The Role of Geospatial Thinking and Geographic Skills in Effective Problem Solving with GIS: K-16 Education

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Your file Votre référence
ISBN: 978-0-494-54258-3
Our file Notre référence
ISBN: 978-0-494-54258-3

THE ROLE OF GEOSPATIAL THINKING AND GEOGRAPHIC SKILLS IN EFFECTIVE PROBLEM SOLVING WITH GIS: K-16 EDUCATION

by

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DISSERTATION

Submitted to the Faculty of Arts/Department of Geography and Environmental Studies
in partial fulfilment of the requirements for the
Doctor of Philosophy
Wilfrid Laurier University
Waterloo, Ontario, Canada
2009

ABSTRACT

Effective use of a Geographic Information System (GIS) is hampered by the limited geospatial reasoning abilities of students. The ability to reason with spatial relations, more specifically apply geospatial concepts, including the identification of spatial patterns and spatial associations, is important to geographic problem solving in a GIS context. This dissertation examines the broad influence of three factors on GIS problem solving: 1) affection towards computers, geography, and mathematics, 2) geospatial thinking, as well as 3) geographic skills.

The research was conducted with 104 students in Waterloo, Ontario, Canada. Students were drawn from four educational levels: grade 9 students, 13 to 14 years of age; 1st year undergraduate university students, 3rd and 4th year undergraduate geography majors; and geography students at the graduate level ranging from 22 to 32 years of age. The level of affection is measured with modified scales borrowed from psychology. Results show that students in general exhibit positive sentiments toward computers and geography but less so towards mathematics. Spatial thinking and knowledge of geospatial concepts are measured by a 30-item scale differentiating among spatial thinkers along a novice-expert continuum. Scores on the scale showed an increase in spatial reasoning ability with age, grade, and level of education, such that grade 9 students averaged 7.5 out of 30 while the mean score of graduate students was 20.6.

The final exercise assessed pertinent skills to geography namely inquiry, data collection, and analysis. In general, there was a positive correlation in the scores such that the skill proficiency increased with grade. Related analysis found three factors that affect problem-solving performance with a GIS. These include age, geographic skills (inquiry and analysis), and geospatial thinking (subscales analysis, representation, comprehension, and application). As well, the relationship(s) between performance on the geospatial scale and the observed problem-solving sequences and strategies applied on a GIS was examined. In general, students with lower scores were more apt to use basic visualization (zoom/measure tools) or buffer operations, while those with higher scores used a combination of buffers, intersection, and spatial queries. There were, however, exceptions as some advanced students used strategies that overly complicated the problem while others used visualization tools alone.

The study concludes with a discussion on future research directions, followed by a series of pencil and paper games aimed to develop spatial thinking within a geographic setting.

ACKNOWLEDGEMENTS

When I was accepted into the Waterloo-Laurier Graduate Program in Geography, my heart had a strong desire to learn about geographic education. Seven years later, a dream has been realized and the fruit of labour is this dissertation.

Geographic education in my mind is the pillar of a Geography Department. How students respond to and the level of excitement ignited by their geography courses determine the growth of a future generation of geographers. However, geographic education is actively investigated by a small number of interested researchers in Canada and even fewer have graduate students engaged squarely on this topic. Nevertheless, the universe conspired to help me reach my dream; I met Dr. Bob Sharpe. Dr. Sharpe is a pioneer of GIS education in the Department of Geography, is an exemplary mentor, and is a geographer interested in teaching about geography.

Dr. Sharpe played an integral role in geographic education in general, but a pivotal role in my dissertation more specifically. I have fond memories of discussions, being challenged and arriving at solutions together with Dr. Sharpe. Many ideas, innovation and creativity resulted from repeatedly long chats, often paused by a coffee break. Aside from the dissertation, Dr. Sharpe has been a long-time mentor for me, helping me mature into a young academic by involving me in his research and as an invited guest to his classes. Along the way, he instilled seeds of collaboration and academic honesty by modelling them. Without his clarity, wisdom, and generosity, my doctoral experience would not have been so rich and enjoyable.

Dr. Sharpe's tireless energy promoting geographic education has attracted a number of graduate students. Chris Charman is a dynamic geography teacher in high school as well as a colleague. His role and connections in the education field played a significant part in giving me access to grade 9 students. Thank you, Chris, for being a great colleague.

I have stumbled along the road of scale creation and statistics. However, the fall was cushioned by resourceful and caring faculty. I would like to extend my heartfelt gratitude to Dr. Eileen Wood who discussed with me on numerous occasions, how to build a scale and what to consider in formulation of question items. To Dr. Jean Andrey and Dr. Scott Bell who explained some complicated statistics so that I can make sense of the data. To Dr. Mary-Lou Byrne who played multiple roles: as a committee member, a donor of prizes and provider of hugs to boost the writing spirit. My sincerest gratitude goes to Dr. Bednarz for her contribution to an enjoyable defence experience and for flying from Texas to serve as my external examiner.

The data collection process was made possible by faculty and lab instructors (Dr. Doherty, Dr. Hamilton and Mr. Igor Hoogendoorn) who allowed me to recruit students from their classes. The successful recruitment process was primarily due to staff who posted advertisements and sent e-mails to students (Ms. Lynn Finch, Ms. Jo-Anne Horton, and Ms. Melissa Ireland). Thank you. Funding and prizes were generously donated by faculty (Dr. Byrne, Dr. Doherty, and Dr. Sharpe) as well as various departments (WLU Bookstore, President's office, Department of Geography and Environmental Studies, and the Dean of Arts Office). Despite the enticing prizes, the dissertation would not have been possible without the generous time and interest of participants (grade 9 students from Huron Heights C.I.; first year geography students, third and fourth year geography students from WLU; as well as graduate friends in the joint geography program).

Much gratitude is extended to the Social Sciences and Humanities Research Council (SSHRC) for the generous funding of my work.

I have been supported immensely by my dear friends in London (U.K.), Singapore, Toronto and Waterloo. Your friendship helped me focus and complete what I started.

When I wasn't sure whether I should continue, my dear brother Ho Lun, very gently told me the answer. I am finishing because of your words, thank you for knowing what to say. To my mother and father, My Quynh and Chau Huynh, wonderful parents who have never given me pressure in life but instead allowed me the freedom to choose my own career path. I dedicate this dissertation to you. I can never repay the depth of your love but because of your love, patience, support, and understanding, I have the chance to attend graduate school and learn for the purpose of learning.

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CHAPTER 1: INTRODUCTION

Since the 1970s, various geographic information technologies have been integrated into higher education. Indeed, over the past decade, geotechnologies, including Geographic Information Systems (GIS), Remote Sensing (RS), and Global Positioning Systems (GPS) have become fully integrated in university-level Geography programs, and are also used in other disciplines, particularly Planning and Civil Engineering. Their integration into secondary and elementary school curriculum, however, has been somewhat slower than anticipated by researchers and educators (Audet and Paris 1997; Bednarz and Audet 1999; Bednarz et al. 2004). Estimates suggest that as of the late 1990s and early 2000s, between one and 20 percent of American schools teach GIS (Audet and Paris 1997; Kerski 2003), and, in Canada, the penetration is also low, at less than one-third of schools (Charman 2007). Where GIS is taught, Laskin (2005) found that, in a sample of 99 Ontario secondary-school teachers, only six percent thought that they were fulfilling the Provincial curriculum expectations of integrating geotechnology in teaching.

When geotechnologies, and GIS more specifically, were developed, many in the higher education community hoped that their introduction into curricula would renew Geography as a discipline (Abler 1987; Nellis 1994; Waters 2003). At the high school level, however, educators were particularly interested in how GIS might facilitate spatial thinking (Gatrell and Oshiro 2001; NRC 2006) and reasoning through visualization, representation, and spatial analysis (NRC 2006). Although GIS has the potential to be a useful tool in teaching geography and spatial thinking, past experiences with technology integration in the classroom (e.g., radio, television, early computer-assisted instruction) caution that computerized tools require effective instruction and teaching strategies (Lou et al. 2001).

When GIS was first introduced to the classroom, there was an implicit assumption that students have sufficient geographic knowledge and skills to use these new technologies. Of particular importance to GIS is spatial thinking, a component of spatial intelligence (Gardner 1983) whose value is determined by the society (Gardner 1983) and education system (NRC 2006). Thousands of years ago, its value to hunters and gatherers was survival whereas at present spatial thinking plays diverse roles in humans' interaction with the natural and built environment. Some daily usage of spatial thinking includes navigation, assemblage of furniture, and locating your car from a full parking lot. The general trend, however, has been that educational technologies outpace the development of associated knowledge rooted in learning and teaching (Audet and Abegg 1996; Kerr 1996; Willis and McNaught 1996; Jackson 2000). Not surprisingly then, the integration of GIS into the K-12 stream has faced challenges. Some of the challenges are due to students' weak foundation in geographic concepts such as scale or pattern identification. Other contributing factors include inadequate financial commitment, which translates into too few workstations; too few trained teachers; and the complicated nature of the software (Bednarz and Ludwig 1997; Kerski 1999; Kemball 2004). With respect to the latter point, it is important to note that geotechnologies are developed primarily for professional use, and even in these contexts only 10 percent of software functionality is typically used (Tomlinson 2003).

