990s led to the development of new tools and methods for representing, visualizing, and interacting with geographic data beyond the traditional cartographic map. Geovisualization is an interdisciplinary scientific field of research dealing with the development and use of visual representations of geographic data (MacEachren and Kraak, 2001). Geovisualization research incorporates principles from cartography, human-computer interaction, geographic information systems, psychology, educational theory, interface design and research, and computer science to explore the tools and methods used to explore, interpret, and visualize geographic data as well as how people use, modify, and construct knowledge from interaction with visualizations. The term may also refer to a particular instance of visual geographic representation (e.g. - a 3D terrain model, dynamic animation, map). Examples of geovisualizations include geographic information systems (GIS), 2D and 3D terrain models, Google Earth™, interactive Flash™ animations, Quick Time™ panoramas, and virtual environments (Figure 4).

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12 Geovisualization is shorthand for geographic visualization.
Figure 4. Examples of geovisualizations. (a) Augmented-reality model of Whistler-Blackcomb ski resort (Source: Nick Hedley with permission). (b) Digital topographic map of Brighton Ski resort, Utah (Map produced by the US Geological Survey). (c) Flash™ animated 2D terrain photograph from the Canadian Avalanche Centre’s online course (Source: Ian Tomm with permission). (d) Screenshot of Rogers Pass, BC in Google Earth™.
Interface research and design

Technological development, particularly in computer devices, has stimulated the development of new ways of representing and interacting with geographic data (MacEachren and Kraak, 2001). Alongside improvements in computing power, the increased portability and affordability of computers have allowed for visualizations to become accessible to large numbers of people in the home, and even in field settings (e.g. laptop computers, mobile GPS, PDA). Computing technology has enabled the map to develop from a means for representing spatial data to a tool for exploring, interpreting, and re-representing information.

Print or digital maps, images, illustrations, animations, QuickTime™ panoramas, geographic information systems, Google Earth™, and Google Maps™ represent geographic information in different forms. Each of these tools provides access to, and mediates interaction with, geographic content; as such, they can be considered interfaces to geographic spatial and non-spatial data.

The features of an interface exert much control over what spatial information people interact with, as well as how they interact with it. Interfaces are combinations of display devices, controls, metaphors, functionality, and what Gibson (1977) called affordances\textsuperscript{13}. Interfaces differ greatly in the amount and types of feedback (e.g. visual, auditory, haptic) they provide, the level of interactivity and manipulation possible, access to single or multiple views, and the types of representations they provide (2D or 3D, realistic or abstracted), interaction design. For example, paper maps provide visual feedback, but offer no possibilities for manipulation other than physical rotation. In contrast Google Earth™ allows users to physically manipulate the visualization through buttons and sliders that permit zooming and rotation. They can also control the display of information by turning layers on and off and creating data layers.

\textsuperscript{13} See glossary for definition.
Current desktop computing relies on 2D graphical user interfaces (GUI) in combination with input devices such as keyboards, a mouse, touch pad, or stylus. Features of GUI interfaces, such as different combinations of content (2D maps, dynamic images, and 3D models), interface controls (navigation buttons, slider bars, and zoom buttons), and feedback (icons, text, colour schemes, sounds, and animations) may reinforce or undermine the message the interface is trying to convey (Slocum et al., 2001; Hedley, 2003). User variables, such as level of expertise, cultural context, gender, personal experiences, training, and intelligence, may affect their ability to use and learn from visualizations.

Early geovisualization research focused on interactions between the user and the interface, whereas current research focuses on how the interface may facilitate understanding of a problem by the user (Hedley, 2003). Wood and Fels (1986), MacEachren (1995), and Hedley (2003) point out that we cannot assume visualizations will do what we want. They caution that development of education tools, accessed via the web or in new virtual environments, must avoid a deterministic approach, where it is assumed that if people use a tool that they will automatically learn from it. Understanding the ways in which individuals use and modify geovisualizations are important components to understanding how individuals develop meaning and construct internal representations of knowledge, and ultimately how interface design responds to the needs of different users and to learning tasks.

An interface designer cannot govern the use of a geovisualization. The interface’s components must be filtered through the user’s understanding before they can influence the user’s cognitive model. Individuals bring intangible elements (experiences, culture, and beliefs) into their interaction with the tangible (e.g., controls, display device, and representations) components of an interface. The user-interface interaction may reveal affordances that were unanticipated by the designer. However, by limiting the interface components, researchers can observe how individuals use the interface and investigate how the use affects the resulting cognitive models (Hedley, 2003). Understanding how a variety of users, with different sets of backgrounds and experiences, create cognitive models may
allow developers to create enough flexibility within the interface’s components that a wide range of people, with different learning styles, can effectively acquire information during use.

Interfaces that capitalize on previously learned or habitual human behaviours are described as ‘transparent’. Transparent interfaces minimize the time a user spends learning or thinking about how to use the tool and maximizing the time spent interacting with the content. Requiring a user to repetitively click or shuffle between control buttons with a mouse reduces the time spent interacting with the interface and results in what Furness (2003) calls ‘low bandwidth’ between user and computer – the flow of information from the computer to the user is slow. Intuitive interface design attempts to minimize the time the user spends learning how to use the tool by employing natural behaviours or natural interaction metaphors (Furness, 2003). Of course, any attempt to render the interface intuitive must itself be tested – ultimately it is the user’s experience that determines whether the interface is transparent.

Construction and implementation of new geovisualizations require developers to consider the content under study, the user’s ability to interact with both the content and the interface, and the goals of the visualization. When evaluating new interface technologies, the researcher can use empirical studies to identify what components are facilitating user comprehension: Is the content design facilitating effective interaction and understanding? Is the style of feedback they receive effective? Is the reification of abstract or hidden processes helping or impeding learning?

This study focuses on how people use and learn from computer-based 2D visual representations. Interface features of the CAC’s route-finding exercise and modifications input into the experimental RFE for the purposes of this study are discussed further in the methods chapter.
Spatial cognition

Investigating how people construct cognitive models\textsuperscript{14} is important for understanding how they learn about environments and the strategies they use to navigate in those environments (MacEachren, 1991; Kitchen and Blades, 2002). Much geovisualization research has focused on how people learn about abstract processes and complex scientific concepts\textsuperscript{15}. In spite of the potential value of this research, no one has yet applied it to avalanche education, thus we do not know what types of materials best facilitate learning about different avalanche concepts. Geovisualization, specifically GIS, is commonly used as a tool for forecasting and avalanche hazard mapping (Kriz, 2001; Delparte, 2008). Galanda (2000) used 3D GIS to visualize the Austrian avalanche bulletin. Gruber (2004) considered using computer-simulated role-playing games. Suter, Purves, and Harvey (2008) are currently exploring the potential of using mobile learning (or 'mLearning'), through PDAs, as a mobile avalanche education resource.

Longland, Haider, Haegeli, & Beardmore (2005) investigated decision-making and behaviour of recreationists before and during recreation activities. Participants were given data on nine slope variables and surveys recorded participants' decisions of whether or not to enter the slopes. Haegeli and Haider (2008) investigated use of the Avaluator in decision-making and the behaviour of recreationists before and after an AST 1 course. Participants were given hypothetical, yet realistic scenarios, which Haegeli and Haider admit lack the complexity of real decision-making scenarios. Scenarios included a terrain image and information about the presence or absence of obvious clues. Although each study considers human and environmental factors affecting participants' decisions Haegeli and Haider (2008) do not address whether the visualizations (i.e., terrain images on a desktop computer) have affected behaviour. Neither study addresses whether the structure of the simulated task may also have

\textsuperscript{14} Refer to glossary for definition.
\textsuperscript{15} Refer to Hall-Wallace and McAullife (2002), Libarkin and Brick (2002), and Jain and Getis (2003) for further information on the use of web-based geovisualizations in science education. Refer to Dede et al (1998), Shelton and Hedley (2001), and Winn (2002a) for studies that use virtual environments for science education.
affected participant performance. The decision scenario captures only one part of a real decision-making situation. Participants were given either detailed information on the slope and avalanche conditions including slope angle, loading, and path characteristics and no visual material (Longland et al., 2005) or information on the presence or absence of obvious clues with terrain images (Haegeli and Haider, 2008). However, in real travel situations, recreationists must amass this information on their own. Their ability to access this type of information is influenced by the way in which they interact with spatial information during direct navigation and in simulated environments. No studies have yet addressed these issues as they relate to avalanche science Although Haegeli and Haider (2008) explore use of the Avaluator in decision-making they do not directly assess how people use it and whether participants can successfully identify obvious clues present at the time.

Text, 2D images of terrain, and illustrations are common staples used in web-based avalanche education, but videos and interactive animations and exercises are commonly seen as more engaging tools. However, poorly designed interface features, such as limited or awkward controls, insufficient or confusing feedback, and inappropriate representations, can turn an interactive educational tool into an ineffective novelty.

For many years, geovisualization researchers have incorporated principles from cognitive science to inform effective interface design (Scaife and Rogers, 1996; Kitchen and Blades, 2002; Montello, 2005). Winn (2002) and Furness (2003) state that interface design should incorporate the following in an attempt to increase knowledge transfer: i) natural human behaviours and interactions, ii) multi-sensory feedback, and iii) increased human control that permits users to actively construct knowledge from content.

Geovisualization research seeks to understand how people build an understanding of real-world phenomena using geovisual representations (Hedley, 2003). Using geovisualizations for interpretation or exploration of geographic phenomena relies on a person’s ability to identify patterns and construct mental representations of meaning (MacEachren, 1992). These
representations are referred to as ‘cognitive maps’ or cognitive models. Cognitive maps are information encoded in an individual’s mental representation of an environment or object (Kitchen and Blades, 2002). Spatial cognitive models are developed through primary and secondary ‘navigation’ of environments (Kitchen and Blades, 2002; Hedley, 2003; Montello, 2005). Primary learning occurs through direct interaction with, and navigation through, an environment. Secondary learning occurs when a person interacts with indirect sources of spatial knowledge such as maps, books, photos, animations, videos, 2D or 3D models, and text instructions. This research focuses on web-based educational interfaces as forms of secondary learning - including maps, photographs, and models, accessed via desktop computers.

Research conducted over the past 50 years has led to little consensus on how and when spatial knowledge is acquired, how people construct cognitive maps, or the form in which information is encoded (see review in Kitchen and Blades, 2002, pp. 11-32). Some scholars argue that knowledge acquisition develops through, and is represented as, text or images or both (refer to Pavio, 1971; Kosslyn, 1975; Pylshyn, 1984 for further discussion of the imagery debate). Understanding how people encode spatial information is important because learning materials that reflect this encoding process might be able to provide information in a form that may be easily internalized. For example, if spatial information is encoded propositionally, then a text-based approach to avalanche education might be more effective than a visual approach. Thus, the debate about cognitive maps, and the theory advocated by a particular geovisualization researcher, can have many repercussions for the education tools they design.

Most cognitive theories emphasize three forms of spatial knowledge: declarative, procedural, and configurational (Kitchen and Blades, 2002). Declarative knowledge can take two forms: propositional or spatial. Propositional knowledge takes the form of facts and definitions. Knowing that the elevation of a given mountain is 3,553 meters is an example of factual propositional knowledge. Spatial declarative knowledge is a catalogue of spatial features such as
landmarks and roads. These features may act as anchors in a cognitive model. For example, a recreationist might catalogue features such as the distinctive peak of a mountain. Procedural knowledge synthesises declarative knowledge by connecting formerly unrelated facts and spatial features into information that can be used in activities such as way finding. A recreationist might develop procedural knowledge that connects the peak of a mountain to a slope extending from the treeline; this understanding is a potential path to reach the peak. Configurational knowledge is the most advanced and comprehensive form of spatial knowledge. It includes information on angles, directions, and distances used to make spatial associations and inferences between places. A recreationist might know the precise slope of a 'ski hill' and realise that it is a northwest-facing slope. One method for assessing configurational knowledge is the use of sketch maps (Kitchin and Blades, 2002, pp. 139-144).

The order in which people acquire these levels of knowledge and construct spatial understanding is highly debated (see review in Campbell and Bickhard, 1986). Many researchers support a model of progressive development of spatial knowledge from declarative to configurational for primary navigation of environments. Siegel and White's (1975) Landmark-Routes-Survey (L-R-S) theory of environmental learning follows this model and is discussed further in this chapter. However, other researchers, such as Montello (1993), suggest that configurational knowledge begins immediately and is not dependent on successive development of declarative and procedural knowledge. Importantly, in this latter approach, the individual’s configurational knowledge would necessarily be linked to actual spatial knowledge of the given area. For example, a person could know, declaratively, that at its steepest section, the slope of a particular mountain is 23°, but be unable, at a procedural level, to anchor the 23° slope to a particular area on the mountain.

Progressive development theories advocate that people first acquire declarative and procedural knowledge, although through an initial interaction with an environment. Longer exposure to that environment leads to more accurate configurational knowledge. However, some models suggest that configurational
knowledge begins to develop upon initial exposure to an environment and becomes more refined with access to declarative and procedural knowledge. Kitchin (1995) states that it is possible for people to access configurational knowledge from secondary sources such as maps. Map-based learning develops configurational knowledge because maps, photographs, and models provide an exocentric view of an environment, thereby granting immediate access to all features present in that environment.

The associations, relationships, and unique features perceived by individuals as they interact with secondary sources of information depend not only on the representation, scale, and level of interaction associated with the media, but also on the personal experiences and background of the individual.

Rapid advances in computer technology have resulted in new ways of representing and interacting with secondary forms of spatial data. What remains unclear is how users develop spatial knowledge from tools that simulate navigation experiences through the use of secondary sources such as maps or visualizations. Experiments in teaching science concepts by Winn, Windschitl, and Hedley (2001b) use theories by Golledge (1978) and Mark (1993, 1995), which in turn build on Siegel and White’s (1975) L-R-S model of environmental learning to explore cognitive learning.

The L-R-S model presumes that people construct routes by first identifying landmarks, and then subsequently building a route that connects those landmarks (Siegel and White, 1975). Golledge (1978) builds on the L-R-S model with his anchor point theory, stating that individuals identify unique objects that act as anchors in visualizations and link them with routes to build cognitive maps. Anchors may be any objects or features in an environment, such as a hill, stand of trees, or intersection, and are dependent on each person’s unique and memorable experiences. Contextual factors such as age, culture, beliefs, training, and personal experiences likely affect each person’s perceptions, anchors, and ultimately their cognitive models (Hedley, 2003). Geovisualization research commonly surveys contextual information from test subjects to explore whether any of these factors affect their cognitive models.
Mark’s (1994) theory of transperceptual spaces states that all our perceptual experiences derive from primary or secondary interactions with stimuli (Hedley, 2002). In this context, features in geovisualizations can operate as anchors for constructing spatial knowledge and cognitive models (Portugali, 1996; Hedley, 2003). Perception of these features may depend on the type of visual representation (2D or 3D maps, models, or animations), the way a user interacts with the interface (degree of manipulation and interaction metaphors), or the sensory feedback they receive (visual, haptic\(^{16}\), or auditory) (Hedley, 2003).

By carefully controlling an interface’s features, researchers can attempt to explore how specific features affect the development of cognitive models. This study uses repeated survey treatments and sketch tasks to capture the progressive development of participants’ cognitive models in response to specific stimuli in order to infer their internal cognitive representations (Portugali, 1996; Hedley, 2003). The objective is to determine whether these stimuli inhibit or promote learning.

**Constructivism**

People have preferred styles of learning, of which they may or may not be aware (Pritchard, 2005). Although many different classifications of learning styles exist within education and psychology literature (see Fleming, 2001, and Pritchard, 2005 for further discussion), researchers agree that people learn more effectively when highly engaged. Interface features such as feedback, transparency, intuitiveness, and learning design can affect a user’s level of engagement.

Winn (2002a) suggests that students become more engaged and learn more effectively when geovisualizations use a constructivist design. He asserts that such an approach permits users to take control of content and actively

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\(^{16}\) Haptic feedback refers to sensory information gained through touch.
construct their own understanding through exploration, hypothesis genesis, testing, and feedback (Woolfolk, 1993; Winn, 2002b; Pritchard, 2005).

A constructivist approach is well suited for avalanche education, because it mimics the process of decision-making when travelling in avalanche terrain. Route finding in avalanche terrain requires recreationists to constantly re-evaluate their assessment of the risk as new information (i.e. hazards or changing conditions) becomes available (McClung, 2002; Haegeli et al, 2006). A constructivist approach facilitates integration of new information, including perceptions and a priori knowledge, in order to construct understanding (Woolfolk, 1993; Pritchard, 2005). A key aspect of this learning design is that users receive feedback on their understanding. In the case of simulated route-finding exercises, this feedback could be the results of their decisions; such an approach can be powerful when learning about decision making in avalanche terrain.