Over the past two decades, only limited progress has been made in understanding the links between geotechnologies in the classroom with learning geography and spatial thinking despite the increased availability and sophistication of related educational resources and teacher training. Early work suggests that GIS technology has positive effects on student motivation and attitudes, although its role in encouraging inquiry or developing spatial thinking is unclear (Baker 2002; West 2003; Shin 2006). More recent work, which explores how GIS fosters geographic knowledge, shows that GIS promotes student discussion and reasoning with geographic concepts (Wiegand 2003), although spatial analysis skills need improvement (Baker and White 2003; Shin 2006). Still, much has yet to be learned, and two in particular are to 1) develop methods for measuring relevant impacts and 2) to produce replicable empirical evidence in order to advance our understanding of learning issues associated with geotechnologies.

GIS studies traditionally compare students who are within and between the same grade or age cohort. These clustering methods assume that participants within a group are uniform in their knowledge range, skill sets, and affection to the subject. In this study, GIS results vary, an indication that geospatial knowledge application to novel GIS problems differ across traditional delineation groups. To this end, a methodological gap exists; past empirical studies confuse the heterogeneity of skills within cohorts. A solution to these problematic categories is to group participants according to performance levels; novice through to expert categories is used to frame this dissertation.

The novice-expert continuum first appeared in chess research (Simon and Chase 1973; deGroot 1978) and is applied to different domains (Ericsson and Smith 1991). In geography, the novice-expert dimension has been used in education related research (Audet and Abegg 1996; Anderson and Leinhardt 2002; Wigglesworth 2003; Virvou and George 2008). The research strength of grouping students into expertise categories is that it is a truer reflection of performance outcome. As a result, the categories are useful to match lessons and assignments with each individual's or group's level of learning.

This research is conducted for three main reasons. Due to a paucity of reliable and valid tasks to identify geospatial expertise, this study first designs a scale that identifies students based on their geospatial knowledge. Second, the geospatial scale may explain how expertise in geospatial thinking develops and how it may be related to GIS problem solving. Third, reliable identification of students across expertise levels can produce tailored teaching lessons and evaluation materials.

Since this study borrows theories from geography, psychology, and education, similar terms with somewhat different interpretations are possible. Furthermore, collaboration creates hybrid vocabulary that may be new to both parent disciplines. The terms below are defined to clarify their meaning within a geographic context.

Geographic affection is a person's total inclinations and feelings, prejudice or bias, preconceived notions, ideas, fears, threats, and convictions about geography (Thurstone 1928).

Geographic education is a hierarchical education system governed by four main actors (government, teacher training institutions, teachers, and students) with the aim to encourage geographic learning (Bednarz and Bednarz 1995).

Geographic knowledge is an understanding of concepts, theories, and processes related to the study of geography.

Geographic perspectives describe one's point of view towards geography. A perspective shapes the way one looks at the world through personal experience and subjective evaluation (Geography Education Standards Project 1994).

Geographic skill is the ability to understand geography through five actions that include: 1) asking geographic questions, 2) acquiring geographic information, 3) organizing geographic information, 4) analyzing geographic information, and 5) answering geographic questions (Geography Education Standards Project 1994)

Geospatial knowledge is a hybrid of geography and spatial thinking to create information that further resolve issues 'of' or 'about' space in geography.

Geospatial thinking is the sequential process of working through a problem that requires geospatial knowledge.

GIS problem solving is a task that applies geospatial knowledge, geographic skills, and geographic perspectives to reach a solution that satisfies geospatial criteria using GIS.

Spatial ability is the capability to perform any three mental skills, orientation, spatial relations, and spatial visualization (McGee 1979; Gilmartin and Patton 1984)

Spatial reasoning is a process whereby relevant spatial information are identified and organized to understand geographic phenomena.

Spatial relations is an ability to understand pattern(s) resulting from an arrangement of visual objects (Gilmartin and Patton 1984)

Spatial thinking is a form of thinking that includes cognitive skills that embody concepts of space, tools of representation, and processes of reasoning (NRC 2006).

1.1 Statement of research problem and research objectives

The overarching research problem is to investigate the role of geospatial knowledge, geographic skills, and perspective as well as geospatial thinking in problem solving with a GIS. There are eight principle objectives in this research.

The first research objective is to develop an instrument, a geospatial scale, to designate one's level of geospatial thinking.

The second objective is to examine the relationship between geospatial thinking, as measured by the geospatial scale, to age, grade, gender, and level of formal geographic education.

A third objective is to identify the dimensions of geospatial knowledge that differentiate novice-intermediate-expert levels of geospatial thinking. Of interest here is a clearer specification of the components of geospatial thinking.

The fourth objective is to examine the geospatial scale's relationship to individual affection and skills. The logic here is that an individual's geospatial thinking is partially influenced by their affection towards computers, geography, and mathematics and by their level of geographic learning skills (inquiry, organization, and analysis).

The fifth objective is to develop a problem-based computer exercise to measure how a GIS is used to solve a geographic question. Aspects of performance that are of particular interest include the problem-solving process, time to complete task, and sequence of problem solving.

The sixth objective is to examine the relationship between one's geospatial expertise level with performance on the GIS exercise. How do the geospatial dimensions relate to problem solving? How do different orders of task sequences correlate to problem solving?

The seventh objective is to examine the differences between novice, intermediate, and expert levels of thinking by drawing on observations and creation of an expertise profile.

The eighth objective is a cumulative outcome of the seven objectives; to develop pencil and paper exercises aimed to develop geospatial and GIS knowledge.

1.2. Dissertation outline

The dissertation is divided into seven chapters. Chapter Two provides a literature review of four areas. The first is a focus on past geographic and GIS education research, followed by a general review of literature on spatial cognition, spatial thinking, and reasoning. The third area of literature summarizes expertise levels and the novice-intermediate-expert continuum. The fourth section describes two qualitative assessment methods. The first method introduced is the Structure of the Observed Learning Outcome (SOLO) taxonomy (Biggs and Collis 1982). This is followed by a sequence analysis method using a software called CLUSTALW (EMBL-EBI 2007).

Chapter Three discusses methodology starting with an overview of the data collection procedure. This is followed by an explanation of the assessment scales, selection of participants, and overall research design.

Chapter Four describes the results. Each objective is analyzed by a combination of statistical calculations and student observations.

Chapter Five discusses selectively interesting findings and surprising results. This is followed by Chapter Six which concludes the thesis with a summary and suggestions of future research directions that are closely related to this study.

Chapter Seven extends the discussion by applying the findings of this study to three areas. The first section discusses teaching implications based on observations of participants. The second section examines GIS learning on-line or in a blended teaching environment. Finally, the last section is a collection of pencil and paper tasks that introduce GIS operations and develop geospatial knowledge.

CHAPTER 2: LITERATURE REVIEW

The literature review is organized around four main themes. The first theme relates to geographic and GIS education research, providing an overview of three attributes, namely geospatial knowledge (e.g., primitive through to higher order concepts and vocabulary), geographic skills (e.g., asking geographic questions), and perspectives (e.g., spatial). This is followed by a review of GIS teaching practices. These two research areas are combined to explore the nexus of geographic and GIS education.

The second theme relates to spatial thinking. The literature reviewed considers educational psychology and the development of spatial thinking. The third theme is the concept of expertise. An overview of expertise is described and the significance of its role in differentiating geospatial performance is explained.

The fourth theme reviewed is two analytic methods applied to the GIS problem-solving task. The first, Structure of the Observed Learning Outcome (SOLO) taxonomy (Biggs and Collis 1982), is an extended evaluation to assess the overall GIS task. The second analysis applies a sequence analysis to group similar problem-solving styles into categories.

2.1 Geographic education: A study of geographic knowledge, skills, and perspectives

Models of learning and development identify three common but distinct elements within any discipline: *subject matter (background knowledge, core concepts, and vocabulary), skills (criteria for judgement and thinking strategies) and perspectives (habits of mind)* (Bloom 1956; Krathwohl et al. 1964; Harrow 1972; Geography Education Standards Project 1994; Dall'Alba and Sandberg 2006; Denos and Case 2006). The nature of these learning elements and their contribution to geographic education is discussed in the following sections.

Geographic knowledge

Underpinning geographic knowledge (concepts, models, and theories related to human and physical phenomena on Earth) (NRC 2006) is the spatial element (Carstensen et al. 1993; Goodchild 1995; Douglass 1999; Walford 2000). Although disciplines other than geography have a spatial dimension (Ford 1984; Self and Golledge 1994; Golledge 2006), it is core to geography (Golledge 2002; Bednarz 2004). The discipline studies spatial aspects of human existence (Geography Education Standards Project 1994) from a chorological approach, focused on phenomena distributed over space (Hartshorne 1939; Tuason 1987; Harper 1990). In this regard, 'geographic' is a specialization of the spatial domain (Nystuen 1968; Papageorgiou 1969; Goodchild 2001).

Although geographic knowledge is universal and can be accumulated implicitly from daily experiences (Egenhofer and Mark 1995; Nyerges 1995), the specific modes of geographic thinking and reasoning require explicit instruction (Golledge 1992; Golledge 2002). Geographic knowledge learned informally or implicitly, tends to be disorganized and spotted with misconceptions. Synonyms of misconception include preconception or alternative framework (Treagust 1988); they all refer to an interpretation of an idea, concept or theory that differs from that commonly held by the community (Wandersee 1985; Nakhleh 1992). Unlike science education where research on misconception is rich (Nussbaum 1979; Helm 1980; Fredette and Clement 1981; Arnaudin and Mintzes 1985; Treagust 1988; Nakhleh 1992; Zeilik 1998), a review of the literature resulted in little work on geographic misconceptions, except for isolated reports on spatial terms (Marsh et al. 2007). Thus, the area of misconceptions in geographic learning is a fertile area for research effort.

Geographic knowledge is imparted by explicit introduction of concepts (Bruner 1963; Golledge 2002; Kirschner et al. 2006) that have domain-specific primitive terms. Golledge (2002) attributes the slow development of geographic knowledge to a lack of well defined and widely taught primitives. Primitives are the building block, that combined can derive more complex spatial and geographic concepts which then form principles. Thus, a conceptual framework for a lexicon of geographic knowledge is created. It loosely follows Kuhn's (2001) ordering of activities, builds on geographic guidelines (NCGE and AAG 1984; Geography Education Standards Project 1994), geographic themes (Pattison 1964), and early work on geographic primitives (Nystuen 1968; Papageorgiou 1969; Walker 1976; Goodchild 2001; Golledge 2002; Kaufman 2004; Golledge 2006; Marsh et al. 2007). Table 2.1 is both a conceptual framework and theoretical foundation that provides a tool to communicate knowledge *about* the central themes of geography, in particular the spatial arrangements of activities and processes in geographic space (Nystuen 1968; Kaufman 2004).

Higher order geographic concepts	Spatial Tradition (spatial analysis)	Man-Land Tradition (human ecology)	Area Studies Tradition (regional geography)	Earth Science Tradition (physical geography)	Examples of Concept-based geospatial tasks and relations developed in a geography classroom
	World in Spatial Terms Global Connections	Human Systems Environment and Society	Place and Regions	Physical Systems Resources	GIS
Fourth-order concepts derived from primitives, first-, second- and, third-order concepts	Overlay	Network (location, connectivity) Hierarchy (location, magnitude, and connectivity)	Correlation	Environmental perception	Cognitive mapping: To illustrate relations between subjective and objective knowledge. Task: Ask participants to draw from memory the spatial relationships in an environment. Associate and correlate spatially distributed phenomena Understand use of spatial hierarchies
Third-order concepts derived from primitives, first- and, second-order concepts		Spatial association	Pattern matching	Projection	Recognition of spatial Distribution and spatial patterns
Second-order concepts derived from primitives and, first-order concepts	Density and distance decay (from boundary, distance, magnitude, and distribution) Nearest neighbour	Dispersion/spatial variance	Spatial association (from location, magnitude, and distribution) Boundary	Pattern and shape, clustering, and dispersion (from arrangement of distribution) Slope	Density: To comprehend a spatial interpretation of the concept of 'ratio'. Task: Ask participant to calculate the population density for different area and order them from most to least crowded. Identify shape Understand distance decay and nearest neighbour

First-order concepts derived from primitives	Spatial Hierarchy and dominance (from magnitude and location) Scale (size and place)	Frame of reference (from size and shape) Orientation and directions (from location, identity, and frame of reference) Connection/linkage*	Regions (aggregations of place specific identified) Site and situation (developed from size, place containment, and connectivity)	Distribution/Arrangement (from multiple locations) Distance/height (length between points)* Order/categorization (by magnitude) Sequence (space-time)	Order/Categorization: To introduce ideas of classes or categories. Task: Ask participant to pile illustrations of similar objects together Connect locations Regionalizing Wayfinding in real world frames of reference Map comparison
Primitives (simple geographic concepts)	Connectiveness (adjacency or relative position) Location Magnitude Place specific identity Representation Size Time				
An example of problem solving with primitives, adapted from Kaufman (2004)	How should the best location of a new sports stadium be determined? Size: is there enough space for parking? Distance: will parking be close to the entrance? Containment: does this region already have enough stadiums?				

Table 2.1: A summary of geographic knowledge: Primitive to complex concepts

(Pattison 1964; Nystuen 1968; Papageorgiou 1969; Walker 1976; Geography Education Standards Project 1994; Golledge 1995; Golledge 2002; Bednarz 2004; Golledge 2006)

Geographic skills

Five widely recognized geographic skills are 1) asking geographic questions, 2) acquiring geographic information, 3) organizing geographic information, 4) analyzing geographic information, and 5) answering geographic questions (Geography Education Standards Project 1994).

i) Asking geographic questions

The types of questions asked include 'where and why'. Hypotheses can be developed to contemplate reasons for why phenomena appear where they are and how they appear there.

ii) Acquiring geographic information

Geographic data collection can be from such sources as fieldwork, interviews, and library archives. Skills developed from data collection include locating and compiling data, observing and systemically recording geographic information (e.g., GPS points), reading and interpreting maps, and other graphic representations of spaces and places.

iii) Organizing geographic information

The organization of geographic information can take many forms, depending on the nature of the data collected. Some examples of data organization include mapping, written summaries, and data tabulation.

iv) Analyzing geographic information

The analysis of geographic data is focused on pattern seeking, making connections, and understanding relationships. A synthesis of observed patterns, for example in the environment, generates explanations about geographic phenomena and potential predictions about extended geographic relationships.

v) Answering geographic questions

Answering geographic questions requires a culmination of the skills '1' through '4'. It is the ability to (progress from) analysing information and developing general explanations to making conclusions.

Geographic perspectives

A perspective is a point of view that affects how one sees, interprets and understands the world. It is developed continuously through one's lifetime, and influenced by life experiences. Geographically informed persons develop two geographical perspectives, namely ecological (human ecosystem interaction) and spatial (Geography Education Standards Project 1994). Affection (e.g., level of motivation, their likes/dislike) is influenced by one's perspectives. In psychology, 'affection' is used synonymously with 'emotion' although some psychologists use 'affection' to describe a motivational condition that can take the form of an emotion or a drive state such as hunger (Izard 2000). In this study, affection describes one's attitude and likes towards geography resulting from ecological and spatial perspectives. It should be reminded that affection an attitude is a complex characteristic that cannot be completely understood or explained with any single numerical index (Thurstone 1928).

2.2 GIS education

Electronic devices have been used in the classroom ranging from film (1920s-1930s), radio (1920s-1940s) and instructional television (1950s-1960s) to computers (1980s to present). Currently, the ideal geography classrooms are equipped with computers, which challenge students through multidisciplinary projects and group work (Means and Olson 1994) that are integrated with curriculum rather than presented as isolated computer exercises (Collis 1994). In geography, computers are favoured as their dynamic and visual representation are assumed to better represent reality, develop spatial concepts, and improve understanding of processes (Gold et al. 1991). Means (1994) defines GIS as a general-purpose software used to complete such tasks as data storage and data analysis. Compared with Figure 2.1, GIS encompasses problem solving through to data management which are at the higher level of computer interaction and thinking.

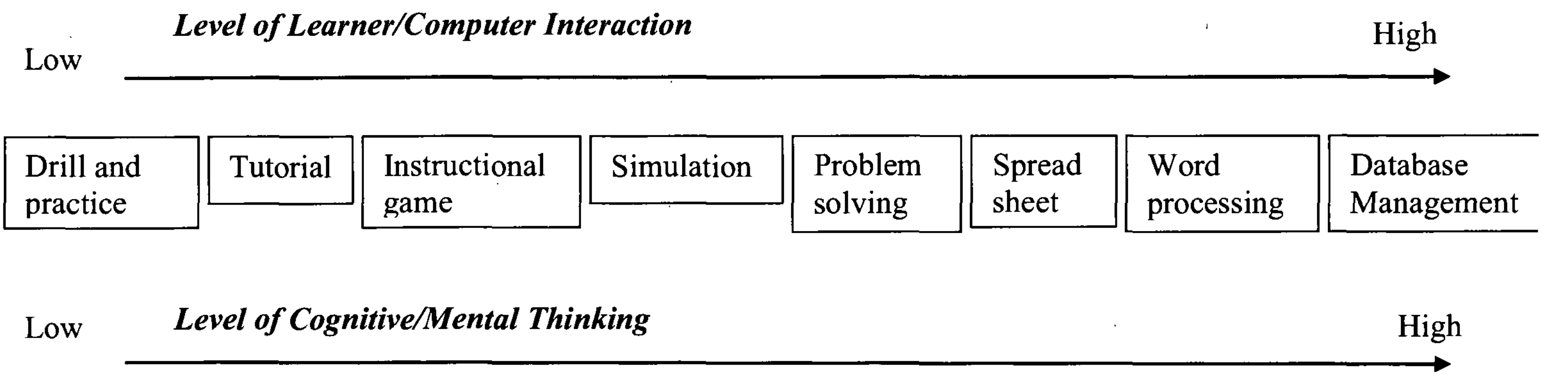


Figure 2.1: Typology of learning technologies
Source: Cummins & Sayers (1990)

GIS is promoted as an educational tool to encourage positive learning of data exploration, critical thinking, literacy, computer skills, and spatial awareness (Faison 1996; Audet and Paris 1997; ESRI 1998; ESRI 2006). Supporters claim that GIS can better teach spatial concepts and processes through dynamic and visual mapping (Gold et al. 1991) compared to static textbooks and lectures (Zerger et al. 2002).