**Feedback and representation**

Users gain information from an interface through a variety of sensory feedback mechanisms, including visual, auditory, haptic (touch), and proprioceptive (body) modes of feedback. Web-based interfaces are generally restricted to static or dynamic visual feedback. The ability to interact with or control the style of feedback differs between interfaces. Static images or passive animations permit little or no input or control by a user. In contrast, dynamic animations permits manipulation of the visual feedback by changing the colour or size of text, highlighting or outlining objects, or using Flash™ pop-ups. Auditory cues, or ‘earcons’, are sounds such as clicks, buzzers, and bells, used to confirm, emphasize or draw attention to user interface events. They may be used to confirm that an action, such as a selection or ‘OK’. has been actuated, convey a right or wrong answer, or provide ambient sounds and noises associated with the content under study. For example, an avalanche tool could combine the sound of an avalanche slab collapsing (“whumpf”) with an image or animation of the process.
Including multiple forms of feedback in an interface can be powerful, because sensory stimuli provide anchors for cognitive models. Applying the conceptual framework of IRN to interface design, increased feedback and the use of stimuli for anchors in constructing cognitive representations should result in more accurate cognitive models (Hedley, 2003). Interfaces that provide multiple types of feedback are also more likely to engage users, although too much feedback can be overwhelming or distracting (Hedley, 2003).

Shelton and Hedley (2002) point out that the existing research comparing 2D and 3D representations indicates that 2D forms are limited in their ability to convey abstract or complex spatially dynamic phenomena and processes. However, it is unwise to assume that 3D tools will work better than 2D ones (Scaife and Rogers, 1996). Early research in educational technology successively focused on the content to be learned, its presentational format, and the use of simulations of phenomena. Computer simulations permit users to explore spatial relationships and interface with content in a way that would be either impossible or too dangerous in the real world (Winn, 2002b). Early geovisualization research attempted to increase learning through visual fidelity (photorealistic representations). However, interaction has a greater effect on cognition than visual fidelity (Winn, 2002b). Hidden or intangible processes cannot be seen in ‘realistic’ visualizations, which could lead to incorrect cognitive models. For example, if the goal of an activity is to learn about the role of shear stress in landslides, a high-resolution satellite image would not show shear stress because it is not a visible, tangible feature. However, it is possible to reify the concept of shear stress through an interactive geovisualization that uses dynamic symbols to represent the changes in shear stress that lead to slope failure.

The CAC’s route-finding exercise reifies the concept of hazard using pop-up Flash™ polygons. The way the feedback is presented (colour, shape) and the manner in which users interact with it (popping up) may additionally affect users' cognitive models.

Effective visualizations must consider the goals of the tool (i.e. what meaning should users access), the nature of the content, and users' ability to
interact with the interface. A 3D tool can be realistic, but if it does not provide enough interaction and useful feedback, it is just a flashy tool. Conversely, highly interactive 2D tools that incorporate multiple sensory stimuli may be more effective for some applications than for others. It is important that research explore uses of different feedback and representations for teaching avalanche hazards and route finding.

**Single vs. multiple viewpoints**

A person’s vantage point can greatly affect their perception of an environment. Standing at the base of a slope or viewing that slope from an adjacent ridge can affect perception of distances, slope characteristics such as angle, elevation, and orientation, and adjacent features (Figure 5). Frames of reference (viewpoint) refer to the way in which individuals perceive the location of objects relative to themselves. People orient themselves and derive a sense of direction from frames of reference (Kitchin and Blades, 2002).

**Figure 5 Terrain images with different frames of reference (viewpoints).** Image (a) was taken from a helicopter and provides an exocentric (3rd person) view of the terrain. Image (b) was taken on a slope in the valley bottom and provides an egocentric (1st person) viewpoint (Source: Grant Statham modified with permission)
In the real world, our view is static until additional perspectives become available through movement. In the case of route finding, viewpoints and information vary along the route. However, static geovisualizations, such as maps or terrain photographs, only offer one frame of reference (see Figure 4b,c, and d). Photos taken from individual viewpoints similarly limit recreationists' ability to perceive complete terrain information, which can affect their ability to accurately assess avalanche risk during route planning or in learning exercises.

Constructing an accurate cognitive map of risk may depend on several factors. During direct navigation within a terrain, individuals receive sequences of multiple views, which enable them to view features, angle, and distances from multiple perspectives. However, the view(s) available to an individual interacting with a secondary spatial source of information depend on the type of visual representation used. For example, an individual using a single terrain image is limited to a single view of a geographic environment from which to estimate distance, depth, slope, or orientation. On the other hand, access to multiple views of a geographic environment enables an individual to view the same scene from several different angles and distance. The individual thus may be able to visually and spatially explore hypotheses about the spatial relationships between objects that can be seen in a scene, relative to his or her own position. The individual may then be able to build up a more complete or accurate mental model of objects in an environment.

The previous paragraph discusses single static views versus multiple static views. In contrast, dynamic representations such as animations or 3D models offer multiple, sequential views. The ability to manipulate a model through rotation delivers seamless transition between multiple views. Further, advanced virtual environments such as video games can provide players with multiple simultaneous views from different frames of reference. For example, a 1st-person game provides multiple, seamless egocentric views of an environment, similar to direct navigation. This egocentric view could be
augmented by displaying a map of the game’s level in the corner of the display, which would provide another, exocentric or abstracted view of the environment.

Many visual, perceptual, and interactive variables may affect users’ perception of the environment.

Although there are many possible variables to consider, the focus of this research is to explore whether access to single or multiple, simultaneous views of avalanche-prone environments (one or three images at once) affects users’ abilities to estimate distance, slope angle, and identify terrain hazards.

**Review of current route-finding exercises**

Minimizing avalanche risk during backcountry or out-of-bounds recreation involves planning a safe route before you go and making decisions based on slope conditions during a trip. Determining a route appropriate for the conditions is a key element in minimizing avalanche exposure. Doing so, however, requires recreationists to not only recognize avalanche terrain but also to understand the significance of hazards in relation to current snow and weather conditions.

Many North American and other websites provide avalanche safety information through text, drawings, diagrams, animations, videos, discussion forums, and other media. It is beyond the scope of this thesis to review all desktop-based tools. Rather, the focus here is on the following educational tools delivered to amateur recreationists using desktop computers: the CAC online route-finding exercise, the US Forest Service interactive backcountry tour, Jim Conway’s online avalanche course, and the White Risk CD-ROM produced by the Swiss Federal Institute for Snow and Avalanche Research (SLF). These tools focus on route finding for amateur recreationists. Although the AVALUATOR is a hand-held tool, it is included because it was built into the testing website. It also functions as an interface, because it mediates access to and use of spatial information.
The AVALUATOR

The AVALUATOR is a hand-held decision-support tool for trip- and slope-scale evaluation (Figure 6). It was designed to assist amateur recreationists as they make decisions in avalanche terrain (Haegeli and Haider, 2008). The trip planner aids recreationists in choosing appropriate terrain given the current avalanche conditions. CAC has rated many popular backcountry trips using the Avalanche Terrain Exposure Scale (ATES); trips are designated as simple, complex, or challenging (Stathem, McMahon, & Tomm, 2006). Recreationists plot the rating of their intended trip with the hazard level to receive a travel recommendation. CAC also features an online trip planner tool on their website (www.avalanche.ca). The site dynamically links current hazard bulletin information with ATES-rated trips. Recreationists chose their bulletin region, backcountry activity, sub-region, and trip. An automated star appears to indicate the travel recommendation on an image of the trip planner.

The slope-scale component prompts the user to evaluate the terrain based on a list of ‘obvious’ clues, which include: recent Avalanches, Loading, avalanche Paths, Terrain traps, current danger Rating, and signs of Unstable snow, and Thaw instability. The clues form the acronym ALPTRUTH, which helps recreationists remember them. Recreationists are encouraged to regularly use the checklist to identify the number of obvious clues present and consider the corresponding hazard recommendation in deciding whether to continue on their route (i.e. cross a slope), avoid the slope, or return home. The AVALUATOR is intended for field use by recreationists who have completed a basic avalanche safety-training course. This research incorporates the AVALUATOR card and booklet into a web-based route-finding exercise in which users can identify hazards and plot a route through avalanche terrain.
Figure 6 AVALUATOR™ booklet and decision-making card. The AVALUATOR™ uses the ALPTRUTH obvious clues to help amateur recreationists identify signs of increased hazard during backcountry or out-of-bounds recreation (Source: Canadian Avalanche Centre with permission; Obvious clues © Ian McCammon with permission)

Canadian Avalanche Centre (CAC) online route-finding exercise

The CAC online avalanche course, launched in 2006, provides basic avalanche safety information using text, 2D photographs, animations, videos, and an interactive Flash™-based exercise. This study focuses on the Flash™-based interactive route-finding component of the course, which serves as a model for the development of the interactive route-finding testing exercise.

The route-finding exercise provides recreationists the opportunity to apply their understanding of terrain hazards by plotting a low-risk route through avalanche terrain. Users must draw a safe route on a digital photograph from points A to B in terrain with a ‘considerable’ avalanche hazard rating (Figure 7a). Red polygons and text boxes pop up to identify hazards, providing users with visual feedback indicating where their route is risky (Figure 7b).
Figure 7 Screenshots of the Canadian Avalanche Centre’s web-based route-finding exercise (RFE). Users test their knowledge as they attempt to (a) draw a safe route (red lines) from points A-B and (b) avoid hazards (red polygons) (Source: Canadian AvalancheCentre with permission; Photo credit: Canadian Mountain Holidays with permission).
Users mark the path of their route with a black line by holding down the left mouse button. Although feedback is strictly visual, the information is encoded using images (red polygons and black path) and propositional knowledge. Users cannot zoom in or out, and they cannot manipulate the terrain photograph in any way. They have access to only one terrain photograph, taken from a perspective view.

The CAC route-finding exercise is a step forward in actively engaging the user in learning. Individuals plot their own route instead of passively viewing images, animations, maps, or videos of safe routes. However, if users move their mouse immediately from point A to point B, a line appears marking a safe route (Figure 7a). The user thus can receive the correct answer without having to test their understanding or learn where hazards exist and why they increase risk. This outcome might have been avoided if a different interaction design had been used. Route selection is a step-by-step process in the real world, yet there is no restriction on how a user explores or plots a path in this exercise.

Perhaps the exercise could be improved by restricting movement of the cursor, forcing users to structure their learning through feedback on safe and hazardous areas as they explore the terrain. Earcons simulating cracking and fracturing of unstable snow could be added to provide a link between the virtual representation and the real-world phenomenon. This feedback could provide anchors for users to construct their cognitive maps of where instability exists on the slopes and what factors affect the level of risk. A further feature of this interface is its use of a single terrain photograph. The use of a single image may limit users’ perceptions of terrain features (slope angles and orientations, elevation, and distances), terrain hazards (loading, gullies, and cliffs), and their resulting cognitive models of hazard and risk.

17 See glossary for definition.
USFS NAC interactive backcountry tour

The US Forest Service National Avalanche Center website hosts a ‘choose-your-own adventure’-style exercise to help users make decisions when selecting routes (Figure 8). The exercise uses illustrations and text, but no terrain visualizations. Users begin by describing their group, their trip, and the weather and snow conditions. A cartoon map indicates the start and end points, a route through mountainous terrain, numbered checkpoints along the route, and a skier whose position moves through the mountains while progressing through the exercise. Users begin the exercise by clicking on the first checkpoint. As they travel along a route by clicking a ‘next’ button, they receive information on changing weather and snow conditions and the current time. At decision points, they must select one of three options. Depending on their choice, they may find themselves victims of an avalanche, digging a snow cave and waiting for help, or facing another scenario and a set of three other options.

The interface provides visual feedback through images, text, and colour. Interaction is largely passive, although the user must click ‘next’ to proceed and click on buttons to make decisions. Users can only go backward or forward, giving them limited options in case they wish to change their decision and explore other possible outcomes. Permitting users to move back and forth between decisions allows them to explore the decision-making process and potential consequences. However, this flexibility is potentially problematic because users can skip sections by clicking on any of the sequential checkpoints and proceeding from that point onward. The exercise also fails to link the simulated situation to visible indicators of risk. Although the exercise mimics decision-making, it provides no discussion or visualization of what those decisions are based on, which could affect conceptual understanding.
Figure 8 U.S. Forest Service interactive backcountry tour provides scenario information, including a cartoon map (a) that changes as you progress through the trip, scenario details, and decision-making options (b) (Source: US Forest Service Avalanche Center with permission).
SLF White Risk CD-ROM

The Swiss Federal Institute for Snow and Avalanche Research in cooperation with Suva, a Swiss insurance company, created the White Risk interactive CD-ROM. White Risk is a comprehensive avalanche education tool that provides information on weather, terrain, snowpack, and search and rescue. The CD-ROM uses a combination of 2D and 3D diagrams, images, Flash™ rollovers, icons, animations, videos, and interactive exercises (Figure 9). The terrain section includes a route-finding component with several exercises. Given the nature of my research project, I will only discuss the interactive route-finding exercise. The route-finding exercise prompts users to draw a route on a topographic map, decide the location of decision points, and then review the correct route and decision points (Figure 9).

Figure 9 The White Risk™ interactive CD-ROM from the Swiss Federal Institute for Snow and Avalanche Research features many interactive learning tasks using text, images, animations, and 2.5D models. One of several route-finding exercises (below) permits users to practice identifying routes and estimating slope on a terrain photograph (Source: White Risk with permission).
The mouse cursor, which is only partly visible through a viewing window, turns into a pencil icon when users begin to draw on a large-scale topographic map. Users must pan around the image to draw a route from start to finish. They can access a terrain photograph showing a portion of the area, a smaller-scale topographic map of the entire area, and a topographic map depicting slope angles in colour by means of clearly marked links located under the viewing window. Next, users place decision-point markers on the map. Clicking ‘finish’ allows a comparison of their path (red line) to the safest route (purple line). After reviewing their ascent route, they must draw a descent route, which they can compare to the suggested descent route. After plotting their routes, users are asked to estimate slope angle using an interactive ruler, slope aspect, and elevation for specific locations on the map. They type their answers into spaces provided to the right of the viewing window and then click a button to see the correct values.

This exercise actively involves users through manipulation, visual feedback, and a constructivist design. The activity is structured so that users hypothesize a route and then receive feedback on their mental map of where it is safe to travel. Users receive visual feedback as they draw a route (i.e., a line appears), when they place a decision point (an icon appears on the map), and when the correct route (purple line) and decision points (purple icons) appear (Figure 13). Manipulation is possible through drawing, clicking buttons, dragging icons, panning around the image, and sliding the virtual ruler.

The exercise is engaging and supplies multi-modal feedback, but it has several deficiencies. The terrain image is oriented opposite the topographic map, which may create a cognitive mismatch if the users cannot mentally rotate one of the images to match the other. It is not possible to view the entire topographic map at one time, which may be an impediment to developing configurational knowledge from the map. Forcing users to construct their cognitive map from multiple sequential frames of reference likely affects their ability to accurately plot a route. Only the lower left corner of the map is visible at first; the top of the map is out of range, although accessible by scrolling.
This initial view predisposes users to draw a line toward the open space at the bottom and right, instead of to the top, which is the correct direction, but not visible. Lastly, the exercise relies on a user's ability to accurately use a topographic map. Many people, even after taking geography or earth science courses, have difficulty interpreting landscape from topographic maps, which may undermine the effectiveness of this exercise (Gilhooly, Wood, Kinnear, and Green, 1988; Savage, Wiebe, and Devine, 2004).

**Jim Conway’s online avalanche course**

Teton Gravity Research hosts an educational website narrated by Jim Conway, an avalanche professional. The website has an online avalanche class, which includes a module on route finding. The module uses a Flash™-based animation in combination with audio commentary (Figure 10). Users click buttons to proceed through the following route-finding topics: introduction, uphill (ascent), downhill (descent), treeline, and review. The exercise provides multi-sensory feedback in the form of audio commentary, coloured polygons that reify risk across a slope, animated skiers and avalanches, and text. Manipulation is sparse, as users can only click buttons to move back and forth between topics.

Potential drawbacks of the exercise include the relatively simple 2D animations, which at times make it difficult to discern the actual shape (convex or concave) of the terrain. The skier's path in Figure 10 is the same shape as the bowl, although contour lines help the user to differentiate the two. Users may find it difficult to understand why one area is less hazardous when they both look alike, leading to a cognitive mismatch. However, the combination of auditory and interactive representations makes it much more engaging.