Many forms of GIS teaching and curricula have been proposed at the undergraduate level (Goodchild 1985; Mueller 1985; Burns and Henderson 1989; Nyerges and Chrisman 1989; Walsh 1992; Carver et al. 2004) in addition to broad teaching models (Kemp et al. 1992; Sui 1995; Marble 1997; Frank and Raubal 2001; Wikle and Finchum 2003). Undergraduate instruction was refined to a two-tiered learning model that distinguishes between education and training (Mueller 1985; Poiker 1985; Burns and Henderson 1989; Kemp et al. 1992; Ventura and Sullivan 1992; Walsh 1992; Sui 1995; Longley et al. 2001). By the late 1990s and early 2000, GIS education was reorganized to include a hierarchical knowledge structure (Xiang 1992; Marble 1997; O'Kelly 2000) which was manifest as a national (U.S.A) GIS curriculum (Kemp and Goodchild 1991; NCGIA 2000; UCGIS 2003). O'Kelly (2000) and Poiker (1985) suggested that a sequence of courses must be followed, built around a core of fundamental theory. Once students have mastered the theory, their next focus is dedicated to techniques followed by applications of the tool. To date, there is still little consensus on prerequisite courses or requisite skills (Goodchild 1985; Morgan 1987; Chen 1998) such that some classes base the curriculum solely on reading and discussion, with no computer practice (Wright and Dibiase 2005).

2.2.1 GIS-based geography courses

Early GIS-based geography courses, mainly coming from the United States, were dominated by such common elements as 1) the nature of geographic data and geographic data collection, 2) geographic data analysis and data display, 3) database management, and 4) types and uses of GIS (Morgan 1987). However, students lacked understanding of spatial concepts and geospatial lexicon creating over-reliance on software (Walsh 1992). So, in the 1990s, components of geography were integrated into the GIS curricula, usually in the form of cartography (Walsh 1992), geographical problem solving, and data analysis (King 1991). Recently, the need for students to learn basic geographic concepts is raised (Bampton and McAnneny 2006) to prevent them from becoming 'buttonologists' with GIS and to surrender to *technocentrism* (Bednarz, 2004).

Two broad GIS curricula designed for post-secondary level were found in the literature, both from GIS organizations established to promote GIS. In 1990, the National Center for Geographic Information and Analysis (NCGIA) produced a 75-lecture outline to provide teaching content and resources for GIS educators across U.S.A (Kemp and Goodchild 1991). Since then it has been updated once, in 2000 (NCGIA 2000). The first version focused on GIS topics in general and GIS technology in particular. The elements of this curriculum resemble those of other teaching models produced by Morgan (1987) and Marble (1997). A decade of revision led to a second edition, which departed from the first by an increase in geographic concepts. This came about from the guiding principle at NCGIA that underlying geographic concepts and geographic knowledge distinguish GIS and geographical information technologies from other software applications. Geographic concepts include "primitive elements, features, and relationships used to analyze, model, reason, and make decisions in a geographic context" (NCGIA 2000). The curriculum is organized with foundational geographic concepts inserted throughout. For example, geographic concepts like visualization as well as a brief introduction of maps and map analysis (spatial relations) are integrated.

The second curriculum is the 'Development of Model Undergraduate Curricula for Geographical Information Science & Technology: The Strawman Report (UCGIS 2003)', developed by a sub-committee born out of the NCGIA, called the University Consortium for Geographical Information System (UCGIS). The Strawman report was a response to students' weak knowledge in critical components of GIS such as computer science, information technology, and spatial analyses. Similar to the NCGIA (2000) curriculum, the Strawman report operates on the principle that spatial (geographic) concepts are a critical foundation of GIS education. However, the order of geographic knowledge introduced in these curricula is fragmented, commencing with higher order concepts, e.g., 'spatial association' without review of the primitives. The breadth and depth of geographic knowledge taught is directly applicable to GIS applications; however, due to its focused nature, the geography introduced is only a subset of an informed person's geographic knowledge base.

This discussion transits from a global to local scale. At the secondary-school level in Ontario, education is mandated by provincial curricular guidelines. Ontario was the first province in Canada to develop a GIS education curriculum, offering two GIS-based geography courses. The first course, "Geographics: The Geographer's Toolkit, Grade 11, Workplace Preparation (CGT3E)" is an introductory course designed for students entering the workforce after secondary school. The second course, "Geomatics: Geotechnologies in Action, Grade 12, University/College Preparation" is theoretically and practically oriented to prepare students for post-secondary education. A study by Sharpe and Huynh (2004) found two domains of geospatial knowledge in these geomatic courses. The first is related to the basic concepts of geography while the second is linked to slightly more specialized GIS concepts. Examples of basic geographic concepts include location, coordinates (latitude and longitude), distance (primitives), and maps, while buffer and overlay (higher order primitives) exemplify GIS operations.

2.3 The nexus of geographic and GIS education

2.3.1 Geography and GIS education research

The geography literature is rich in ad-hoc research, anecdotal teaching observations, and teaching resources such as lesson plans (White and Simms 1993; Ramirez 1996; Alibrandi 1997; West 1999; Gatrell and Oshiro 2001; Broda and Baxter 2002) but deficient in empirical data (Downs 1994b). Research that investigate how GIS fosters reasoning and analytical use of geographic data with technology is immediately desired (Lemberg and Stoltman 2001) as there is currently no research to confirm the connection between spatial relational skills and GIS instruction (Bednarz 2004). By the late 1990s onwards, empirical data on geographic and GIS education started to emerge, principally from dissertations (Audet 1993; Weller 1993; Baker

2002; Shin 2003; Qiu 2006) and masters' theses (Palladino 1994; Crechiolo 1997; Wardley 1997; Storie 2000). These publications follow five general avenues of research, 1) the effects of GIS use on geographic learning and motivation, 2) the effects of GIS on spatial ability, 3) the effects of GIS as a problem-solving tool (such as in the disciplines of Science and Geography/History), 4) the level of geographic knowledge and its impact on GIS use, and 5) problem-solving styles using GIS. A summary of GIS education research can be found in Table 2.2. Research investigating the first two categories, has produced findings favourable to GIS, albeit modestly. The research instruments are commonly standardized tests, which are administered pre- and post- GIS use (Patterson et al. 2003; Qiu 2006; Lee and Bednarz 2009). Although useful, standardized tests are static and do not capture the processes through which the transformation of geospatial knowledge is applied in a GIS environment. A second common research design is to compare concepts and skills exhibited during GIS problem solving to expectations derived from the National Geography Standards (Geography Education Standards Project 1994). The third category of research, external to the geography discipline, focuses on GIS as a research tool to reason *with* rather than *about* GIS (Sui 1995). The results suggest that GIS has moderately positive effects on student attitudes towards scientific inquiry and geographic learning. However, students had considerable frustration in mastering the technology, interpreting the spatial outputs (Baker and White 2003; West 2003; Wiegand 2003) and lacking in geographic skills (e.g., inquiry) (Keiper 1999; Shin 2006). Although copious research advocate that GIS can be used to teach geography (Fitzpatrick 1993; West 1998; Keiper 1999; Kerski 2000; Gatrell 2001; Kerski 2003; Patterson et al. 2003; Shin 2003) and spatial abilities (Lee 2006b; Qiu 2006; Lee and Bednarz 2009), the literature produces a vague description of the geography learned (Bednarz 2004) and spatial abilities assimilated (Meyer et al. 1999; Kerski

2000; Baker 2002), producing scepticism of the true learning value with a GIS (Meyer et al. 1999; Shin 2003).