Conway’s commentary provides depth through descriptions, facts, and concepts, which are visually reinforced through the actions of animated skiers who move along a route, dig a snow pit, or initiate avalanches. In addition, coloured polygons reify risk distribution across a slope.
Figure 10 Interactive animation by Teton Gravity Research. The route finding exercise features five components and narration by Jim Conway (Source: Glissemedia LLC with permission).
CHAPTER 3: METHODS

Introduction

This project involved the development of a testing website featuring an interactive learning exercise. A 2D Flash™-based route-finding exercise was designed to explore how web-based avalanche education materials affect users' factual and conceptual understanding of avalanche hazards. I also used multiple validation exercises to investigate the effect of specific interface components on users’ spatial understanding and ability to identify terrain hazards. Testing explored the effects of single vs. multiple viewpoints on users’ ability to estimate slope angles, distances, elevation, and to identify terrain hazards. The experimental route-finding interface extends the current CAC exercise by incorporating increased feedback, a design based on constructivist learning principles, and access to multiple views as visual frames of reference. It also incorporates a digital excerpt of the AVALUATOR booklet and card.

The test website consists of three basic components: i) surveys conducted before, during, and after use of the website; ii) a route-finding exercise, including sketch tasks; and iii) a validation exercise. During the route-finding exercise, participants completed six sketch tasks including three hazard identification sketches (i.e. loading, paths, traps) and a succession of three route sketches (attempts 1, 2, and 3). Each of the components was used to investigate the research objectives outline in Chapter One. The overall design of the test website, with surveys, sketch mapping tasks, and validation exercises is illustrated in Figure 11. The experimental RFE, which includes the AVALUATOR, hazard-identification sketch tasks, and route-finding sketch tasks is discussed later in this chapter.
Surveys were used to establish, and then measure, changes to participants' factual and conceptual knowledge at different points during use of the website. Sketch tasks allowed me to infer how each participant’s cognitive model of hazard develops through the route-finding exercise. Validation exercises enabled an evaluation of users’ comprehension of avalanche hazard and ability to choose a safe route through avalanche terrain. All testing materials were developed in the Spatial Interface Research Lab (SIRL) at Simon Fraser University\textsuperscript{18}.

**Experimental design**

This work utilizes a repeated measures\textsuperscript{19} experimental design (Myers and Well, 2003, pp. 342-345). Separate repeated measures were used for both the surveys and sketch tasks (see Shelton and Hedley, 2002, for a similar research design). Repeating the same survey identified changes in user knowledge between experimental treatments (Figure 11). Similarly, the use of repeated sketch map tasks enabled me to explore changes in participants' responses to activities that served as a surrogate measure of their cognitive models of hazards and routes. The sketch and validation exercises also represent to what degree participants can apply their factual and conceptual knowledge, i.e. these exercises have participants put these skills into practice. Additionally, the sketch map tasks and validation exercises play an additional role in allowing me to examine user behaviour when interacting with the interface. In other words, these tasks permit an examination of the influence of the interface features on user understanding of avalanche concepts.

The experimental design uses *convergent methods* (Nyerges, 1995; Slocum et al., 2001, p. 13) to assess the mediating role of interface features on user knowledge. Testing materials assess knowledge of avalanche facts and concepts through surveys as well as participant ability to apply knowledge to the

\textsuperscript{18} Fellow SIRL researchers Cyrille Médard de Chardon and Maciej Kurowski assisted with programming the testing website and database.

\textsuperscript{19} See glossary for definition.
practical task of identifying hazards and a safe route during sketch tasks. Analyses assess their performance through outcome-based measures (i.e.- total hazards identified or encountered) as well a process analysis of how they draw routes and interact with the interface (i.e.- feedback). The implications of using convergent methods for advancing avalanche education are explored further in the discussion.

**Figure 11 Design structure of the testing website. Participants complete a series of surveys and sketch tasks before, during, and after interaction with experimental content and activities.**
Participants completed the testing website in one continuous session; i.e. no ‘save’ functions were allowed. A continuous session minimizes distractions and reduces the opportunity for the participants to seek additional avalanche information during the testing session.

All survey questions, photographs, and text comments were chosen in consultation with three avalanche experts. Terrain hazards and safe routes used in both the 2D route-finding exercise and the validation exercises were based on expert evaluation of digital terrain photographs (see below). Digital elevation models (DEM) and satellite imagery were processed into 3D models in ARCSce to determine slope angles, distances, and elevations for survey and validation exercise questions. VrWorx and 3DEM software were used to create QuickTime™ Virtual Reality (QTVR) object models for use in the validation exercises. However, testing errors prevented the analysis of data from validation exercises that used the QTVR object models. Programming errors in the testing website and database resulted in unequal numbers of participants receiving each of the QTVR validation exercises. The QTVR models received an insufficient number of users for statistical analysis; only 11 participants used the 3D QTVR model.

Study area

The testing website used data and images from backcountry terrain near Roger’s Pass, in Glacier National Park, British Columbia (Figure 12). Glacier National Park attracts over 500,000 people per year, and the number of winter recreationists has increased steadily since 1995 (Parks Canada, 2006). Although the Park is popular for its easy access to stunningly beautiful scenery, its terrain is challenging and sometimes deadly – seven high school students were killed in a large avalanche in the park in 2003.

I originally had planned to use data and images from lesser-known backcountry terrain. The use of familiar terrain introduces the possibility that some users either will recognize it, which could bias their performance, or use the exercise as a predictive tool instead of an educational exercise. However, I
was unable to acquire complete data sets for any other backcountry area. Mitigating the use of images of Rogers Pass is the lack of visible contextual features, such as roads or buildings, in the test materials, and the fact that the terrain photographs were taken from less recognizable vantage points, either from helicopter or distant ridges. Also, it is unlikely that novice recreationists are familiar with the area, as it is classified as ‘challenging’ terrain according to the Avalanche Terrain Exposure Scale (Statham et al., 2006).

Figure 12 (a) Google™ Map of Glacier National Park and (b) photo of Rogers Pass area (Source: Bruce Jamieson with permission).
Expert review

I developed testing materials with input from avalanche experts to ensure the materials were appropriate for the target audience and contained accurate avalanche information. Three avalanche professionals from CAC and Parks Canada, referred to as ‘experts’ in this study, helped select appropriate terrain photographs, identify terrain hazards, and assist in developing survey questions.

The experts reviewed three different digital terrain images and identified all visible terrain traps, avalanche paths, loaded areas. They then determined a safe route from point A to point B. The information they provided formed the basis for hazard feedback given to users as they interactively plotted their routes on attempt 3. The experts were also asked to explain, to a degree appropriate for amateur recreationists, why identified terrain features are hazardous. Their responses were incorporated into feedback that pops up when users encountered a hazard during the interactive route-finding exercise. The separate expert analyses were compiled as layers within Photoshop to determine the cumulative ‘best fit’ polygon outlining each hazard and the safe route. Text denoting the start (point A) and end (point B) of the route were added to each of the three terrain photographs.

The three experts have extensive experience in the study area. The expert input was used to ensure external validity, i.e. that the methods and materials used in the interactive terrain identification and route-finding exercise are comparable to those used by avalanche professionals in existing safety courses. Expert input also provided the standard by which I analyzed participant success on hazard identification sketch tasks and interpreted performance on route sketch tasks. Participants’ hazard identification and route sketches were evaluated on the basis of their deviation from the expert delineated hazards and safe route.

Users were provided with a modified avalanche bulletin from CAC web archives when taking the route-finding exercise (Appendix C). The bulletin was revised in cooperation with the experts to remove any complex concepts that would likely confuse novice recreationists. The bulletin was chosen to reflect a
‘moderate’ hazard, with no new snowfall in the past 24 hrs\textsuperscript{20}. It was necessary to choose a bulletin with a ‘moderate’ danger rating because, as mentioned above, the study area is classified as challenging (Statham et al., 2006). A higher hazard level would make conditions too dangerous for novice recreationists, and the avalanche experts did not want to encourage novice recreationists to enter this type of terrain under high hazard conditions.

**Interface design**

**Route-finding exercise**

The test website features an experimental RFE that attempts to mimic steps in careful route-finding: i) review your trip scenario, ii) consult the avalanche bulletin, iii) plan your route, iv) identify any obvious hazards from the trailhead and along the route, and v) make decisions about the route based on the hazard level. Table 1 lists the eight tasks in the RFE as well any testing measures associated with each task. The exercise promotes active learning by requiring users to hypothesize and draw a route from point A to point B on a digital photograph, identify terrain hazards, and then re-hypothesize the route after self-identifying visible hazards. After identifying hazard locations, users interactively plot a route, while polygons and text pop-ups indicate hazards (Figure 13). Users must then decide whether to ignore the hazard, alter their route, or return to the trailhead. The **AVALUATOR** obvious clues are listed along the right margin of the interface to reinforce the link between terrain features identified in the exercise and hazard concepts (see Appendix B for all screenshots).

The RFE bundles interface components such as representation and dimensionality, feed back, educational and interaction design (usability, interaction, and control), and viewpoints. Relevant interface features of the CAC and experimental RFEs are listed in Table 2.

\textsuperscript{20}Roger’s Pass is deemed ‘challenging’ terrain. Recent snowfall (i.e. snowfall within the past 24 hours) would have caused the avalanche danger to increase from ‘moderate’ to ‘considerable’.
Table 1: Tasks in the experimental route-finding exercise. Participants progress through eight steps intended to mimic the process of route finding and identifying terrain hazards. Participants complete 6 sketch tasks that were digitally captured and analyzed to explore performance.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>Description</th>
<th>Testing Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Read scenario</td>
<td>Review trip scenario for information on group, preparations, and intended route</td>
<td></td>
</tr>
<tr>
<td>2. Read bulletin</td>
<td>Review avalanche bulletin for current hazard rating, additional information on snow and weather conditions</td>
<td></td>
</tr>
<tr>
<td>3. Add up hazards in bulletin</td>
<td>Interactively select (by clicking checkboxes) any obvious clues identified from bulletin or scenario. Total # of clues checked appears at bottom of card for use with travel recommendation scale.</td>
<td></td>
</tr>
<tr>
<td>4. Hypothesize route</td>
<td>Draw the location of a ‘safe’ route (with desktop mouse) from points A-B on terrain photograph.</td>
<td>Route sketch: attempt 1</td>
</tr>
<tr>
<td>5. Identify hazards</td>
<td>Successively outline any visible loaded area (5a), avalanche paths (5b), and terrain traps (5c) on terrain photograph</td>
<td>Hazard identification sketches</td>
</tr>
<tr>
<td>6. Re-hypothesize route</td>
<td>Apply self-identified hazard knowledge gained from task 5 into revised drawing off a ‘safe’ route from points A-B</td>
<td>Route sketch: attempt 2</td>
</tr>
<tr>
<td>7. Plot route interactively</td>
<td>Plot a route in response to real-time feedback on terrain hazards <em>(Error! Reference source not found.)</em></td>
<td>Route sketch: attempt 3</td>
</tr>
<tr>
<td>8. Review</td>
<td>Individually or collectively review expert-identified location of the safe route and terrain hazards</td>
<td></td>
</tr>
</tbody>
</table>
Figure 13 Screenshot of the experimental route-finding exercise. Task 7 (pictured) provides interactive feedback through pop-up hazard polygons and text. The AVALUATOR clues are listed on the right side of the interface (Image source: Phil Hein modified with permission).
Table 2 Overview of variations in interface design components between the CAC and experimental route-finding exercises.

<table>
<thead>
<tr>
<th>Interface design features</th>
<th>Route-finding exercise</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CAC</td>
<td>Experimental</td>
<td></td>
</tr>
<tr>
<td>Representation</td>
<td>2D static image</td>
<td>2D static image</td>
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<tr>
<td>Feedback type</td>
<td>Visual</td>
<td>Visual</td>
<td></td>
</tr>
<tr>
<td>Interaction</td>
<td>Drawing with mouse</td>
<td>Drawing, clicking buttons with mouse</td>
<td></td>
</tr>
<tr>
<td>Views and frames of reference</td>
<td>1, exocentric</td>
<td>1, exocentric + access to an additional 2 exocentric</td>
<td></td>
</tr>
<tr>
<td>Educational design</td>
<td>Unknown</td>
<td>Constructivist</td>
<td></td>
</tr>
<tr>
<td>Interaction design</td>
<td>Unrestricted access to feedback</td>
<td>Restricted access to feedback</td>
<td></td>
</tr>
</tbody>
</table>

**Feedback mechanisms**

The route-finding exercise provides four types of visual feedback: text, images, icons, and Flash™ rollovers. Substantial consideration was given to the visual feedback. Colour was used to establish and reinforce relationships between spatial features, such as terrain hazards, and concepts, such as the obvious clues. During hazard identification tasks (5a, b, and c), the text of obvious clues is greyed out, with the exception of loaded areas, avalanche paths, and terrain traps (Appendix B). Each hazard appears, one at a time, highlighted in green, red, or blue, and the participant must outline any areas where the hazard occurs on the image. Red instructional text appears below the terrain image to clearly indicate which hazard to identify. When the user finishes outlining the hazard, it is greyed out and the next hazard is highlighted.

As the participants draw their route in Task 7, colour-coded polygons pop up to indicate the presence of a hazard (Figure 13). This feedback mechanism is the same as the one used in CAC’s route-finding exercise, except for the colour of polygons. The hazard polygons have outlines and semi-transparent colouring.
so as not to completely obscure the underlying terrain; users must be able to associate the terrain feature on the image with the hazard concept if they are to learn to recognize hazards. When a user triggers a polygon, the corresponding hazard is highlighted in a matching colour on the list of obvious clues. A text box appears below the terrain photograph with a description of the hazard; it prompts the user to make a decision: continue through the polygon, avoid it, or return to the trailhead (point A). Hazard polygons overlap in some areas; the interface is coded so that a polygon and corresponding hazard text are visible until the user’s mouse intersects a new polygon. Clicking buttons, placed below the main window in task 8, triggers hazard polygons to appear on the terrain image; a corresponding definition pops up in a colour-coded box below the image. A ‘finish’ button is also visible. When participants click ‘finish’, a box pops up over the main terrain image indicating that they have completed the exercise.

Users can view additional terrain photographs, a topographic map, the avalanche bulletin, and scenario in tasks 4-8. Additional terrain images include text and icons that identify the trailhead (point A) and destination (point B). Their purpose is to assist users in orienting their viewpoint in each image (see Appendix B for all screenshots). Each image also contains a compass in the right corner so that any aspect information mentioned in the text matches the orientation of features in the image; doing so may help avoid cognitive mismatches. Users have access to a topographic map, from which all identifying information has been removed to minimize the chance they will recognize the location.

**Education design**

The exercise applies a constructivist approach to hazard and route-finding tasks in order to reinforce the natural, iterative process of selecting a route. Each participant makes three attempts at drawing a safe route and outlines three different types of obvious clues. The users are expected to engage in hypothesis testing as they plot successive routes, trying, and rejecting, possible solutions.
The first route attempt establishes participants’ initial understanding of the location of a safe route in the terrain. Following the establishment of this baseline, the hazard sketch tasks provide an opportunity to identify new information, by identifying loaded areas, paths, and traps. Route attempt 2 permits them to incorporate this new information and update their safe understanding of a safe route. Participants test this understanding and receive feedback on their route choice as they interactively plot a route in attempt 3.

**Usability and interface controls**

A major design constraint was using only software that users are likely to have on their computers or that could be easily and freely downloaded from the web. The interface was developed using Adobe Flash™ Professional 8.0 and Actionscript 2.0. Participants must have Adobe Flash™ 8.0 player on their computers to view the route-finding and validation exercises. Flash™ movies were used, as they are likely to be familiar to computer users. Flash™ is commonly used on Internet websites; therefore participants have likely already downloaded the necessary plug-in. Many web browsers automatically install the missing plug-in when users attempt to access Flash™ content.

A key component of the interface design is preventing users from receiving feedback on hazards without actively participating in learning. In the interactive route-finding task, hazards only pop up when a user holds down the left-mouse button to draw. Users can only receive feedback on their route when they are plotting it. In contrast, in the CAC online safety exercise (Figure 7), simply floating the cursor over the hazard triggers feedback. This control restriction promotes active engagement, which may, in turn, increase learning. The feedback aspect of the website is discussed further in the ‘feedback’ section of the discussion.

It is important to minimize redundant and tedious actions in order to create a user-friendly and transparent interface. I used intuitive controls in an attempt to maximize the participants’ focus on content and tasks, and avoid distractions and
complications. Based on previous CAC research (Tomm, 2005), most users of
the online avalanche course have display screens of 1024 x 768 pixels. The
Flash™ exercise is slightly smaller than these dimensions, thus the entire content
is visible and users do not have to scroll up or down. Repetitively clicking buttons
to access content or facilitate tasks draws users’ attention away from content. In
this exercise, participants did not have to click any buttons to begin drawing
routes or outlining hazards\textsuperscript{21}. However, they had to click ‘finish’ to submit the x
and y coordinates of their drawing to a database. The ‘continue’ button pops up
only when the user clicks ‘finish’; the intent is to deter them from skipping steps.
A ‘finish’ button also appears in task 8, even though it is the last task. Once users
click ‘finish’ a pop-up box appears over most of the interface to let participants
know they have finished all tasks in the interactive route-finding exercise. A small
image and text identify buttons that access additional terrain images and the
topographic map. All buttons are aligned on one side so that users do not have to
move back and forth across the interface.

There is no ‘back’ button, thus participants cannot redo previous tasks. Doing so
would overprint the initial sketch maps and bias results. It might be
beneficial to include a ‘back’ button in a non-testing version so that users could
repeat tasks. Participants cannot draw routes outside the realistic terrain
boundaries. Permitting them to do would create a cognitive mismatch between
the simulation and reality.

Participants can track their progress through the exercise. Each of the
tasks is listed horizontally at the top of the interface (Figure 13), and a red outline
appears around the current task (Appendix B). Instruction boxes pop up at the
beginning of each task. Text is minimal and wording is simple; key tasks appear
in bold font to draw users’ attention. The main task also appears in red font under
the terrain image to reinforce the task. Once users minimize the instruction box, it
appears as a button above the AVALUATOR list of obvious clues. At any time,
users can access the current instructions by clicking on this button. Only these

\textsuperscript{21} Screenshots of the route-finding exercise in Appendix B show a ‘start’ button, however this
button was not present on the final version used in the testing website.
elements are present in the interface layout for tasks 1-3. A continue button is initially visible in both task 1 and 2, but only appears in tasks 3-8 after users complete tasks by clicking ‘finish’.

Testing measures

Surveys

The study employs four different surveys: i) repeated measures for avalanche knowledge, ii) validation exercise surveys for spatial skills, iii) an eligibility questionnaire, and iv) a background information questionnaire. Surveys measured changes in user comprehension of avalanche facts and concepts through a series of pre- and post-test surveys (Appendix A). Participants completed the same survey three times (repeated measures): first, before they began the exercise (pre-test 1); second, after reading the digital AVALUATOR booklet (post-test 1); and third, after completing the route-finding exercise (post-test 2) (Figure 11). The pre-test survey determined their knowledge level before they were exposed to the testing materials. Post-test 1 evaluated whether exposure to a digital excerpt from the AVALUATOR booklet affected their comprehension. Post-test 2 compared user comprehension after the route-finding exercise.

The ‘content’ that participants read included the ‘identifying avalanche terrain’ and ‘slope evaluation’ portions of the Avaluator booklet. These sections present basic information on recognizing signs of avalanche-prone terrain such as damaged trees and slopes over 30° as well a brief description of each of the ALPTRUETh obvious clues.

Each of the pre- and post-test surveys includes ten questions related to concepts and facts from the terrain identification and slope evaluation portions of the AVALUATOR booklet. Only one question, concerning convex versus concave slopes, tests material not presented in the AVALUATOR.

The wording of each question is consistent between survey treatments, but the sequence of questions was randomized to reduce the potential for so-
called ‘priming’ effects. If questions were not randomized, participants might be primed to simply select the same answer as they did on the previous survey. Priming reduces the degree to which survey results accurately represent participants’ knowledge.

Each validation exercise includes five survey questions, and each participant completed two validation exercises. At the end of the learning exercise, participants completed a background survey that collects contextual data such as age, gender, education, and recreation experience. These data were used to explore any potential correlation between performance and personal experience, such as educational background or winter recreation experience. Exposure to experimental material may not be the only variable affecting participant performance; contextual factors can affect how well participants learn.

Eligibility survey questions established whether users had previous exposure to the CAC route-finding exercise and website, and their level of avalanche education. These data were used to separate users that might have been primed by their exposure to the content this research builds on. Additionally, all incomplete and repeat data sets were excluded from analysis, because each of the three surveys must be compared and the background survey is needed to explore any contextual explanations of performance.

**Sketch maps**

No established methodology exists within the avalanche community for formal assessments of visual education tools. This study took a hybrid approach to obtaining graphic tasks through modified cued sketch map, recognition, and completion tasks. Traditional approaches using sketch map, recognition, and completion tasks to elicit participant knowledge of configurational spatial relationships were not appropriate to the context of avalanche hazards or testing via web-interfaces.

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22 See glossary for definitions.
Traditionally, sketch mapping is a manual task using paper and pen, which requires researchers to manually evaluate sketches using a subjective classification scheme (Kitchin and Blades, 2002). This project adapted sketch mapping tasks to a web-based environment using mouse tracking to automate testing\(^\text{23}\).

Participant’s drawings of hazards and safe route were captured, through the Adobe Flash™ interface, as x and y coordinates in a database. The coordinates were referenced to a bounding box around the main terrain image. Based on the IRN-based conceptual framework of this research, each user’s drawing is an externalized sketch of their cognitive map and identifies where they perceive hazards and a safe route. The database captured three route drawings and three hazard outlines (loading, avalanche paths, and terrain traps) from each user. The successions of user-drawn routes record the evolution of the user’s cognitive map.

Each participant’s sketches were reconstructed in GIS and treated as 2D data for analysis. It is important to note that the x and y coordinates are not traditional 2D data. The 2D mouse tracks were captured as 2D data from a 2D perspective photograph of a real, 3D environment. Participant-drawn sketches and expert-drawn hazards do not therefore precisely correspond to the real location of hazards. The locations of expert-identified hazards are dependent upon the view afforded in the image. That said, participant-drawn sketches are compared against the expert-drawn hazards with the assumption that the expert’s drawings identify the correct location given the view of the terrain.

Quantifying participant performance on sketch mapping tasks is subjective and may not accurately reflect participants’ knowledge and ability to identify hazards or a safe route. Participant-drawn polygons may include multiple or partial hazards. Sketch maps were imported into a GIS and evaluated using

\(^{23}\) Cyrille Medard de Chardon developed and implemented this novel use of mouse tracking as a means of capturing participant-drawn sketches on the testing website.
spatial analysis techniques in order to reduce the subjectivity. Overlay analysis\textsuperscript{24} tools such as intersect, clip, and erase determine the overlap of the real and hypothesized polygons. In this research, a participant was deemed to successfully identify a hazard if the hazard was encompassed by 50% or more of the test subject’s polygon. Participant performance is measured by the number of each hazard successfully identified out of the total of each hazards present.

It is also possible to study the time sequence of each sketch to determine the hazards that participants identified first and in what order they identified them. The sequence of identification reflects the hazards that are most apparent to each participant (Kitchin and Blades, 2002; Blajenkova et al., 2005).

Three route sketches (attempts 1, 2, and 3) from each participant were individually evaluated using spatial analysis techniques in a GIS. Every point along the route was highlighted, using query functions within each route’s attribute table, in order to determine whether the route entered into a hazard and in which order hazards were encountered. A participant’s route had to fully enter into a hazard, not just touch the hazard polygon, in order to count as an ‘encounter’.

The relative position and concentration of participant-drawn hazard and route sketches were compared to expert-identified hazards using density analysis. Density maps of participant sketches show density contours from participant’s x and y mouse points. The contours represent magnitude per unit area however; I use them for visual analysis to indicate the general concentration of sketches.

Expert recreationists and avalanche professionals are trained to evaluate a terrain with ‘avalanche eyes’. An expert can look at a terrain image and immediately identify obvious hazard areas. Amateurs, however, may plot a route through these hazards. No formal research has yet identified how well amateur recreationists identify hazards or where they plot routes in avalanche-prone terrain. Previous research focused on route choice and decisions of amateur

\textsuperscript{24} Refer to Lo and Yeung (2002) for additional information on geo-processing tools including overlay analysis.
recreationists in hypothetical situations (Longland et al, 2005; Haegeli and Haider, 2008), and not hazard identification per se. Although avalanche safety courses include tests in identifying hazards (Tomm, 2005) and plotting routes, no one has published data on how well novices actually identify hazards. It is possible that users form different cognitive maps when they identify hazards than when they receive external feedback on hazard locations.

The exercise did not separate those who identified hazards without triggering external feedback from those who identified hazards after receiving external feedback. This limitation is discussed in the discussion section of the thesis.

Validation exercises

After the route-finding exercise, participants completed a validation exercise consisting of two possible visualizations and five survey questions. Participants were randomly assigned to view either (a) one static image of an avalanche terrain scenario or (b) three static images of the same avalanche terrain scenario. An identical image was used in each of the two visualizations, but exercise (b) included two additional images that showed the same location as image (a) but from two additional viewpoints.

Participants answered a series of four multiple-choice questions and one open-ended question in randomized order (Appendix A). These questions correspond to markers labelled a-e in Figure 14 and polygons that delineate possible avalanche paths. Validation survey questions assess participants’ abilities to estimate elevations, slope angles, route steepness, and the location of avalanche paths from single or multiple images.

The validation exercise tested whether access to single or multiple frames of reference (one or three images) affect participants’ ability to extract spatial information from terrain photographs. The exercises use images of terrain adjacent to the area featured in the route-finding exercise. It is possible that these images may bias responses if users recognize the terrain.
Figure 14 Validation exercises included (a) one image or (a, b, and c) three images. Tear-drop shaped icons and letters identify features related to questions 1-5 (see Appendix A) (Image source: Grant Statham modified with permission).
However, this area is the only available backcountry site for which I could obtain satellite imagery and three terrain images taken from different vantage points. The images include both slope-scale views (egocentric) and perspective views from adjacent terrain or a helicopter (exocentric).

Most route-finding materials rely on terrain images with exocentric viewpoints, because very few slope-scale images are available. No data exist to assess whether participants judge terrain features more accurately with exocentric or egocentric viewpoints. I recognize that using both may affect user performance, although testing does not address this issue. The use of egocentric and exocentric viewpoints is discussed further in the limitations section of the discussion.

**Study participants**

Testing targeted novice recreationists between 18 and 30 years of age with access to an Internet-capable computer. I assumed that all participants had familiarity using a desktop computer. A total of 403 individuals completed the testing website of which only 172 responses were eligible for analysis. Eligible participants included 82 females and 90 males. Sixty-three of the 172 participants self-identified as non-recreationists, and the remainder self-identified as recreationists (99). The most common recreational activity was downhill skiing (58 individuals). The mean age of participants was 22 years.

Incomplete surveys, responses from participants with formal avalanche training at AST level 2 or higher or previous exposure to the CAC’s online avalanche course were excluded from the analysis using eligibility questions (Appendix A). Recreationists with AST 2 training have more familiarity with route-finding concepts; their performance would likely be influenced by their prior knowledge.

Data from users under 16 years of age were excluded to reduce the potential for interference from cognitive differences between children and adults.

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25 Testing targeted 18-30 year olds as most avalanche victims in the US and Canada are 20-29 years old (Jamieson and Geldsetzer, 1996).
on spatial tasks (Piaget and Inhelder, 1963; Winn et al., 2001a). Teenagers older than 16 years were included because they are increasingly becoming involved in backcountry and out-of-bounds recreation. Organizations such as SNOWSMART (www.snowsmart.ca) and Know Before You Go (Gordon, 2005) target high-school students to help them learn avalanche safety skills before entering the avalanche-victim age group.

Although testing was open to the World Wide Web community, participants were primarily recruited from a university student population in a large Canadian city. Students enrolled in Physical Geography 111, an introductory Physical Geography course at Simon Fraser University (SFU) in Burnaby, British Columbia, received 5% course credit if they participated. Email advertisements were sent to SFU Earth Science 110 students, and links to the test website were posted on ski, snowboard (www.biglines.com, www.clubtread.com) and biking (www.fixedvancouver.com) forums. Introductory geography and geology courses attract people in the target age group and represent a diverse cross-section of the general public. Furthermore, students in these courses, which meet the basic science requirement for all degree-seeking students, represent a wide range of the university population.

Focus group testing was done in July 2007 with students in the Introduction to Geographical Information Systems course (GEOG 255) at Simon Fraser University. The online-testing website portion of the study was available to students and the general public for formal testing between September and December 2007.
CHAPTER 4: RESULTS

Structure of analytical methods

This chapter reports results of three sets of analyses. The first set of analyses examines participants’ results on surveys administered prior to any training, after AVALUATOR training, and, lastly, after a route-finding exercise (N = 172). The second set of analyses examines three attempts at tracing a safe route by a subset of participants (N = 24). The third set of analyses examines validation exercises administered after the surveys were completed, again to a subset of participants (N = 106).

Analysis 1: Avalanche terrain surveys

One hundred and seventy two participants completed three surveys that measured changes in factual and conceptual knowledge after each intervention. Each of the 172 participants answered the same 10 questions (Appendix A), in randomized order, on three successive surveys: i) prior to testing (pre-test), ii) after reading the AVALUATOR content (post-test 1), and iii) after using the route-finding exercise (post-test 2).

Survey questions one through nine contained were multiple-choice and question 10 used a Likert scale. Questions 7-9 referred to features marked on terrain images. Questions 1-9 were coded as a dichotomous pass or fail.

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26 Participants read a digital portion of the AVALUATOR booklet, including the ‘recognizing avalanche terrain’ and ‘slope evaluation’ components, and then complete the route-finding exercise.

27 T-test analysis compares means from two data sets. Likert questions assess participants’ level of agreement to a statement using a rank scale. Responses are characterized using the mode or median. The data do not provide a mean statistic, making it is inappropriate for t-test analysis.
Question 10 was excluded from t-test analysis because it required the use of a Likert scale. It was excluded from further analysis because it was poorly designed and failed to provide any reliable data. Total scores ranged from 0 to 9.

Paired t-tests were used to test for significant differences in the number of correct responses after each intervention. Analysing total scores indicates whether performance increases, but the source of any improvement remains unknown (e.g., small improvements on every question, large improvement on a few questions). Survey scores were compiled for each question and analyzed, using McNemar tests for the dichotomous data on each question, to identify changes in participant performance. Responses from recreationists and non-recreationists were also compared in a similar fashion (i.e. paired t-test for total scores, McNemar tests for question-by-question analyses).

T-test analysis of total scores

Descriptive statistics

Table 3 presents the total number of participants, mean scores, and score significance values for the three surveys, referred to as pre-test, post-test 1, and post-test 2. Overall, scores are highest for post-test 2 (post-RFE), that is after the route-finding exercise. The only perfect scores, however, are on post-test 1 (post- AVALUATOR). The pre-test scores are lowest. The distributions of the pre-test, post-test 1, and post-test 2 scores appear to be normal.

Test statistics

The mean score increased with each survey administration, from 4.8 on the pre-test, to 5.5 on post-test 1, to 5.6 on post-test 2. Analysis shows that mean scores increased significantly (p > 0.05) after exposure to the AVALUATOR content (Table 3). Completion of the route-finding exercise did not produce a significant increase in mean scores: the mean number of correct answers remains the same between post-test 1 and post-test 2.
Table 3. Descriptive statistics for correct responses from all participants on repeated survey treatments.

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th>Post-AVALUATOR</th>
<th>Post-RFE</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>172</td>
<td>172</td>
<td>172</td>
</tr>
<tr>
<td>Mean</td>
<td>4.8</td>
<td>5.5</td>
<td>5.6</td>
</tr>
<tr>
<td>P &gt;</td>
<td>*<em>0.0001</em></td>
<td></td>
<td>0.358</td>
</tr>
</tbody>
</table>

Asterisk indicates a statistically significant value at an alpha level of 0.05.

Analysis of individual survey questions

Questions 1 through 7 test users’ factual and conceptual knowledge of avalanche terrain features (Appendix A). Question 8 tests their ability to estimate slope angles, and question 9 targets their route-finding abilities. Table 4 summarizes the total correct responses per survey question for each administration of the survey. Table 5 summarizes significance values for each survey question from McNemar test comparisons between survey treatments. The McNemar test approximates a t-test for dichotomous data.