Research Focus	Researcher(s)	Grade of Participants	Discipline	Research Goals	Methodology	Results
Effects of GIS on geographic learning	Patterson, Reeve & Page (2003)	Grade 12 and first year university students	Geography	To learn whether GIS use improves geographic learning	Control group: Subgroup of students in class Test group: GIS use Standardized test to reveal level of geographic knowledge	Geographic knowledge is improved with GIS use
	Kerski (2000)	Grades 9, 11, 12	Geography	To learn whether students learn geography or computer tool	Control group: Subgroup of students in class Test group: GIS use Standardized tests (geographic literacy) and spatial analysis test were used	Geographic knowledge is improved with GIS use although spatial thinking and reasoning is lacking
	Keiper (1999)	Grade 5	No major	To learn how effective GIS is for geographic education	Problem solving in groups of 2-3. Students asked to reason aloud	Students showed effective application of previously learned geographic knowledge
Effects of GIS on spatial learning	Lee and Bednarz (2009)	University students (undergraduate level)	Geography	To determine if GIS affects spatial thinking development	Control group: Students who have not taken GIS or cartography course(s) Test group: Students taking cartography, GIS or a combination of both Use of pre- and post- spatial skills test	GIS learning helps students think spatially Lab work correlates with results of spatial skills test
	Qiu (2006)	University students (1-3rd year)	Geography	To learn about the cause and effect relationship between GIS use and spatial ability	Control group: First year geography students Test group: Geography students in GIT courses Use of pre- and post- spatial thinking test	Overall spatial ability improved (visualization, orientation, and relations)
	Wiegand (2003	14-15 year olds and 16-17 year olds	Geography	How do students make meaning of choropleth	Audio and video were used to record the map making procedure	Students did not have problems with the software but difficulties interpreting data

		(British school system)		maps and what cartographic strategies are used	whilst working in groups	("high on illiteracy and low on higher education" pg. 239)
	Wigglesworth (2003)	Grade 6 and 7	No major	To learn how students navigate and route-find in a GIS environment	Background survey, Group Assessment of Logical Thinking (GAL), and think aloud transcripts	Route selection is performed in three different ways: visual, transitional, and logical
Effects of GIS on learning (Science, History/Geography)	Baker & White (2003)	Grades 6, 7, 8	Science	To learn about student attitude after use of GIS in a science problem-solving environment	Control group: First year geography students Test group: Geography course without GIS technology Affective test given to students	GIS found to modestly increase data analysis skills though spatial abilities are weak and thus students not equipped to make general basic patterns
	Shin (2003)	Grade 4	No major; case study on a class	To learn how GIS affects student learning in geography/history	Background survey, pre- and post-test; self report inventory	GIS helps students construct understanding of geography
	West (2003)	Grades 8, 10, 11	No major	To learn how GIS affects student attitude	Pre- and post-test using GIS	Student improvement is observed although it is unclear whether it is due to GIS or computer use. However, mastery of technology produced negative attitude
	Meyer, Buttwerwick, Olkin & Zack (1999)	Grade 8	No major	To learn about the effects of GIS on learning	Students conducted a water quality experiment, using GIS program to analyse data	Students did not obtain spatial skills, rather cartographic output only. Learning of the technology took away from the thinking
Effects of geographic knowledge on GIS use	Marsh, Golledge, & Battersby (2006; 2007)	Grade 6, high school (various levels) and university	No major	To understand the grade related understanding of spatial concepts	Paper-pencil tests were administered: -circling terms that describe a spatial relationship -ordering spatial terms from easiest to most difficult	Understanding of spatial relationships increases with age, though it is incomplete.
	Battersby, Golledge, & Marsh (2006)	Grades 6, high school (various grade levels) and university	No major	To examine at what grade level map overlay can be appropriately taught	Paper and pencil problem to test student understanding and application of map overlay	Map overlay is a higher order concept that is not well understood in middle school
	Drennon (2005)	Introductory university GIS Course (university students)	No major	To investigate how GIS is used in the nature of a problem-solving environment	Students had 14 weeks to solve a real-life problem: addition of a school district in San Antonio. GIS was applied during the process.	Students were successful in solving a real world problem, without focus on GIS (teaching 'about'), but as an application (teaching 'with')

	Carver, Evans & Kingston (2004)	University students	No major	To examine the role of web-based GIS in teaching core GIS concepts and application	A web-based GIS for students to search for a nuclear waste disposal site. Student feedback is analyzed	Survey indicated that students found tool useful for learning about nuclear waste management and spatial decision-making. The most difficult part was the GIS tool, perhaps due to lack of GIS or spatial analysis knowledge
	Audet & Abegg (1996)	High school students, high school teachers, GIS experts	Chemistry	To examine how GIS experts problem solve in order to formulate teaching strategies of GIS in high school settings	Use of GIS to problem solve and prepare a map that satisfied given criteria	A spectrum of problem solving styles were discovered, from trial and error, spatial querying to logical querying

Table 2.2: Review of past GIS education research studies

Source: Author, 2008

The fourth research category examines the nature of geospatial knowledge used explicitly in GIS, across grade levels. Although the data suggested that geospatial knowledge is evident in students, that knowledge is incomplete (Golledge 1992; Golledge 1995; Marsh et al. 2007). Further, few studies provided an opportunity for participants to take part in problem solving with GIS; insight into the link between applied geospatial concepts, and in-situ spatial problem solving is not documented.

The fifth and final research category revolves around problem-solving methods with GIS. Findings in this research area suggested that students can successfully integrate GIS into their problem solving (Carver et al. 2004; Drennon 2005). These results, however, often lack an evaluation of geographic knowledge, geospatial knowledge, and a systematic method to evaluate the GIS solution. Furthermore, differences in problem-solving styles are usually distinct between age cohorts and experience (novice and expert). Without a pre-test of geospatial knowledge, however, students' command of geospatial knowledge can only be assumed.

The research arena for GIS education is broad; hence, a framework is proposed to organize the types and nature of research needed. A simple x-y-z model is proposed, where the x-axis represents grade level while the y-axis describes themes of teaching or learning applications of GIS (Figure 2.2). A z-vector represents different subject areas where cross-disciplinary integration of spatial thinking and GIS can be applied. Each diamond symbolizes an area of research published in the literature showing an emphasis on the K-12 range, however, work in other education levels is equally significant because the K-12 students will graduate into these higher grades.

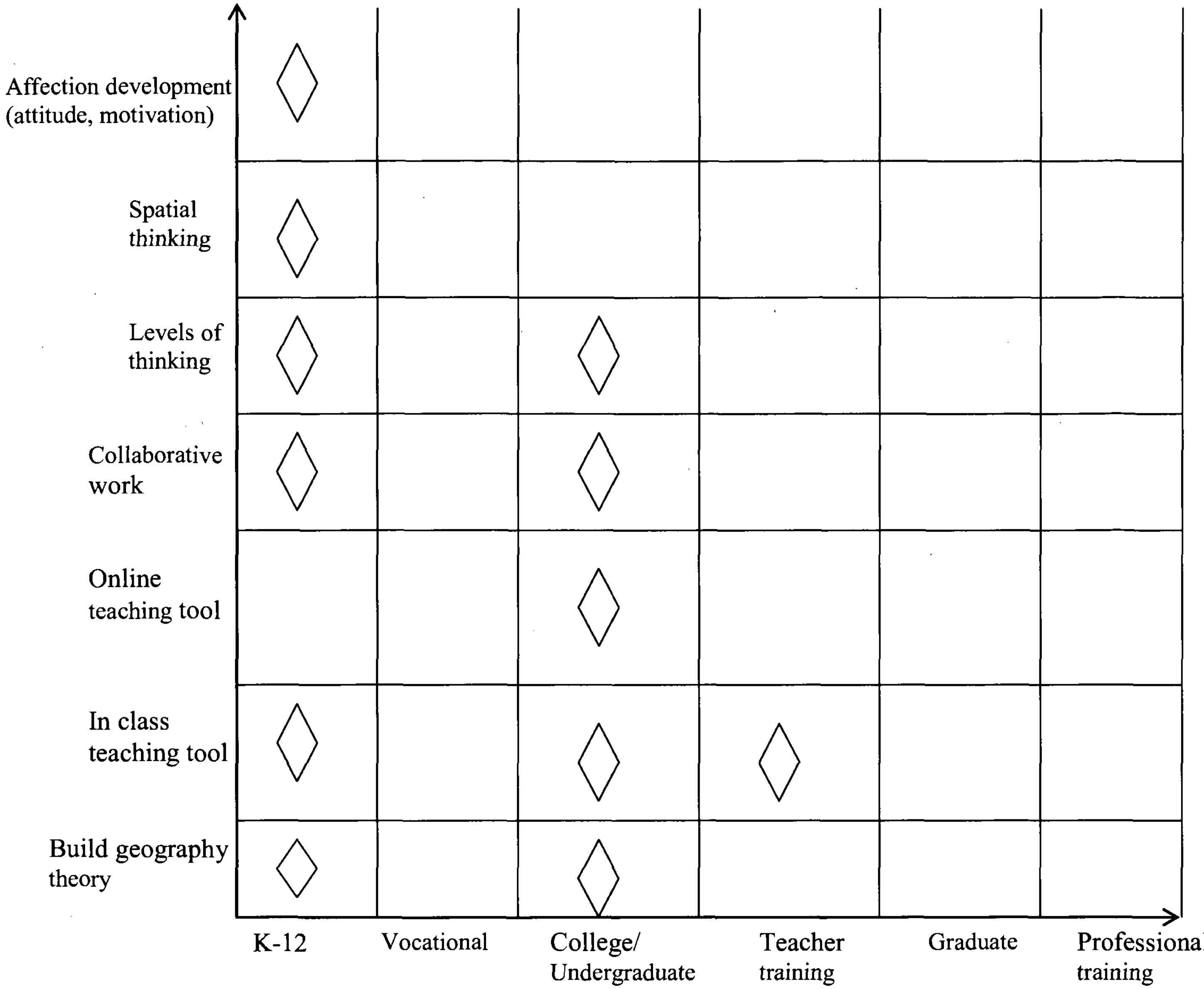


Figure 2.2: Framework of GIS education research agenda

Source: Author 2008

2.3.2 Spatial thinking

GIS and geography are associated by a common link, spatial thinking; a product of combining space, representation, and thinking (NRC 2006). Spatial thinking ability is widely researched in psychology, tested for in psychometric scales and intelligence tests (Corballis 1982; Gardner 1983; Liben 2002). Psychometric testing comprises a range of knowledge tests, (Hestenes and Wells 1992; Hufnagel 2002; Qiu 2006; King et al. 2008), cognitive abilities (Teasdale and Owen 2008), attitudes (Hambrick et al. 2008; Kroner and Biermann 2008; Spinath et al. 2008) and personality traits (Hambrick et al. 2008). However, there is disagreement on the meaning of spatial ability between geography and psychology (Gilmartin and Patton 1984). In particular, researchers are uncertain whether spatial tests are measuring a single dimension or whether multiple factors are involved (Newcombe 1982). At present, the discipline of psychology recognizes two spatial factors as components of spatial ability: spatial visualization, and spatial orientation and relations (McGee 1979). Geography considers spatial relations (e.g., spatial association, spatial pattern) as the foundation of spatial ability (Gilmartin and Patton 1984), while psychology summarizes spatial ability as a collection of transformation, visual perception and orientation (McGee 1979; Pellegrino and Kail 1982).

The importance of spatial relations to geography created a third dimension to spatial ability, spatial relations, although it is not well defined in psychology (Self and Golledge 1994) and its merit as a spatial ability is questioned (McGee 1979). Thus, spatial ability in geographic research is composed of three rather than two factors: *spatial visualization, spatial orientation,* and *spatial relations* (Self et al. 1992; Self and Golledge 1994; Golledge and Stimson 1997; Albert and Golledge 1999).

Spatial visualization is concerned with mental manipulation of visual cues through rotation, twisting or inversion of the object (McGee 1979). This ability is mostly related to mathematical problems and constitutes a large component of psychological spatial abilities tests (Self and Golledge 1994; Kaufman 2008). In geography, this ability may be applied to understand relationships between dynamic three-dimensional relationships such as plate tectonics (Gilmartin and Patton 1984). The second spatial ability is spatial orientation. This is the ability to imagine how an object appears from another perspective (McGee, 1979), making it useful in map reading. The third ability is spatial relations which enables patterns to be discerned (Gilmartin and Patton 1984; Self and Golledge 1994). To narrow and focus the research scope, spatial relation is emphasized in this investigation given their unique relevance to geography (Self et al. 1992; Self and Golledge 1994; Albert and Golledge 1999; Bednarz 2004) and the attribute of spatial thinking most developed in geography courses (Bednarz 2004).

GIS integrates all three components of spatial thinking. In particular, Table 2.3 shows the role of spatial relations in GIS use. For example, an evaluation of randomness and regularity is derived from the spatial ability to identify patterns from spatially distributed phenomenon. This suggests that the ability to think spatially contributes to GIS tasks that require identification of features, clusters, and spatial association (Self et al. 1992). From this interrelationship, two related teaching methods are possible. First, GIS can be employed to teach geography and spatial relations (Seong 1996; West 1998; Keiper 1999; Patterson et al. 2003) or geospatial knowledge can facilitate learning of GIS analytical techniques (Self et al. 1992). While the former approach has received research attention, the latter has not.

Spatial Relations	Processes used in GIS
Abilities (skills) that recognize spatial distributions and spatial patterns	Determining dispersion/patterns; evaluating regularity or randomness; determining cluster
Identifying shapes	Defining shapes; constructing gradients, and surfaces layering
Recalling and representing layouts	Regionalizing
Connecting locations (spatial linkage)	Aggregating
Associating and correlating spatially distributed phenomena	Correlating; assessing proximity (requires knowing location)
Comprehending and using spatial hierarchies	Forming hierarchies
Comprehending distance decay and nearest neighbour effects in distributions (buffering)	Associating; assessing similarity
Way finding in real world frames of reference	Measuring distance
Direction giving	Measuring directions

Table 2.3: Comparison between spatial thinking and GIS skills

(Self et al. 1992; Self and Golledge 1994; Bednarz 2004)

2.4 Geographic attributes in GIS instruction

In this study, the question is not how 'GIS informs geographic learning' but how 'geospatial thinking informs GIS learning.' This section will compare the three geographic attributes, namely knowledge, skills, and perspectives, with those presented in the GIS education literature and curricula.

2.4.1 GIS-based geography courses (undergraduate and secondary school)

Geographic knowledge

GIS knowledge includes the *problem domain* (principles of geography which are further divided into conventional spatial knowledge and professional knowledge) and the *tool domain* (principles of GIS) (Nyerges 1995). The domains interact to provide a basis for GIS problem solving (Nyerges 1995; Bednarz 2004). For example, professional or experienced users in a discipline have an understanding of the nature of data (domain knowledge), ways of thinking (domain related skills), and problems characteristic of the field (domain related perspective). Similarly, without adequate geospatial knowledge, GIS users are likely to have difficulty interpreting problems within a geographic setting (Nyerges 1995; Marsh et al. 2007). Likewise, when the tool domain knowledge is inadequately developed, GIS users may struggle to select appropriate operations to solve the problem (Nyerges 1995).

In GIS-based geography courses, geographic knowledge is primarily a result of implicit learning through problem-based solving (White and Simms 1993; Drennon 2005) and project-based education (Chen, 1998). It is unclear exactly what geographic knowledge, primitive or higher order concepts, is developed by GIS (Storie 2000; Bednarz 2004). A number of researchers argue that if GIS is to teach any geography, spatial analysis must be explicitly taught (Meyer et al. 1999; Baker 2002; Bampton and McAnneny 2006) and geographic skills introduced prior to GIS use (Poiker 1985; Burns and Henderson 1989).

GIS teaching models and curricula offered at the undergraduate level are driven primarily by technical and tool-domain knowledge (NCGIA 2000; UCGIS 2003); where geospatial knowledge is integrated in a limited capacity. Where geospatial knowledge is introduced, it is directly related to GIS analysis, usually comprising the higher-order concepts in Table 2.3 Geographic primitive concepts are gained through implicit means or accumulated through GIS use causing misunderstanding and error-ridden knowledge (Golledge 1992; Egenhofer and Mark 1995). Such insufficient problem-domain knowledge results in poor spatial analysis and problem-solving abilities (Kerski 2000; Baker 2002; Baker and White 2003).

Geographic skills

Geographic skills are developed through problem solving and decision making in authentic, real-world contexts (Tinker 1992; Keranen 1994; Audet and Abegg 1996; Michelson 1996; Ramirez 1996; Alibrandi 1997; Audet and Paris 1997; Ministry of Education 1999; Newcombe 1999). For example, GIS promote hypothesis formation (Weller, 1993 found in Keiper, 1999), problem solving (Keranen 1994; Michelson 1996; Ramirez 1996; Alibrandi 1997; Furner and Ramirez 1999; Summerby-Murray 2001), and application to social issues (Albert et al. 1995). Geographic skills are represented in a non-uniform manner in GIS courses. For example, geographic inquiry, data acquisition, and organization are encouraged in Alibrandi (1997), though the remaining two skills, analyzing geographic information and answering geographic questions, are absent. Other studies introduce a similarly incomplete set of geographic skills in GIS instruction (Audet and Abegg 1996;

Ramirez 1996; Alibrandi 1997; Chen 1998; Keiper 1999; Baker and White 2003; Patterson et al. 2003; Shin 2003; Drennon 2005).

A number of weaknesses are found in the way geographic skills are introduced. First, skills developed from GIS are likely to be technical in nature, such as database awareness and operation execution which are more visually grounded than geographical or spatially related (Bednarz 2004). Second, when geographic skills are addressed, they are of higher order concepts (image & network analysis, 3-D analysis skills) or technical operations (re-projecting data, symbolizing points, lines and areas) (Bednarz 2004).

Geographic perspective

In the literature, a general assumption is that students will inevitably develop one or multiple geographic perspectives by working with geographic data. The term 'spatial' was extensively used in the literature. This suggests that the spatial perspective is prominent in GIS instruction, although not explicitly discussed or assessed. The following section will investigate the development of spatial thinking in children and young adults to advise the introduction of GIS curriculum that is founded on geographic knowledge.

2.5 Spatial thinking and reasoning

2.5.1 Spatial thinking development

The preceding section established that geographic knowledge includes primitives that form the basis of complex geographic concepts. In this section, the cognitive development underlying spatial thinking in geography understanding is reviewed. The discussion will begin with a summary of young children's spatial development followed by the nature of geographic reasoning at older ages.