Descriptive statistics

Although total mean scores increased from the pre-test to post-tests 1 and 2, performance on individual questions differs considerably (Table 4). On each survey, the percentage of correct responses ranges from less than 10% to nearly 80%. Performance on questions 1 and 2 improved from 50% or less on the pre-test to 60-75% on the two post-tests. Less than 35% of participants answered question 3 correctly in the first two survey treatments, and correct responses only increased to 42% in the third survey (Table 4). Correct responses to question 5 were nearly 73% for all three surveys. Nearly 80-85% of participants successfully identified a convex slope (question 7). Most participants greatly overestimated the slope angle (question 8; Figure 15); only 6% of them correctly estimated the slope angle of point A on all three surveys. Approximately 60-75% of participants correctly answered questions 4, 6, and 9 in all three tests.
Table 4. Summary of correct responses per survey question for all participants

<table>
<thead>
<tr>
<th>Survey question</th>
<th>Pre-test</th>
<th></th>
<th>Post-AVALUATOR</th>
<th></th>
<th>Post-RFE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Correct responses</td>
<td>%</td>
<td>Correct responses</td>
<td>%</td>
<td>Correct responses</td>
<td>%</td>
</tr>
<tr>
<td>Q1</td>
<td>85</td>
<td>49%</td>
<td>131</td>
<td>76%</td>
<td>130</td>
<td>75%</td>
</tr>
<tr>
<td>Q2</td>
<td>72</td>
<td>42%</td>
<td>110</td>
<td>64%</td>
<td>125</td>
<td>73%</td>
</tr>
<tr>
<td>Q3</td>
<td>56</td>
<td>33%</td>
<td>59</td>
<td>34%</td>
<td>72</td>
<td>42%</td>
</tr>
<tr>
<td>Q4</td>
<td>108</td>
<td>63%</td>
<td>125</td>
<td>73%</td>
<td>124</td>
<td>72%</td>
</tr>
<tr>
<td>Q5</td>
<td>126</td>
<td>73%</td>
<td>125</td>
<td>73%</td>
<td>123</td>
<td>72%</td>
</tr>
<tr>
<td>Q6</td>
<td>110</td>
<td>64%</td>
<td>124</td>
<td>72%</td>
<td>118</td>
<td>69%</td>
</tr>
<tr>
<td>Q7</td>
<td>134</td>
<td>78%</td>
<td>136</td>
<td>81%</td>
<td>144</td>
<td>84%</td>
</tr>
<tr>
<td>Q8</td>
<td>11</td>
<td>6%</td>
<td>10</td>
<td>6%</td>
<td>11</td>
<td>6%</td>
</tr>
<tr>
<td>Q9</td>
<td>117</td>
<td>68%</td>
<td>128</td>
<td>74%</td>
<td>118</td>
<td>69%</td>
</tr>
<tr>
<td>N</td>
<td>172</td>
<td></td>
<td>172</td>
<td></td>
<td>172</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. McNemar test values for comparisons of correct answers to the nine questions for different survey treatments.

<table>
<thead>
<tr>
<th>Survey question</th>
<th>Pre-test vs. Post-AVALUATOR</th>
<th>Post-AVALUATOR vs. Post-RFE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>P value</td>
<td>P value</td>
<td></td>
</tr>
<tr>
<td>Q1</td>
<td>0.000*</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Q2</td>
<td>0.000*</td>
<td>0.033*</td>
<td></td>
</tr>
<tr>
<td>Q3</td>
<td>0.710</td>
<td>0.043*</td>
<td></td>
</tr>
<tr>
<td>Q4</td>
<td>0.003*</td>
<td>1.000</td>
<td></td>
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<td>Q5</td>
<td>1.000</td>
<td>0.815</td>
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<td>Q6</td>
<td>0.061</td>
<td>0.327</td>
<td></td>
</tr>
<tr>
<td>Q7</td>
<td>0.383</td>
<td>0.267</td>
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</tr>
<tr>
<td>Q8</td>
<td>1.000</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Q9</td>
<td>0.091</td>
<td>0.134</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>172</td>
<td>172</td>
<td></td>
</tr>
</tbody>
</table>

Asterisk indicates a statistically significance at an alpha level of 0.05.
Test statistics

Table 5 summarizes significance values for individual survey questions based on McNemar test. This analysis tests for significant changes in user comprehension after interaction with the AVALUATOR content and the route-finding exercise. Significantly more participants answered survey questions 1 and 2 (p< 0.001), and 4 (p< 0.003) correctly on post-test 1 compared to the pre-test (Table 5). There was a significant increase in correct responses on post-test 2 on questions 2 (p< 0.033) and 3 (p< 0.043).

Participants generally overestimated the slope at point A\textsuperscript{28} by 15-20° (Figure 15). The mode of the slope estimates successively decreases, although not significantly, from pre-test to post-test 2. The mode is 41-45° on the pre-test, 36-40° on post-test 1, and bimodal (31-35 and 36-40) on post-test 2 (Figure 15).

Figure 15 Image used in survey question 8. Participants estimate the slope angle at point A. The correct answer is 21-25°(Image source: Grant Statham modified with permission).

\textsuperscript{28} The slope at point A is approximately 23° (± 5°). A 25-m DEM was used to estimate slope angle.
Figure 16: Histograms of slope estimates (question 8) for pre-test, post-test 1, and post-test 2 surveys (N = 172). The red line indicates the actual slope angle (23°) of point A.
Comparison of survey scores of recreationists and non-recreationists

Sixty-three of the 172 participants (37%) reported not engaging in winter recreation activities. One hundred and nine participants (63%), referred to as recreationists in this analysis, participate in resort or backcountry skiing and snowboarding, snowshoeing, snowmobiling, cross-country skiing, or other outdoor winter sports. Sixty-three of the 109 recreationists were randomly selected and their scores compared to the scores of the 63 non-recreationists using repeated paired t-tests. Recreationists' mean scores are approximately one point higher than those of non-recreationists on each of the three surveys (Table 6). The pattern of increase was similar across the two groups (Figure 17).

Figure 17: Total group (N = 126) and sub-group (N = 63) mean scores across all survey treatments.
Table 7 summarizes the total correct responses of recreationists and non-recreationists to each survey question. I anticipated that participants with recreation experience would have more correct responses than non-recreationists, yet despite significant differences in total mean scores, the total correct responses between groups differ significantly on only a few questions. Recreationists accounted for significantly more correct responses than non-recreationists on pre-test question 3 and post-test 2 question 5. However, recreationists’ performance was low on pre-test question 3; only 41% responded correctly. No significant difference is apparent between sub-groups on the remaining questions for each survey treatment.
Table 6. Descriptive statistics for survey correct responses of recreationists and non-recreationists

<table>
<thead>
<tr>
<th></th>
<th>Pre-test</th>
<th></th>
<th></th>
<th>Post-test 1</th>
<th></th>
<th></th>
<th>Post-test 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Recreationists</td>
<td>Non-recreationists</td>
<td>Recreationists</td>
<td>Non-recreationists</td>
<td>Recreationists</td>
<td>Non-recreationists</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
<td>63</td>
</tr>
<tr>
<td>Mean</td>
<td>5.1</td>
<td>4.1</td>
<td>5.9</td>
<td>4.94</td>
<td>6.0</td>
<td>5.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P value</td>
<td>0.002*</td>
<td>0.002*</td>
<td>0.003*</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

Asterisk indicates a statistically significance at an alpha level of 0.05..

Table 7 Summary of recreationist and non-recreationist correct responses to survey questions.

<table>
<thead>
<tr>
<th>Survey question</th>
<th>Recreationists</th>
<th>Non-recreationists</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of participants with correct response</td>
<td>Number of participants with correct response</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pre-test</td>
<td>Post-test 1</td>
<td>Post-test 2</td>
<td>Pre-test</td>
<td>Post-test 1</td>
<td>Post-test 2</td>
</tr>
<tr>
<td>Q1</td>
<td>29</td>
<td>51</td>
<td>51</td>
<td>27</td>
<td>46</td>
<td>43</td>
</tr>
<tr>
<td>Q2</td>
<td>31</td>
<td>44</td>
<td>47</td>
<td>18</td>
<td>34</td>
<td>45</td>
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<tr>
<td>Q3</td>
<td>26*</td>
<td>25</td>
<td>28</td>
<td>9</td>
<td>15</td>
<td>21</td>
</tr>
<tr>
<td>Q4</td>
<td>40</td>
<td>47</td>
<td>47</td>
<td>34</td>
<td>41</td>
<td>41</td>
</tr>
<tr>
<td>Q5</td>
<td>51</td>
<td>53</td>
<td>53*</td>
<td>43</td>
<td>39</td>
<td>38</td>
</tr>
<tr>
<td>Q6</td>
<td>43</td>
<td>45</td>
<td>44</td>
<td>39</td>
<td>42</td>
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<td>Q7</td>
<td>51</td>
<td>54</td>
<td>56</td>
<td>47</td>
<td>50</td>
<td>51</td>
</tr>
<tr>
<td>Q8</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Q9</td>
<td>45</td>
<td>49</td>
<td>45</td>
<td>38</td>
<td>42</td>
<td>43</td>
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<td>63</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Asterisk indicates a statistically significance at an alpha level of 0.05..
Analysis 2: Sketch map tasks

Twenty-three participants completed six sketch-map tasks that were built into the route-finding exercise. The map used in the exercise is shown in Figure 18. Tasks included sketching three successive safe routes (attempt 1, 2, and 3) between point A and point B, and identifying specific hazards visible on the terrain photograph. Participants completed attempt 1 at the beginning of the exercise, attempt 2 after identifying terrain hazards, and attempt 3 as they explored an interactive version of the terrain photograph. After completing attempt 1, but before completing attempt 2, participants identified locations of visible loaded areas, avalanche paths, and terrain traps in successive sketch tasks.

Hazard identification sketch tasks

Before we can understand how people learn about hazards and identify safe routes, we must determine which hazard areas they can successfully identify. We can then explore which hazard areas are troublesome and how to assist people in perceiving and identifying those hazards.

Participants were prompted to successively identify, by drawing on the non-annotated terrain photograph with their mouse, visible loaded areas, avalanche paths, and terrain traps. Analysis of the map by three avalanche experts revealed that 16 loaded areas, 12 avalanche paths, and eight terrain traps are visible on the terrain photograph (Figure 18). Three hazard sketches (loading, paths, and traps) from each participant were individually analyzed to provide data summarized in Table 8.
Figure 18: Terrain photograph used for sketch map tasks and validation exercises. Coloured polygons indicate locations of avalanche hazards: loaded areas (red), avalanche paths (yellow-green), and terrain traps (light blue). Each polygon is numbered in a corresponding colour. The black line indicates a safe route. The placement locations of hazards and the safe route are based on expert review (Image source: Phil Hein modified with permission).

Table 8. Summary of participant-identified hazards in hazard identification sketch tasks.

<table>
<thead>
<tr>
<th>N = 23</th>
<th>Hypothesized</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Loading</td>
<td>Avalanche paths</td>
</tr>
<tr>
<td>Mean</td>
<td>4.7</td>
<td>5.1</td>
</tr>
<tr>
<td>Minimum</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Maximum</td>
<td>9</td>
<td>17</td>
</tr>
<tr>
<td>Std. dev.</td>
<td>1.7</td>
<td>3.1</td>
</tr>
<tr>
<td>Total hazards</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Percentage of hazards identified</td>
<td>25%</td>
<td>31%</td>
</tr>
</tbody>
</table>
Descriptive statistics

Table 8 summarizes the mean, minimum, maximum, and standard deviation for participant performance on hazard identification sketch tasks. Sketches were analyzed based on the number of polygons drawn by each participant and the total number of hazards correctly identified within those polygons. Participant-drawn polygons are imprecise; one polygon commonly encompasses several hazards (Figure 19).

In other cases, participants failed to identify any hazards with their polygons. Therefore, the ‘hypothesized’ column in Table 8 shows the total number of hazards drawn by participants, regardless of accuracy, assuming that participants used one polygon to represent one hazard. The ‘actual’ column shows the number of real hazards identified by the participant (i.e. one polygon may have identified several actual hazards).

Figure 19: Sketch map of loaded polygons hypothesized by participant 381. The test subject drew four polygons that encompass multiple loaded areas (red polygons). Sketch map analysis is subjective because the researcher must decide whether the participant successfully identified a hazard (Image source: Phil Hein modified with permission).
Participants hypothesized a mean of 4.7 loaded areas, 5.1 avalanche paths, and 3.7 terrain traps (Table 8). The maximum number of hazards hypothesized differs greatly among the participants, with a maximum of 9 for loaded areas, 17 for avalanche paths, and 8 for terrain traps; the corresponding minimum numbers are 2, 1, and 0. The accuracy of identified hazards is low; participants successfully identified only 25% of loaded areas, 31% of avalanche paths, and 18% of terrain traps. At best, participants identified only 50% of loaded areas, 83% of avalanche paths, and 75% of terrain traps.

**Loading**

On average, participants identified only four of the 16 loaded areas (25%), but the following hazards were identified more frequently: 7, 12, and 14. Seven participants (26%) identified loaded area 14 first (Figure 20). Fourteen participants (61%) identified loaded area 7 and twelve identified (52%) loaded area 12. Seven participants (30%) identified loaded area 14. Six or fewer participants (<26%) identified each of the remaining hazards. Participants should travel through loaded area 8 if they are following the safe route, but only seven of them (26%) recognized this hazard.
Figure 20: Distribution of loading polygons successfully identified by participants (N = 23) during hazard identification tasks. A striped pattern indicates necessary hazard(s). An asterisk marks the hazard most frequently identified first by participants.

Figure 21a shows all participant-drawn sketches for the loading hazard task. These sketches are also represented by the density map in Figure 21b. Dark areas in density maps are areas where a greater number of participants hypothesized a hazard. Although Table 6 indicates that participants were most successful on the avalanche path task, analysis of density maps indicates that loaded areas were drawn more accurately.

Participant sketches are more densely clustered around loaded areas (red polygons in Figure 21b) than avalanche paths or terrain traps. The darkest areas in the density maps coincide with loaded areas 7, 12, and 14, all of which were identified by 30% or more of the participants. Each of these frequently identified loaded areas appears shaded in the terrain image and includes prominent ridges with visible cornices.
Figure 21: (a) Sketch map of participant-drawn hazards for the loading task. Participant sketches are shown by black dotted lines; loading hazards are indicated by red polygons (Image source: Phil Hein modified with permission). (b) Density map of participant-drawn loading hazards shown in (a).
Avalanche Paths

Although participants more accurately identified loaded areas, they identified certain avalanche paths more accurately than any other hazards (Figure 22). Twenty participants (87%) correctly identified avalanche path 7, the highest success rate in all three of the sketch tasks (Figure 23). Sixteen participants (70%) identified path 10, and this path was the first hazard sketched by 13 (57%) of them. Ten participants (44%) identified path 11. Nine or fewer participants (< 40%) identified each of the remaining paths. According to expert analysis, participants should encounter paths 1, 6, and 7 when travelling on the safest route.

Figure 23 shows all participant sketches of hypothesized avalanche paths and a corresponding density map of these sketches. Darks areas in Figure 23b suggest that participants were able to recognize parts of each avalanche path, but not the paths as a whole.

Figure 22: Distribution of avalanche path polygons identified successfully by participants (N = 23) during hazard identification tasks. A striped pattern indicates necessary hazards. An asterisk marks the hazard most frequently identified first by participants.
Figure 23: (a) Sketch map of participant-drawn hazards for the avalanche paths task. Participant sketches are shown by black dotted lines; hazards are indicated by green (paths) polygons (Image source: Phil Hein modified with permission). (b) Density map of participant-drawn avalanche paths visible in (a).
Examples of these partially identified paths can be seen at the bottom of paths 6, 7, and 10, as a dark line extending up path 7, and at the tops of paths 11 and 12. Paths 7 and 10 are both classic avalanche paths; path 10 also terminates in the foreground of the photograph (Figure 23). Many participants misidentified the valley at the lower left of the photograph (Figure 18) as an avalanche path (Figure 23b).

Most participants identified avalanche paths using polygons, but participants 381 and 395 used arrows. Arrows imply both location and movement (i.e.- flow). These sketches suggest that the participants conceptualize avalanche paths as dynamic entities (Figure 24).

Figure 24: Sketches of avalanche paths by participants 381 and 395. Testing materials instructed participants to ‘outline any visible hazards’. Both participants used arrows instead of the polygons used by all others (Image source: Phil Hein modified with permission).