Seminal work by Piaget and Inhelder (1971) provides a model to organize geographic concepts, based on three areas that are central to understanding graphic representations of the world: 1) *spatial concepts,* 2) *representation,* and 3) *logical relations* (Downs and Liben 1991; Liben and Downs 1994). Despite the immense influence on developmental psychology, Piagetian theories have been criticized. In general, researchers challenged the accuracy of Piagetian conclusions, criticized the research as epistemologically weak and philosophically naïve (Lourenço and Machado 1996). Of these broad critiques, three are immediately related to the cognitive development and education strands of this study. First, chronological age does not correlate consistently with associated operational level (Almy 1967; Stoltman 1971; Rand and Towler 1974). Replicated Piagetian experiments generally agree with the sequence of spatial development proposed (Eliot 1970; Laurendau and Pinard 1970; Hart and Moore 1973), however, the age allocation to each developmental stage is not found universally (Almy 1967; Stoltman 1971; Pufall and Shaw 1973; Rand and Towler 1974). Second, Piagetian theory overlooks the importance of social factors in development (Vygotsky 1978; Broughton 1981). The third shortcoming is that Piagetian theory ignores cognitive development post adolescence (Riegel 1975; Commons et al. 1982). Despite these criticisms, the Piagetian cognitive theories are useful to understand spatial thinking and are applied to this study.

The development of geographic reasoning, using map understanding as a classic example, is discussed in terms of five stages of parallel development (Hart and Moore 1973): 1) spatial cognition (sensorimotor, preoperational, concrete operational, and formal operational), 2) systems of reference (egocentric, fixed, and coordinated), 3) modes of representation (enactive, iconic, and symbolic), 4) types of spatial relations (topological, projective, and Euclidian), and 5) types of topographical representations (route and survey). The discussion will begin at the Concrete Operational period as this age range is parallel to the spatial cognition development stage when GIS is usually introduced (Figure 2.3).

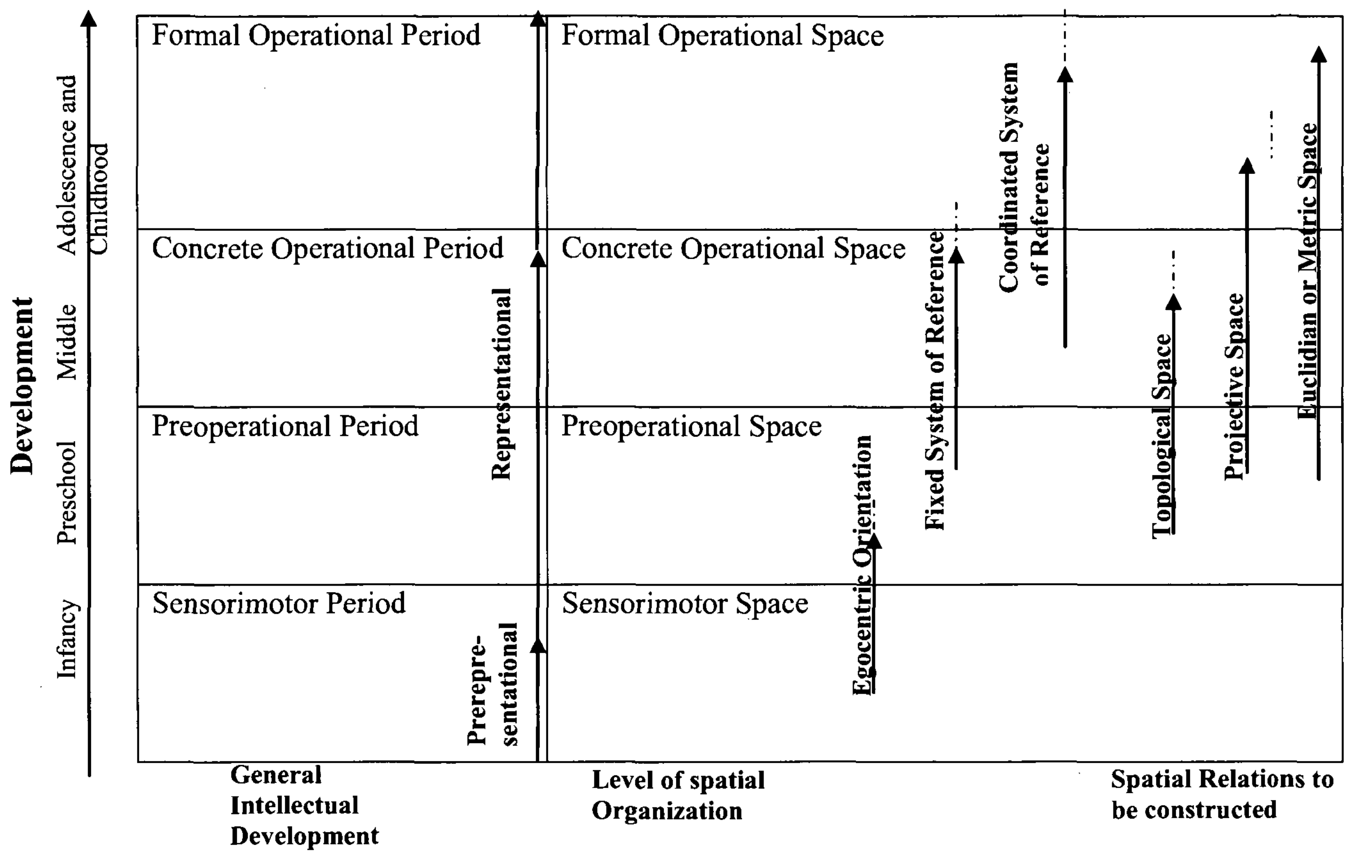


Figure 2.3: Schematic representation of Piagetian theory on children's conception of space development
Source: Hart and Moore (1973)

Concrete operational period (5 to 10 years old)

Between the age of 5 to 10 years old, children develop multi-viewpoints, retaining the egocentric perspective or frame of reference but developing a 'domicentric' view (Hart & Moore, 1973). In this study, a frame of reference includes a locus or set of loci from which a spatial position is determined (Pick and Lockman 1981). A domicentric view is the ability to include oneself as one part of the spatial world. The frame of reference used by young children may occur in overlapping stages, first they recognize relationships that are near-far, then left-right, and finally combine the two abilities (Lord, 1940 from Hart & Moore, 1973; Pufall & Shaw, 1973; Hart, 1981). Students who have not developed a frame of reference or who employ an egocentric perspective experience difficulties in problem solving (Blair, 1964 from Rhys, 1973; Rhys, 1973). At this stage, children begin to understand that objects in space can be represented in an abstract way (symbolization), with reference to each other (Catling, 1978) and have metric properties (Gregg and Leinhardt 1994). They begin to understand that projective space requires a point of view, such as left/right, front/behind, up/down or view-specific properties (object viewed from front or back) (Liben & Downs, 2001).

Bluestein and Acredolo (1979) found that children developed a sense of projective space by the age of five. This early concept of space permits children to compensate for the rotation of a map by 180° to locate a toy. These findings are supported by similar results on young children, using a rotated map (Pufall & Shaw 1973; Presson, 1982; Liben & Downs, 1989) and aerial photographs (Downs, Liben & Daggs, 1988). However, rotational abilities are not sufficiently developed until the late concrete operational stage (DeLoache, 1989). Projective space (and symbolization) is not a primitive or easily learned skill, but rather builds on prior knowledge (Wilson 1980 from Stoltman 1971).

Formal operational period (9 years and above)

Children develop a mature understanding of space by the age of 12 years old, known as the formal operation period. This is the final stage of cognitive and spatial development; it is also when the most abstract and developed concepts are understood. At this stage, the frame of reference is *allocentric*. An allocentric frame of reference is external to the observer, it relies on object-object relations (Pick and Lockman 1981; Liben 2002). For example, an allocentric frame of reference is required to complete a puzzle, where each subsequent piece (object) is placed in relation to another piece(s) (object).

Children comprehend a frame of reference that begins with the self (egocentric), progressing to between objects (allocentric), and finally escalate to abstract (Euclidean). At the Euclidean stage, children possess accurate conceptions of angles and distances (Catling 1978) advanced by experience in the spatial environment. At this stage, interpretation and inferences can be made with geographic media such as maps, thematic maps, and aerial photographs (Catling 1978). By this stage, children develop a fully coordinated topological representation (Hart, 1981).

Scale is another concept understood at this stage. Students understand linear scale by grade 4, followed by area and scale in grade 6 (Beilin 1971). Confusion with scale may be attributed to a lack of understanding in proportion and metrics (Liben and Downs 1989). For example, upon identification of a road on an aerial photograph, one child declared that a road was too narrow for two cars to travel on. In the same research, a child mistook boats for fishes (Downs et al. 1988).

2.5.2 Geographic reasoning

The following section applies spatial knowledge development to geographic reasoning. The attributes of geography used in section one will be applied here as guideposts in the discussion of knowledge, skills, and perspectives.

Gregg and Leinhardt (1994) contended that the purpose of knowledge gain is to reason with it. Reasoning *in* geography is "using geographic facts and tools of spatial analysis to understand the phenomena and processes that the discipline considers important" (Gregg and Leinhardt, 1994, 328). This is different from reasoning *with* geography, which is when "our knowledge of geography becomes a tool for reasoning and for organizing knowledge in other disciplines such as history, economics, political science, geology or anthropology" (Gregg and Leinhardt, 1994, 328). In other words, the former produces new geographic knowledge and the latter produces new knowledge about the spatial aspects of other disciplines.

Knowledge

Spatial development is not limited to young children nor is it complete and perfected. Rather, spatial development is gained gradually throughout life experiences but individual differences are widely documented (Wigglesworth 2003). Wigglesworth (2003) attributed this difference to cognitive development, experience with maps, and access to a variety of spatial activities.