Terrain Traps

Participants were least successful in identifying terrain traps (Table 8). Of the eight terrain traps present, only traps 6 and 8 were identified by more than five participants (>22%) (Figure 25). Twelve participants (52%) identified trap 6, and all but one of them identified it first out of all possible traps. Six participants (26%) identified trap 8. When travelling the safe route, participants should travel through trap 6.
Traps 6 and 8 are gullies, located in the immediate foreground of the photograph (Figure 26a). According to the experts, participants must travel through a small part of trap 6 if they are on the suggested safest route (Figure 18).

Fewer than five participants identified traps 3, 4, 5, and 7. Each of these traps is a gully located along a ridge that is almost perpendicular to the viewpoint of the photograph (Figure 18). The cliff bands in traps 1, 2, and 9 were also missed by most of the participants. Dark areas in the density map (Figure 26b) indicate areas where many participants erroneously identified terrain traps. Test subjects misidentified as terrain traps the ridge up to point B (path 1), the valley bottom, loaded area 14, the tops of paths 11 and 12, and the bottom of path 10.
Figure 26: (a) Sketch map of participant-drawn hazards for terrain traps task. Participant sketches are shown by black dotted lines; hazards are indicated by blue polygons (Image source: Phil Hein modified with permission). (b) Density map of participant-drawn traps hazards visible in (a).
Route identification sketch tasks

Three route sketches (attempts 1, 2, and 3) from each participant were individually evaluated using spatial analysis techniques in a GIS (Table 9-Table 10; Figure 27-Figure 35). Participants attempted to draw a safe route from point A to B three times on the same terrain photograph. In attempts 1 and 2, participants drew their route without any feedback regarding hazard locations. They received interactive feedback about hazards on the slopes during attempt 3. Different coloured hazard polygons indicate the presence of terrain traps (blue), loaded areas (red), and avalanche paths (green) (Figure 13). The suggested safe route, drawn by experts, is not hazard-free. The route passes through paths 1, 6, and 7, trap 6, and loaded area 8. If participants travel the suggested safe route they should pass through each of these five ‘necessary’ hazards (Figure 18).

Descriptive statistics

Table 9 summarizes the mean, minimum, maximum, and standard deviation for the total terrain hazards encountered during each attempt. Participants encountered more hazards than necessary. Participant-drawn routes pass through a mean of 7 hazards on attempt 1 and 2. Test subjects encountered the most hazards during attempt 3.

The mean for attempt 3 differs depending on what was counted – only discrete encounters with each hazard (attempt 3) or cumulative encounters with each hazard, including repeated entries (attempt 3-cumulative). Participants passed through a mean of 10 hazards in attempt 3, which is double the expert’s total.

The mean more than triples that of the expert’s total in attempt 3 (cumulative), rising to an average of 18 hazards encountered. Attempt 3 (cumulative) more accurately describes their behaviour and performance during the exercise because it reflects the total number of hazards participants passed.
through in response to pop-up hazard feedback, including repeated entries into the same hazard.

Table 9. Summary of cumulative hazards encountered by participants (N = 23) during route sketch-mapping tasks.

<table>
<thead>
<tr>
<th>Route</th>
<th>Expert total</th>
<th>Total hazards encountered by participants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Min</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>3 - cumulative</td>
<td>5</td>
<td>18</td>
</tr>
</tbody>
</table>

The scores in Table 9 do not indicate whether the participants’ mean score is influenced equally by each hazard type or more by a specific hazard type. Table 10 separates the total hazard score listed in Table 9 into individual hazards types. Table 10 summarizes the mean, minimum, maximum, and standard deviation for loading, avalanche paths, and terrain traps.

Participants encountered more hazards as they progressed through the three route sketch-mapping tasks. Compared to the expert total, test subjects encountered, on average, only one more hazard than necessary on attempts 1 and 2. The means for loading and traps increase slightly in attempt 3, where participants entered, on average, two more hazards than the experts.

During the interactive sketch task (attempt 3), participants repeatedly entered hazards as they responded to feedback polygons. If these repeated hazard encounters are included (see attempt 3 ‘cumulative’ in Table 8), the mean increases substantially for paths and traps.

On attempt 3, the mean number of paths encountered increases from 4.5, which is one more than necessary, to 10. The mean number of traps encountered increases from 2.8 to 5.4 on attempt 3 (cumulative).
Table 10. Summary statistics of terrain hazards encountered by participants (N = 23) during route sketch map tasks.

<table>
<thead>
<tr>
<th>Attempt</th>
<th>Terrain hazard</th>
<th>Expert hazard total</th>
<th>Participant hazard statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>Loading</td>
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</tr>
<tr>
<td></td>
<td>Paths</td>
<td>3</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Traps</td>
<td>1</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>Loading</td>
<td>1</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Paths</td>
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<td>3.6</td>
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<td></td>
<td>Traps</td>
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<td></td>
<td>Paths</td>
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<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Traps</td>
<td>1</td>
<td>2.8</td>
</tr>
<tr>
<td>3 cumulative</td>
<td>Loading</td>
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<td>3.0</td>
</tr>
<tr>
<td></td>
<td>Paths</td>
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<td>10.0</td>
</tr>
<tr>
<td></td>
<td>Traps</td>
<td>1</td>
<td>5.4</td>
</tr>
</tbody>
</table>

Values in attempt 3 (cumulative) represent total hazards encountered, including repeats, during interactive route-finding exercise.

Test subjects encountered a maximum of seven or fewer hazards on attempts 1-3; however, the maximum numbers of paths and traps increase substantially on attempt 3 (cumulative): paths more than double to 19 and traps increase to 13. This increase implies that participants repeatedly encountered the same hazard, which suggests that they likely did not know the location or extent of each hazard. This result suggests they were using the feedback to guide their movement rather than their knowledge of the terrain hazard and its presence in the terrain.

If participants travel the suggested safe route, they will need to pass through five 'necessary' hazards (paths 1, 6, and 7, trap 6, and loaded area 8; Figure 18). Table 12 shows the total of participants who failed to encounter each necessary hazard.
Table 12. Summary of participants (N = 23) who failed to encountered expert-delineated hazards during attempts 1-3."

<table>
<thead>
<tr>
<th>Necessary hazards</th>
<th>Number of participants who failed to encounter each necessary hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Attempt 1</td>
</tr>
<tr>
<td>Loaded area</td>
<td>8</td>
</tr>
<tr>
<td>Path</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>7</td>
</tr>
<tr>
<td>Trap</td>
<td>6</td>
</tr>
</tbody>
</table>

Many participants failed to encounter the necessary hazards; entrance into these hazards is a proxy for following the safest route. Although most participants failed to identify the expert-identified safe route across the terrain, the result does not tell us routes the participants perceived as safe. Fewer participants failed to enter the necessary hazards in attempt 3, however sketch maps show that attempts 1-3 do not vary dramatically.

The following section details participants’ failure to enter necessary hazards, as well as which hazards participants encountered during route sketch task. Graphs in Figure 27 - Figure 29 summarize the distribution of hazards encountered by participants during attempts 1-3. Figure 30-Figure 32 show the route drawings of all participants for each attempt. Figure 30b, Figure 31b, and Figure 32b present the same data using density maps.

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29 The values for attempts 3 and 3 (cumulative) are the same; attempt 3 records the total of discrete entries into each hazard and attempt 3 (cumulative) reflects repeated entries into those hazards.
Figure 27: Distribution of loaded areas encountered by participants (N = 23) during route attempts 1, 2, and 3. A striped pattern indicates necessary hazards.
Figure 28. Distribution of avalanche paths encountered by participants (N = 23) during route attempts 1, 2, and 3. A striped pattern indicates necessary hazards.
Attempts 1, 2, and 3 show the number of participants who encountered each hazard polygon. The x-axis represents the avalanche path polygon, while the y-axis represents the number of participants. The data is presented as bar charts.
Figure 29. Distribution of terrain traps encountered by participants (N = 23) during route attempts 1, 2, and 3. A striped pattern indicates necessary hazards. An ‘x’ indicates that no participants identified the necessary hazard.
Attempt 1

Attempt 1 represents participants’ initial comprehension of a safe route through the terrain. Dark areas in the density map of attempt 1 sketches show that the routes of most participants correspond roughly to the safe route (Figure 30). Participant ascent routes are concentrated on the foreground ridges near loaded areas 7, 8, and 10. Thirteen participants (57%) encountered loading 7; 12 (52%) entered loading 8, which is a necessary hazard (Table 12); and eight (35%) entered loading 10. Five participants or less (>22%) entered each of the other loaded areas (Figure 27).

Several participants attempted to traverse impassable terrain located along the ridge top above path 7 and the slopes above path 11 (Figure 30). Participants entered more paths than any other hazard (see Table 10); routes crossed all but two of the 16 possible avalanche paths. Seventeen participants (74%) entered path 7, which is a necessary hazard. However, participants tended to enter path 7 near its base, instead of near trap 6 (Figure 30b). Many participants mistakenly travelled to the left of loading 13 instead of continuing through path 7 and exiting it below loading 12.

Of the remaining necessary hazards, only one participant (4%) encountered trap 6, whereas 19 (83%) entered path 1, and 12 (52%) crossed path 6 (Figure 28). Although many participants entered path 1, few of them crossed through the path from the base of the slope. Most participants enter path 1 from above as they traverse the ridge, which also accounts for the majority of routes that cross path 11 (22%).

Many participants incorrectly travelled to the left of loading 10. Twelve entered path 3 (52%), 11 passed through trap 3 (48%), and seven crossed path 4 (30%) as they ascended the ridge to point B (Figure 30). Twenty-five percent or fewer of the participants entered the other paths (Figure 28). Participants encountered only half of the possible eight terrain traps, and only one participant entered traps 1 and 6 (Figure 29).
Figure 30. Sketch map of participant-drawn hazards for attempt 1 of the route sketch task. (a) Participant sketches are shown by black dotted lines; hazards are indicated by red (loading), green (paths), and blue (traps) polygons (Image source: Phil Hein modified with permission). (b) Density map of participant-drawn routes visible in (a); a solid black line represents the safest route.
Attempt 2

Participants completed attempt 2 after finishing the hazard identification tasks (refer to previous section). Density maps (Figure 30b and Figure 31b) show that participants generally passed to the left of loading 13 and ascended the ridge leading to point B in both attempts. These similarities suggest that self-identifying hazards did not radically affect participants’ route choice.

However, cumulative sketch maps (Figure 30a and Figure 31a) and histograms (Figure 27 - Figure 29) reveal important differences between attempts 1 and 2. Specifically, fewer participants crossed the slopes below point B in order to ascend the ridge, and as a result they entered certain hazards more frequently, while avoiding others.

Fewer participants passed through path 1 and loading 8, both necessary hazards, in attempt 2 (Figure 27 and Figure 28). The number of participants that entered path 1 decreased from 19 (83%) to 14 (61%) following hazard identification tasks. Figure 22 shows that nine participants (39%) self-identified path 1 during the path-identification task. Additionally, histograms in Figure 27 shows that the number of participants who entered loading 8 decreased from 12 (52%) to eight (35%) following hazard identification tasks. Figure 20 shows that six participants (26%) self-identified loading 8 during hazard identification tasks.

Rather than cross the slopes below point B, more participants attempted to ascend the ridge by travelling to the left of loading 10 (Figure 31). By doing so, 11 of them (61%) entered path 4 compared to only four (30%) in attempt 1. Although more participants entered path 4, only one more entered path 3 in attempt 2(Figure 28).
Figure 31: Sketch map of participant-drawn hazards for attempt 2 of the route sketch task. (a) Participant sketches are shown by black dotted lines; hazards are indicated by red (loading), green (paths), and blue (traps) polygons (Image source: Phil Hein modified with permission). (b) Density map of participant-drawn routes visible in (a); a solid black line represents the safest route.
Participants continued to incorrectly traverse to the left of loaded areas 13 (Figure 31) and away from path 7. Slightly fewer participants passed through path 7 (Figure 28), whereas participants entering path 6 increased from 6 to 16. Five participants (22%) entered trap 5, and nine participants entered trap 7 (39%). No participants had entered traps 5 or 7 during attempt 1. Sketch and density maps reflect this shift; routes are less clustered and dark areas are less dense above traps 5 and 7 (Figure 31).

Attempt 3

In attempt 3, the number of participants who missed each of the necessary hazards either decreased or remained about the same (Table 12). Entering the necessary hazards was used as a measure of how closely participants’ routes match the safest route. More participants entered loading 8 – only eight participants (35%) failed to encounter it compared to 15 (65%) in attempt 2 (Figure 27). All but one participant (96%) failed to enter terrain trap 6. Substantially more participants entered necessary path 1, whereas relatively the same number of participants encountered necessary paths 6 and 7 (Figure 28). Only 6 participants (11%) failed to enter path 1, compared to 9 (39%) in attempt 2. The number of participants who missed paths 6 and 7 decreased slightly from seven (30%) to six (26%). About the same number of participants entered paths 3 and 4 and traps 3 and 4 (Figure 27 and Figure 28).

The distribution of participant routes in attempt 3 is similar to those in attempts 1 and 2. Most participants approach point B by ascending the ridge above path 1 and loading 7, 8, and 10 (Figure 32a). However, routes are less clustered as they approach the ridge; grey areas are less dark above trap 5 and new light grey areas appear below trap 5 (Figure 32b). Routes are clustered above trap 4, leading to darker areas near trap 3 and loaded area 10, which reflects the values in Table 12. In an attempt to avoid these hazards, a few participants continued to traverse the ridge tops above path 7.
Figure 32: Sketch map of participant-drawn hazards for attempt 3 of the route sketch task. (a) Participant sketches are shown by black dotted lines; hazards are indicated by red (loading), green (paths), and blue (traps) polygons (Image source: Phil Hein modified with permission). (b) Density map of participant-drawn routes visible in (a); a solid black line represents the safest route.
Attempt 3 cumulative

Table 9 shows that participants encountered a mean of 10 discrete hazards during attempt 3, which is slightly more than the means for attempts 1 and 2. However, participant behaviour changed substantially in attempt 3. Participants entered hazards only once during attempts 1 and 2. In contrast, participants left and re-entered hazards many times during attempt 3 (Figure 33 and Figure 34). Sketch maps show that routes generally do not continue through hazard polygons. It appears that participants altered their route after triggering pop-ups, causing them to enter more hazards and some hazards more than once. This altered behaviour is reflected in participants’ cumulative encounters with hazards. The cumulative counts reveal that participants encountered a mean of 18 hazards.

Participant 366 entered loading 7 six times, loading 12 four times, and loading 8 twice (Figure 33). Participant 366 encountered a cumulative total of 13 hazards. The values reported previously in attempt 3 reflect only five discrete encounters.

Participant 384 repeatedly entered paths 1, 3, 4, 6, and 11 (Figure 34). The route bounced between paths 3 and 4 several times before ascending the ridge near loading 10. Once on the ridge, participant 384 encountered path 1 six times. It is possible, however, that this participant and others did not intend to repeatedly enter path 1; the ridge appears very narrow in the image and a computer mouse is not a very precise drawing implement.

Participant 354 drew a zigzag route along the ridge up to point B (Figure 35), causing him or her to repeatedly enter paths 1 and 11. It is common practice to zigzag when ascending a ridge or slope; this suggests a behaviour similar during the simulated task to that in a real environment. Participant 354 entered three different traps during attempt 3, including traps 4 and 7 twice each (Figure 33c).
Figure 33: a) Sketch map and b) frequency graphs of cumulative hazard polygon encounters for participants 366 (Image source: Phil Hein modified with permission).
Figure 34 a) Sketch map and b) frequency graphs of cumulative hazard polygon encounters for participants 384 (Image source: Phil Hein modified with permission).
Figure 35 a) Sketch map and b) frequency graphs of cumulative hazard polygon encounters for participants 354 (Image source: Phil Hein modified with permission).
Analysis 3: Validation exercises

One vs. three static images

Descriptive and test statistics

A t-test compared the mean responses of 106 participants, of whom 53 received a visualization with one static image (a), and the other 53 received a visualization with three static images (b). Mean scores of participants who received visualization (a) were higher than those who received visualization (b) (Table 13). The mean number of correct answers is 1.15 for one static image and 0.79 for three static image, although the difference is not statistically significant. The results are approaching significant difference; given additional test subjects use of one static image may have led to statistically significant improvement on questions 1-4.

Table 13. Summary of correct responses for questions 1-4 of the validation exercises. Participants answered question using either one or three terrain images.

<table>
<thead>
<tr>
<th>Visualization type</th>
<th>N</th>
<th>Correct responses per question</th>
<th>Mean total correct (out of 4)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
</tr>
<tr>
<td>(a) One static image</td>
<td>53</td>
<td>13</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>(b) Three static images</td>
<td>53</td>
<td>12</td>
<td>15</td>
<td>11</td>
</tr>
</tbody>
</table>

Slope estimates

Participants estimated the slope angle of point (e) on a static image in question 5 of the validation exercise (Appendix A). This question was not included in the above analysis because it is an open-ended question and provides ratio data. The respondents are the same as those whose scores on other questions are summarized in Table 13.

---

30 See glossary for definition.
Most participants greatly overestimated the slope angle of point (e), which is approximately $8^\circ \pm 5^\circ$ (Table 14). The mean slope estimates for one and three static images are $40^\circ$ and $30^\circ$, respectively (Figure 36 and Figure 37). Participants using three static images estimated the slope angle at point (e) with significantly more accuracy (Paired t-test; alpha level 0.06).

**Table 14. Summary of descriptive and test statistics for comparison of slope estimate for question 5.**

<table>
<thead>
<tr>
<th></th>
<th>Comparison</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(a) One static image</td>
</tr>
<tr>
<td><strong>Q5</strong></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>53</td>
</tr>
<tr>
<td>Actual slope angle</td>
<td>$8^\circ \pm 5^\circ$</td>
</tr>
<tr>
<td>Mean slope estimate</td>
<td>$40^\circ$</td>
</tr>
<tr>
<td>P value</td>
<td>0.006*</td>
</tr>
</tbody>
</table>

Asterisk indicates a statistically significance at an alpha level of 0.05.
Figure 36. Distribution of slope angle estimates derived from question 5 of the validation exercise for one static image. Red line indicates correct slope angle ($8^\circ \pm 5^\circ$).

Figure 37. Distribution of slope angle estimates derived from validation question 5 of the validation exercise for three static images. Red line indicates correct slope angle ($8^\circ \pm 5^\circ$).
CHAPTER 5: DISCUSSION

In this study, 172 people completed an interactive route-finding exercise that incorporated the AVALUATOR decision-support tool. The exercise was modelled after a similar interface used in the CAC’s online avalanche course. Changes in the participants’ knowledge of avalanche facts and concepts were monitored using three surveys, one administered before the AVALUATOR, one after the AVALUATOR, and one after the route-finding exercise. The website also featured a validation exercise, administered after the participants had completed the third and final survey.

Use of the website only marginally increased participants’ knowledge of avalanche-related facts and concepts. Interaction with the route-finding exercise did not significantly increase survey scores above those achieved after the AVALUATOR survey was administered (i.e. there were no statistical differences between the two scores). However, follow-up analysis found that increases in total scores on the survey, for both post-test 1 compared to the pretest and post-test 2 compared to post-test 1 that were limited to particular questions. Specifically, the increases were associated with questions asking about definitions presented in the AVALUATOR. Subsequent analysis of the survey data showed that recreationists, identified as such through responses to a background survey, scored significantly higher than non-recreationists on each survey. However, both recreationists and non-recreationists’ scores increased only marginally after the AVALUATOR component of the website.

Sketch tasks, completed during the route-finding exercise, were analysed for a subset of 23 participants. Participants were largely unable to identify hazards visible in the 2D terrain photograph. On average, only 25% of the hazards (paths, traps, loaded areas) present in the terrain were identified correctly by the participants. Although participants had some success int
identifying run-out zones and tracks of avalanche paths, they failed to identify avalanche start zones.

The validation exercise was used to explore whether single-versus-multiple 2D terrain images had an effect on participants’ ability to estimate spatial features, including distance, elevation, and slope angle. The performance of 106 participants, divided into two groups of 53, shows that use of multiple images led to more accurate slope estimates. However, these more accurate slope estimates were nevertheless substantial overestimates of the actual slope value.

The testing website contains features that should lead to a successful geovisualization, such as a constructivist design, interactivity, and feedback. However, the only true test of a successful visualization is whether it is successful in helping people learn. Why was the testing website used in this study unsuccessful in improving participants’ practical knowledge? The following discussion addresses the overall findings of this study (i.e., the marginal increase in avalanche knowledge through use of the website) by drawing on a geovisualization analysis of both tasks within the route-finding exercise and the validation exercise. Specifically, the discussion focuses on three factors:

1) the different types of knowledge assessed by the survey,
2) the role of representation and feedback in the interactive route-finding task, and
3) the limitations of images in conveying slope angles

Relevant findings

Two questions are posed to focus the discussion. First, why do participants’ survey scores increase only marginally, although statistically significantly, after the use of the AVALUATOR? Second, why did the route-finding exercise fail to increase scores beyond what was achieved after exposure to the AVALUATOR?

The simplest answer to these questions is that the testing website was flawed in some way. To some extent, this assessment probably is correct. Indeed, the following discussion raises some problems with the design of the
exercises, specifically the implementation of feedback and representation. However, the route-finding exercise incorporates similar feedback and representation (i.e. 2D static terrain images) as the route-finding exercise currently used by the CAC. The CAC’s commitment to providing widespread access to basic avalanche safety information restricts the technologies and software available for development of new education tools (i.e., desktop computers, mobile phones, or PDAs). The cost of developing new tools using more advanced geovisualizations, for example intelligent video games or 3D environments, is prohibitive. Therefore, we need to examine the test website constructively, with a view to improving, rather than rejecting, online education.

**Types of knowledge**

The surveys show that participants’ knowledge of avalanche facts improved, but their performance on the route sketch tasks was poor. This result can be understood as a difference between participants’ levels of declarative and procedural knowledge. The test website led to improvement in propositional declarative knowledge (i.e., facts about avalanche hazards), but there was no similar improvement in spatial declarative knowledge (i.e., identification of hazards) or procedural knowledge (i.e., plotting a safe route).

Interestingly, however, the validation exercises showed that the limited ability of participants to estimate slope angles was mitigated somewhat by the use of three static images. The effect of three static images suggests that geovisualizations can impact configurational knowledge, a supposition that will be addressed further in the section on representation and frames of reference.

**Feedback**

Participants’ performance on the interactive route-finding task showed that they had substantial difficulty plotting a route, despite receiving real-time feedback on their decisions. The route sketch tasks allowed me to investigate how and perhaps why participants responded to external stimuli via interactive feedback (hazard pop-ups). I utilized a combination of outcome analysis, for
example the total hazards triggered, and process analysis, such as response to triggers to consider user behaviour in response to pop-up hazard feedback.

Sketch map analysis reveals that aspects of the feedback may have hindered participants’ ability to plot a route. Attempt 2 and attempt 3 are the same task, except that in attempt 3 participants received real-time feedback as they drew their route. Data from the sketch maps show that participants repeatedly ran into the same hazards, but did not cross through them in attempt 3.

The tendency to repeatedly bump into hazards during attempt 3, suggests two things: first, that participants did not have a detailed cognitive model of the extent of each hazard and second, that they interpreted the pop-up hazard as negative rather than informative feedback. The representation of the feedback, with features such as colour (red in the case of loading), size, or triggering (pop-ups when the participants crossed a hazard) encouraged avoidance of hazards.

The implication of this avoidance is that participants may have misinterpreted the meaning of the hazards. The feedback was intended to convey the presence of hazards to the participants and encourage them to factor theirs presence into their route plotting. Instead, the feedback appears to have presented the message that hazards are bad and must be avoided. However, during backcountry travel, a safe route generally involve passing through hazards. Whether or not it is safe to pass through a hazard depends on the conditions. The expert-identified safe route in this exercise is not hazard-free; it passes through five hazards.

It is also possible that participants thought that the size of the feedback polygons were proportional to the amount of hazard they signified. Results show a preference for ascending the ridge up to point B by entering paths and traps 3 and 4 near the end of the ridge. Fewer routes cross the slopes below the ridge, including a necessary hazard. Paths and traps 3 and 4 are reified using narrow, elongate polygons compared to larger, bulbous ones to depict hazards on the ridge slopes. Participants may have chosen to enter the smaller polygons, thinking they were less hazardous.
Several loaded areas exist on the ridge and underlying slopes. These areas were represented using translucent, red polygons. Participants may have avoided these slopes because of the colour implications. Red is commonly used to symbolize a warning.

Although the feedback scheme used here is slightly different from that of the CAC website, my findings suggest that CAC should examine its web-based route-finding exercise along the same lines to evaluate whether similar problems are present.

**Dimensionality and viewpoints**

Although 60% of participants defined terrain traps correctly after reading the AVALUATOR, their ability to apply that knowledge to identify traps was low. Further, participants hypothesized more traps than they actually identified – they thought areas were traps when in fact they were not.

Visual representations in the test website were limited to two-dimensional static images of terrain. Static terrain images are standard tools used to teach terrain and route-identification in field courses, as well as in books and many educational websites. However, 2D static images limit access to spatial features.

Two-dimensional representations provide only one view of the terrain. A single view may misrepresent slope angles and can obscure terrain features. Depending on the vantage point of the camera, angles may become foreshortened and appear steeper than they are. Density maps show that many participants mistakenly identified the gentle valley bottom at the lower left of the image as a terrain trap. Furthermore, gullies and narrow avalanche paths may be obscured, depending on their orientation with respect to the camera. Participants were only marginally successful in identifying trap 6, which is in the immediate foreground of the image. Very few participants identified traps 5 and 7, which were located on a ridge oriented at 45° to the view of the image.

Participants had access to multiple images and thus multiple viewpoints during the route-finding exercise, although in the absence of button-tracking it is unknown whether they were used. In the validation exercises, participants
estimated slope more accurately when they were able to look at three images rather than one. Considering the problems already identified with using a single 2D image, it is tempting to conclude that multiple viewpoints are better than one. However, fewer participants correctly answered the remaining validation questions when using three images, although results were not significantly different.

Participants had significant difficulty in accurately estimating slope angles from terrain photographs on both the surveys and in the validation exercises. Estimating slope angles is key to identifying slopes prone to avalanches (Fredston and Fesler, 1994; Jamieson, 2000). Recreationists are generally cautioned to suspect all slopes over 30° as being avalanche sources, especially open, treeless ones.

The AVALUATOR’s obvious clues framework attempts to reduce reliance on knowledge-based strategies (McCammon and Haegeli, 2007, p. 194) by reducing the need for recreationists to incorporate complex variables such as slope angle into the decision process. However, slope angle is a key factor that determines avalanche paths and the companion booklet reiterates a standard warning that users should suspect all slopes over 30° as potential avalanche terrain. The identification of slope angle is important for both knowledge-based and rule-based approaches such as obvious clues method, which incorporates identification of avalanche paths. The issue of multiple viewpoints and of slope estimation will be discussed further in future directions.

Topographic maps are reliable sources of slope information for amateur recreationists. Professionals and highly trained recreationists commonly use topographic maps during backcountry recreation, and their use is generally recommended. Access to quality topographic maps and their use by recreationists 31 were identified as constraints during development of the AVALUATOR (ADFAR, 2005). Many avalanche education approaches encourage recreations to use topographic maps during pre-trip planning and

31 Snowmobile riders do not commonly use topographic maps during recreation (ADFAR, 2005).
route finding (e.g. CAC online course, Munter’s Reduction Method). However, advocating use of topographic maps assumes that amateur recreationists can read topographic maps well enough to obtain reliable slope estimates and terrain information. Topographic maps, however, require users to make inferences about 3D features from an abstract 2D representation (contour lines) and then relate this information to their view of terrain. Research has shown that inexperienced users have difficulty visualizing and interpreting terrain from topographic maps (Savage et al., 2004; Clarke et al., 2008). This study did not test participants’ ability to interpret slope and terrain features from topographic maps. Testing did, however, target students in Geography and Earth Science courses that specifically teach topographic map reading skills. Analysis showed no significant difference in ability to estimate slope between participants with topographic map experience and those without it\(^\text{32}\). Participants did have access to a topographic map during the route-finding tasks, but it is not known whether they accessed it, because the exercises did not implement button-tracking. The SLF uses topographic maps in its White RISK CD-ROM, although the features of the interface in that activity also may affect how users learn.

Clarke et al. (2008) studied how undergraduate students conceptualize and use topographic maps. They showed that instruction using 2D and 3D representations increased students’ ability to identify familiar features (i.e. hills and valleys) and interpret maps symbols. However, students continued to struggle with tasks that required mental rotation and visualization of terrain. Mentally linking 2D and 3D views of terrain is a complex task requiring considerable spatial ability skills. Clarke et al. (2008) advocate developing visualization skills through targeted activities. It may be necessary for the community to focus on developing deficiencies in map-reading skills through targeted web-based and field-based exercises.

\(^{32}\) The background survey included questions related to experience with topographic maps and level of education in geography and earth science courses.
Limitations

As mentioned earlier, the main limitation of this study is that it was intended to be more elaborate, assessing in the validation exercises the effect of manipulatable 2D and 3D images. Research by Piburn et al. (2005) showed that using interactive computer visualizations increase spatial ability and, in turn, comprehension of geologic concepts. Their research used combinations of static and dynamic 2D topographic images, animations, and interactive 3D models. Participants could interactively control shading, viewpoints, and water levels through zooming, panning, and rotation.

I built 2D and 3D QTVR object models using terrain photographs, DEMs, and satellite imagery. Unfortunately, coding errors eliminated them from the analysis. Fortunately, the missing data were from a random subset of participants; i.e. there was no discernable bias or pattern that might lead to exclusion other than that the participant had been assigned to the 2D and 3D QTVR conditions. Although static 2D images restrict access to spatial information, significant benefits may accrue from using more interactive 2D visualizations. A prototype 3D model was built in an augmented reality (AR) environment (Figure 4a), but testing of the model was beyond the scope of the project. This study also addressed the need for formal testing of current technologies by showing the importance of establishing components or aspects of current tools that are effective before developing and using more advanced tools.

A second limitation was limited access to appropriate high-quality terrain photographs. Signs of loading and terrain traps are dynamic and generally smaller features that may not be easily recognizable from large-scale terrain images. It proved difficult to acquire suitable, medium or slope-scale photos of the study area. Furthermore, the image selected in the present exercise only shows one viable route between point A and point B. The bias introduced by having only a single photograph is evident from the concentration of participant-drawn sketches on the ridge below point B. Participant-drawn routes are similar
to the expert-drawn route and it is tempting to conclude that they performed rather well on route-finding tasks. However, the terrain only offers one viable route up to point B. Density maps show that participant-drawn routes condense at the base of the ridge leading to point B whereas the paths participants take to reach the base of the ridge vary much more. Preferably, the testing website would have featured an image with multiple, viable route options in order to provide a more confident representation of participant performance.

Additionally, most existing terrain photographs represent exocentric views, taken from helicopters or distant ridges. Photographs taken from an egocentric view, simulating the view of a person, are rare. I originally used 3D terrain models, but could not find satellite imagery of suitable backcountry terrain during winter. The dearth of acceptable images meant that participants were given both egocentric and exocentric views of the terrain in the three-image validation exercise. The effect of using both ego- and exo-centric viewpoints was not tested.

Imagery limitations extended to the creation of the 3D validation exercises. No winter imagery was available for suitable backcountry terrain, thus snow had to be digitally added to a satellite image and then mapped onto a 3D model. The avalanche community has only recently begun to use web-based visualizations and is facing a general lack of funding and access to high-resolution data. With inadequate funding, it is difficult to procure high-resolution satellite imagery or other digital data to create 2D or 3D geovisualizations. Data availability is itself a problem because most users of satellite imagery require scenes taken in summer when snow does not obscure the ground. Acquiring new winter images is costly, and cloudy conditions in winter prevent most satellite-based sensors from seeing the ground.

This study examined participants’ knowledge through a simulation. Their behaviour in this simulation may diverge from that outdoors. However, there are a few considerations that mediate this concern. First, there are indications that participants engaged in ‘field-like’ natural actions during their route sketch. For example, in route attempts 1 and 2, many participants drew a route ascending
the ridge exactly as if they were skiing up the ridge (i.e. using a zigzag pattern) (Figure 35). Arguably, the simulation mirrored the real-world activity of planning a route – participants consulted the avalanche bulletin, determined the presence of obvious clues using the AVALUATOR, and identified their intended route and any visible hazards from the trailhead or a distant ridge. The photograph provided to participants during the route sketch is similar to, and serves as a proxy for, a view of the terrain that participants might have from a trailhead or a distant ridge. In the field, a person might use their arms and fingers to ‘sketch’ a route up the mountain, and they do something similar in the simulation using the mouse. The view of terrain from a trailhead, although 3D, appears 2D because distance diminishes depth perception.

Participants’ ability to identify hazards was based on a comparison to the total hazards identified by experts. It is important to note that the experts had previous experience in the study area as well as professional training and experience. Hazards such as Loading 1-5 are small hazards that would likely go unnoticed by recreationists without prior experience in the area. Nearly all the participants failed to identify loaded areas 1-5 in all three attempts. Given the difference between expert and novice knowledge of the terrain, including loading hazards 1-5 in the total score possible (16) misrepresents participant performance. If loadings 1-5 are removed from the total loading hazard possible (16) participants successfully identified 37% of the hazards compared to only 25%. Performance is still low, however the increase is consistent with their performance based on sketch maps analysis.

The route-finding exercise bundled content, interface controls, representation, feedback, and manipulation, making it impossible to determine which features affect performance; any of these interface components, alone or in combination, may affect if and how users learn. Again, this limitation was mitigated somewhat through the use of validation exercises, in which I explored how access to single or multiple viewpoints can influence users’ learning and spatial understanding. A related limitation is that the route-sketching exercise
does not separate those who identify hazards without triggering external feedback from those who identify hazards after receiving external feedback.

Finally, comments left on the website suggest that some participants found that the test website took too long to complete and was repetitious. Although the use of a repeated measures design has the advantage of tracking changes in participants’ knowledge and behaviour, it does require participants to complete certain tasks several times. User testing is crucial to the development of effective education tools, but the final product does not necessarily have to include artefacts of testing such as repeated tasks or surveys.

**Future directions**

This study employed a process approach (e.g., Todd, 1995) to traditional sketch mapping and analysis techniques. Participants’ sketch maps were digitally collected using mouse tracking. Capturing sketch task data through a web-based interface has several advantages over traditional methods. Although the participants were completing a task, they were not explicitly aware that they were being tested on their route plotting. All data were digitally captured and placed in a database, eliminating the time-consuming task of transferring responses from paper and pen sketches. Sketches made on the perspective terrain image were imported into a GIS, although they are not 2D data and therefore not technically suited for GIS analysis. However, I was not interested in distance relationships or other real world metrics that would be affected by using a perspective photograph. Sketches were analyzed to identify the accuracy and pattern of participant-drawn features relative to experts’ features on the image. Use of a GIS for sketch map analysis also allowed me to use non-traditional analytical techniques, including overlay, density, and query functions. The use of these functions reduced some of subjectivity involved in classifying sketch results. Density maps of the user-drawn routes and hazards were used as an alternative method of representing data and offer an additional means to examine user behaviour and the development of cognitive representations. Assessing the data drawn from the sketch tasks in a GIS allowed me to examine not only what
participants drew, but how they drew it. This methodology could be developed in future studies.

Another future research direction is an examination of the implications of the findings of this study for the AVALUATOR. The success of the AVALUATOR depends on a user's ability to reliably extract the seven obvious clues from the environment. Haegeli and Haider (2008) found that graduates of an AST-1 course self-reported a moderate to high level of confidence in their ability to identify hazards. They also report that recreationists' ability to recognize obvious clues from hypothetical decision scenarios improved with use of the AVALUATOR and completion of an AST 1 course. However, the present study suggests that a different picture might emerge if the ability to identify hazards was tested directly, i.e. through a hazard identification exercise, where participants must self-identify clues rather than extract them from synthesized scenario information. I found that the ability of participants to find hazards on a terrain image is poor.
CHAPTER 6: CONCLUSION

Formal assessments of avalanche education tools are scarce. Most research on avalanche education thus far has assessed individuals’ avalanche knowledge, attitudes, and decision-making abilities (Longland et al., 2005; McCammon and Haegeli, 2005), and their retention of avalanche education over time (Pfeiffer and Foley, 2006). No studies have directly addressed the mechanisms by which terrain and route-finding exercises that use interactive visualizations impart avalanche knowledge to individuals. The present study used a convergent approach that combined outcome-based and process-based analytical methods to examine the interaction of participants with an education interface. An integrated approach to survey and sketch map analysis permits deeper understanding of participant behaviour and factors affecting learning.

The route-finding exercise used in this study was less effective than expected. However, the interface was effective in increasing specific declarative understanding of avalanche hazards (beyond improvements gained from reading the AVALUATOR), and, when three static images were presented to a subset of users, in increasing the accuracy of slope estimates. The mixed success of these tools suggests that careful consideration is necessary when developing visualizations to support avalanche education. The features of a visualization affect how well people learn. The present study demonstrated that people learned about avalanche hazards without learning how to identify avalanche hazards on a terrain image. The style of feedback used in the test website inadvertently undermined the message that the learning goal is trying to reinforce. The representations used to depict terrain contributed to participants’ difficulty in estimating slope.

33 However, results from this survey have limited reliability because the researchers did not use a pre-test to establish prior knowledge before the course.
Although participants in this study showed only a marginal increase in their knowledge of specific facts, the study demonstrated the potential for researchers to increase their understanding of the process of avalanche education through the use of geovisualization principles. The avalanche community may be underestimating the role of visual representations in mediating access to factual and conceptual knowledge by failing to consider how features of visual interfaces, such as feedback, representation, and interaction design may inhibit learning. Applying geovisualization perspectives when developing and testing new avalanche education tools will help us understand what recreationists learn from these tools. They also will create a road map for future tool development by identifying what types of representation and which interface components are most effective in facilitating access to avalanche facts and concepts.

Although 2D visualizations are problematic, it is unwise to assume 3D visualizations work better (Scaife and Rogers, 1996). Research by Winn (2002b) indicates that interaction is more important to developing cognitive maps than realism, which is an enticing aspect of 3D visualizations. The avalanche community has shown interest in using new advanced visualization technology such as advanced game engines (serious games) and augmented reality visualizations. Their expense and limited accessibly, however, make them less practical options if the community endeavours to provide education tools that are widely accessible. Furthermore, if such influential organizations are to effectively implement such compelling new public education tools, they need to properly invest in commensurate usability testing and analysis with larger numbers of participants. Highly interactive 2D tools may be effective, but careful consideration is necessary to ensure that learning goals are not undermined by components of the visualization.

A more important consideration for avalanche education is matching the learning activity to the learning goal. The primary goal of the AVALUATOR is to assist recreationists in recognizing obvious signs of avalanche hazard. However, much of the current research into avalanche education (e.g., Longland et al.,
2005; Haegeli and Haider, 2008)), places a heavy emphasis on decision-making while taking for granted participants’ ability to gather relevant information. These efforts provide their participants with spatial data about avalanches (e.g., weather and slope conditions, presence of hazards) and then seek to infer decision-making abilities based on simulated decision-scenarios. However, under natural travel conditions, recreationists must gather information about terrain, weather, and snowpack conditions themselves. My study suggests that amateur recreationists have difficulty identifying hazards during a simulation. Therefore, current avalanche education approaches may not adequately assist recreationists in developing these information-gathering skills and in turn their ability to make informed decisions in the field.

The avalanche community should examine the types of tools that are currently used, their effectiveness, and which new geovisualization technologies might be usefully applied to avalanche education before developing new educational tools or exercises. Otherwise, the community risks wasting resources on tools that do not equip recreationists with the necessary knowledge and skills to make good decisions in avalanche terrain.
REFERENCE LIST


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APPENDIX A: SURVEY QUESTIONS

Correct answers are underlined for the validation exercise and pre- and post-test questions.

Eligibility questions

1. Have you ever completed an avalanche safety course?
   1. Yes          2. No

2. What is the highest level of training you have completed?
   1. None          2. AST1         3. AST2          4. AOL1          5. AOL2

3. How long ago?
   1. NA          2. Less than 1yrs    3. 1-2 yrs      4. 3-4 yrs      5. More than 5 yrs

4. Have you ever used the www.avalanche.ca website?
   1. Yes          2. No

5. If yes, what for?

6. Have you ever used the CAC online avalanche course?
   1. Yes          2. No

Validation exercise questions

1. Which mark is higher in elevation?
   1. a
   2. b

2. Between which marks is the slope the steepest?
   1. a to c
   2. b to d
3. Which route is over steeper terrain?
   1. X
   2. Z

4. Which areas are avalanche paths?
   1. None of them
   2. 1, 3, 6
   3. 3, 4, 5, and 6
   4. 1 and 2
   5. All of them

5. Estimate the slope angle at letter (e). 8° ±5°

Pre-test, Post-test 1, and post-test 2 questions

1. On what range of slope angles do most slab avalanches start?
   1. 15 to 30 degrees
   2. 20 to 35 degrees
   3. 30 to 45 degrees
   4. 45 to 55 degrees

2. ___________ elevate personal risk, increase burial depth, and decrease your chance of survival if the slope avalanches
   1. Large open slopes
   2. Terrain traps
   3. Shaded slopes

3. Cornices, snowdrifts, and scoured snow are signs of
   1. Unstable snow
   2. Recent avalanches
   3. Loading
   4. Thaw instability
4. ___________ are often good ascent routes
   1. Gullies
   2. Open slopes
   3. Ridges

5. Wind is blowing from the southwest. Snow will be re-deposited on
   1. Southwest-facing slopes
   2. North-facing slopes
   3. Northeast-facing slopes
   4. Northwest-facing slopes

6. Of the following, which is the least likely place for avalanches to initiate?
   1. The side of a gully
   2. An open treeless slope
   3. A sparsely treed slope
   4. A slope less than 15 degrees

7. Review the photo below. Which line is on a convex slope?
   1. Line 1
   2. Line 2

   (Source: Grant Statham, modified with permission)
8. Review the photo below. Estimate the angle of the slope at point A.

1. 21-25 degrees
2. 26-30 degrees
3. 31-35 degrees
4. 36-40 degrees
5. 41-45 degrees
6. 46-50 degrees
7. Greater than 55 degrees

(Source: Grant Statham, modified with permission)

9. Review the following terrain photo. Choose the most conservative route

1. Route 1
2. Route 2
3. Route 3

(Source: Grant Statham, modified with permission)
10. On your way to the trailhead, you observe recent avalanche activity. The avalanches are not on the slopes you are going to ski. How important is this information?
   1. Unimportant
   2. Of little importance
   3. Moderately important
   4. Important
   5. Very important

**Background questions**

1. What is your gender?
   1. Female
   2. Male

2. What is your age?
   1. Under 16
   2. 16-18
   3. 19-21
   4. 22-24
   5. 25-27
   6. 28-30
   7. 31-33
   8. 34-36
   9. 37-39
   10. Over 40
3. Do you have any formal or hobby experience with the following?

a. Computer graphics
   1. None
   2. Used once or twice
   3. 1-2 yrs
   4. 2-4 yrs
   5. 5-10 yrs

b. Graphic design/art/sculpture
   1. None
   2. Used once or twice
   3. 1-2 yrs
   4. 2-4 yrs
   5. 5-10 yrs

c. Architecture/surveying
   1. None
   2. Used once or twice
   3. 1-2 yrs
   4. 2-4 yrs
   5. 5-10 yrs

d. Geology/mapping/earth sciences
   1. None
   2. Used once or twice
   3. 1-2 yrs
   4. 2-4 yrs
   5. 5-10 yrs
e. Cartography/GIS/GIScience
   1. None
   2. Used once or twice
   3. 1-2 yrs
   4. 2-4 yrs
   5. 5-10 yrs

f. Computer interfaces (web-based or virtual reality)
   1. None
   2. Used once or twice
   3. 1-2 yrs
   4. 2-4 yrs
   5. 5-10 yrs

4. What is your highest level of education?
   1. Currently in high school
   2. High school
   3. Some university
   4. Bachelors degree
   5. Masters degree
   6. Trade/technical college
   7. Doctoral degree

5. Have you taken any geography or earth sciences courses?
   1. None
   2. 1
   3. 2
   4. 3
   5. 4
   6. 5
   7. More than 5
6. If yes, at what education level?
   1. High school
   2. University
   3. High school and university
   4. Not applicable

7. Have you taken any cartography, GIS, or GPS courses?
   1. None
   2. 1
   3. 2
   4. 3
   5. 4
   6. 5
   7. More than 5

8. How many hours a day, on average, do you use a computer?
   1. None
   2. 1-2
   3. 3-4
   4. 5-6
   5. 7-8
   6. 9 or more

9. Which of the following winter recreation activities do you most frequently participate in?
   1. None
   2. Downhill skiing/snowboarding (resort)
   3. Backcountry skiing/snowboarding
   4. Snowmobiling
   5. Cross-country skiing
   6. Snowshoeing
   7. Other
10. How many days per season do you participate in that activity?
   1. None
   2. 1-3
   3. 4-6
   4. 7-10
   5. 10-15
   6. More than 15

11. Do you ski/snowboard out of bounds?
   1. Yes
   2. No

12. If yes, how many times per season?
   1. Not applicable
   2. 1-2
   3. 3-4
   4. 5-6
   5. 7-8
   6. 9 or more

13. How do you rate your understanding of avalanche theory?
   1. 1 (Low)
   2. 2
   3. 3
   4. 4
   5. 5 (High)

14. How do you rate your backcountry travel skill level?
   1. 1 (Low)
   2. 2
   3. 3
   4. 4
   5. 5 (High)
APPENDIX B: ROUTE-FINDING EXERCISE

Screenshots of experimental route-finding exercise

Task 1 Welcome page and trip scenario
Task 2: Review the avalanche bulletin

Travel Advisory:
Approximately 5-10 cm of new snow accumulated by early Wednesday morning, accompanied by moderate winds out of the northeastern. Weather forecast predicts light winds out of the northwest, little or no new snow, and cold temperatures for Thursday and Friday, which should lead to decreased avalanche danger. Be careful on alpine and open trolley slopes. The wind has blown the snow around so watch for isolated wind slabs behind features like ridges, ice slopes, downslope rib, gullies, and steep relievers. Remember to test the smaller slopes to gain some knowledge before heading to bigger lines. Avalanche risk is increased by traveling above terrain types like gullies and cliffs.

Task 3: Add up hazards present using the AVALUATOR card
Task 4: Route sketch task - Hypothesize route from point A-B (attempt 1)

Task 5a: Hazard sketch task - Identify any visible loaded areas
Task 5b: Hazard sketch task - Identify any visible avalanche paths

Task 5c: Hazard sketch task - Identify any visible terrain traps
Task 6: Route sketch task - Re-draw route from point A-B (attempt 2)

Task 7: Interactive route sketch task - Draw route from point A-B (attempt 3)
Task 8: Review hazards and safe route

When travelling through avalanche terrain, add up the number of obvious clues you observe. The total tells you how your situation compares to the conditions of past accidents. More than two clues is a warning that your next decision should be made very carefully. More than four clues means you should not continue unless you have expert knowledge to evaluate and manage the avalanche hazard. Even then, your best option may be to choose a safer slope.
APPENDIX C: MODIFIED AVALANCHE BULLETIN

Bulletin was modified in coordination with avalanche professions. Participants review the bulletin in task 2 of the route-finding exercise.

<table>
<thead>
<tr>
<th></th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpine</td>
<td>Considerable</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td>Treeline</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low</td>
</tr>
<tr>
<td>Below Treeline</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Date/Time Issued: Wednesday, December 27, 2006 at 3:00 PM
Valid until: Friday, December 29, 2006

Travel Advisory:
Approximately 5-10 cm of new snow accumulated by early Wednesday morning accompanied by moderate winds out of the north-northwest. Weather forecasts predict light winds out of the northwest, little or no new snow, and cold temperatures for Thursday and Friday, which should lead to decreased avalanche danger. Be careful on alpine and open treeline slopes. The wind has blown the snow around so watch for isolated wind slabs behind features like ridges, lee slopes, downslope ribs, gulleys, and steep rollovers. Remember to test the smaller slopes to gain some knowledge before heading to bigger lines. Avalanche risk is increased by traveling above terrain traps like gulleys and cliffs.

Avalanche Activity:
We’re in a period where the snowpack is gaining strength and natural avalanches are not likely. The primary risk is shifting to triggering an avalanche yourself when you rapidly add load to a slope. A size 2 soft-slab avalanche on Monday is an example of this. The slide pulled out on a weak layer 30 cm below the surface when the slope was tested by a rider.

Snowpack:
It’s been quite a run of snowy, stormy weather. But the result is a deep strong snowpack that’s close to 300cm at treeline elevations with few weak layers. The bottom and middle of the snowpack is strong. The primary concerns are found within 50 cm of the surface in the most recent storm snow and these should disappear with a little more time.

Weather:
Another 5-10 centimeters of new snow were added to the snowpack early on Wednesday. Cold dry weather is coming down on a northwest wind and will settle into the region by Thursday and should last for the next several days.

Issued by: Canadian Avalanche Centre