In a geographic context, the ability to problem solve increases incrementally (Table 2.4) (Rhys 1973). Thought processes change between the ages of 12 to 15 and even above 15 years of age. In the latter category, students rely on hypothetico-deductive reasoning, use of concepts and generalizations not part of the problem to solve on issues they have never encountered before (Rhys 1973).

Category	Age	Mental Age	Principal Features
I	11 and below	12 and below	Not reality oriented
II	12 to 12.6	13 to 13.6	Reality oriented; single piece of evidence used
III	Circa 13.6	14 to 14.6	Several pieces of evidence combined; able to relate cause and effect
IV	14.6 and above	15.6 and above	Comprehensive judgement based upon hypothetico-deductive reasoning

Table 2.4: Response levels to geographic problem solving

Source: Rhys (1973)

An adolescent's capacity to reason with geographical material is a slow and gradual process; higher order concepts are developed later in one's spatial development. For example, undergraduate students understand the spatial ability overlay, a GIS function, to varying degrees (Albert and Golledge 1999). The level of geographic knowledge changes with formal instruction (Golledge 2002), an approach that is similar to Bruner's (1963) concept of education. Bruner (1963) argued that the primitives can be introduced early in instruction, and then reviewed repeatedly with concepts of increasing difficulty over the years. This mode of education is referred to as the 'spiral curriculum' that is used by researchers to teach spatial understanding (Catling 1978).

Skills

The literature on spatial development does not suggest any parallel development in skills such as geographic inquiry, data collection, and organization. However, in studies that examined such skills (Rhys 1973), hypothesis formation and the use of deduction to solve problems are evident in the formal operational period. As children move away from the dependence on concrete data to reason with given data, logical propositions and deduction abilities form (Bruner 1964; Almy 1967; Downs et al. 1988).

Perspectives

The progressive development in frame of reference (egocentric, fixed, coordinated) suggests that other frames of reference can be developed. Of interest to this discussion is the nurturing of geographic perspectives, in which the spatial perspective is well positioned as outlined above.

2.6 Level of proficiency: Novice-intermediate-expert continuum

Performance levels generally vary within a cohort and across cohorts (Tyler 1974; Slavin 1987; Carter et al. 1988; Gentner 1988; Livingstone and Lynch 2002). However, it is inefficient to examine students individually in research studies and at the classroom level, hence groups are used, traditionally along the dimensions of grade level, age cohorts, gender or gifted abilities. A number of reasons are suggested for the use of groups. The first reason is to follow the traditional grouping method used by the education system, dividing students by age. The second reason is to learn of group differences which may suggest explanatory factors of difference (NRC 2006). The third reason is that students learn more effectively (Tyler 1974; Kulik and Kulik 1987; Slavin 1987; Lou et al. 2001) and instruction is efficient when teams of students with homogeneous abilities are grouped together (Slavin 1987).

Since performance may not be delineated neatly along traditional age groups that correspond to spatial development, another way of grouping students is based on their performance level in geospatial thinking, which can be categorized as novice, intermediate, and expert. Some common expertise classification methods are based on years of experience (Audet and Abegg 1996; Hmelo-Silver et al. 2007), experience levels (Anderson and Leinhardt 2002; Hmelo-Silver et al. 2002; Livingstone and Lynch 2002; Eells et al. 2005), and to a smaller extent on standardized tests (Heyworth 1999; King et al. 2008). In the education literature, student ability is a common grouping method for instruction (Kulik and Kulik 1987; Slavin 1987; Tomlinson 2006), however, little guidance was found on how to derive a 'cut-score'. Douglass (1999) defined this as a test score that separates between different levels of ability, although a cut-score cannot be derived arbitrarily and there is wide disagreement amongst judges who set one (Douglass 1999).

Ability is a measure of students' performance, on a domain specific assessment, relative to their classmates (Saleh et al. 2007). Students are classified into three groups: high-ability, low-ability, and average-ability students (Webb 1991). Research and practice of grouping is seen in specific subject areas (e.g., math and reading) and learning methods (e.g., mastery learning and cooperative learning) (Slavin 1987; Chorzempa and Graham 2006). Two principal types of grouping are found in education: between-class and within-class. The former is conducted at the school-level where students are placed into classes. Within-class grouping occurs in a single class, to form homogeneous instruction subgroups (Slavin 1987). Each subgroup is provided with instruction matching its level and is allowed to progress at its own rate (Slavin 1987). An understanding of ability-grouping is extended by exploring the theory of expertise, a concept used to frame the overall geospatial classification.

Research on expertise began in the sixties, inspired by the developments in artificial intelligence and cognitive psychology (Glaser and Chi 1988). The study of expertise was intensively studied in chess players (Chase and Simon 1973; Simon and Chase 1973; deGroot 1978) and has been a model for research in other domains such as physics misconception in novice and expert problem solving (Trowbridge and McDermott 1980; Trowbridge and McDermott 1981; Clement 1982).

The characteristics that differentiate between novices and experts are summarized nicely in the literature (Glaser and Chi 1988; Holyoak 1991). In summary, these range from the quality (organization of) and quantity of relevant knowledge (Chi et al. 1981; Glaser and Chi 1988; Hmelo-Silver et al. 2002), memory capacity (Chase and Simon 1973; Simon and Chase 1973), skills (domain related and self-monitoring), training and experience (Kirschner et al. 2006; NRC 2006; Hmelo-Silver et al. 2007; King et al. 2008), and depth of representing a problem (Anderson and Leinhardt 2002; Eells et al. 2005). In particular, guided and structured learning is praised for developing expertise in a discipline more so than independent student discovery (Kirschner et al. 2006).

The novice-expert continuum varies in the number of levels (e.g., 2 to 5) and label terms, such as novice-expert, experienced-inexperienced, novice-competent-expert, novice-apprentice/journey man-expert, and expert-novice-postulant continua (Chi et al. 1981; Gardner 1983; Carter et al. 1988; Ericsson and Smith 1991; Downs 1994a; Anderson and Leinhardt 2002; Dall'Alba and Sandberg 2006; King et al. 2008). Other authors explore expertise with five levels (Anderson and Leinhardt 2002; Dall'Alba and Sandberg 2006). In this study, the traditional three categories, novice, intermediate, and expert are applied.

The novice-expert dimension has limitations at a methodological level. The first concern is that the intermediate stages of expertise is not included (Alexander 2003; King et al. 2008). The second limitation is that an individual classified as a novice or an expert may not fall neatly into the level, such that there may be two levels of novice groups. This is likely the case when the experience or education level of each group is close (e.g., 3 years and under) (Sternberg 1999; King et al. 2008) as expert levels are generally attained after 10 years of practice (Hayes 1985; Sternberg 1999).

Despite some limitations on the novice-expert dimension, it is a useful framework to differentiate between individuals. Unlike the geospatial scale which provides an expertise level based on the total score of correct answers, the qualitative nature of the GIS exercise is less divisive. A Structure of the Observed Learning Outcome (SOLO) taxonomy, described in section 2.7, is used to segregate participants into expertise levels based on the problem-solving process.

2.7 Structure of the Observed Learning Outcome (SOLO) Taxonomy

Where the affection and geospatial scale are evaluated against an absolute correct answer, the GIS exercise has multiple solutions. For this reason, a systematic method to assess the quality of different answers is needed. Voss and Post (1988) suggest that qualitative questions can be evaluated by comparing participant solution to a standard or a control answer that is agreed upon by members of the problem-solving community. For example, an appropriate solution is one where other problem solvers cannot find any errors and accept as a model solution. For this reason, the role of a standardized evaluation rubric, Structure of the Observed Learning Outcome (SOLO) taxonomy, will be described and applied to the assessment of GIS solutions.

SOLO taxonomy, a method of evaluating written and extensive answers, is a systematic way to assess qualitative output from students (Biggs and Collis 1982). The taxonomy structure is founded and aligned with Piaget's cognitive developmental theory, shown in Table 2.5. The left most column describes the Piagetian development terms and time line, supplemented with SOLO terms in the adjacent column. In the third column, 'Capacity' describes the available working memory required for responses; memory capacity increases with age to accommodate higher level and abstract thinking. Increased memory leads to great ability to deduce and induce from information stored, making links with given information. This use of information is termed 'relating operations' (fourth column). The final column describes how an answer is reached (closure) and the consistency of such conclusions.

Developmental base stage with minimal age	SOLO description	Capacity (working memory)	Relating operations (relations between cue and response)	Consistency and closure
Formal Operations (16 + years)	Extended Abstract	Maximal: cue and relevant data and interrelations and hypotheses	Deduction and Induction. Can generalize to situation not experienced	Inconsistencies resolved. Conclusive answers not required – conclusions open allowing for logically positive alternatives
Concrete generalization (13-15 years)	Relational	High: cue and relevant data and interrelations	Induction: Can generalize within given or experienced context using related aspects	Consistencies appear although hypotheses are not fully formed
Middle concrete (10-12 years)	Multi-structural	Medium: cue and isolated relevant data retained	Can generalize only in terms of a few limited and independent aspects	Consistency is felt to be important but inconsistency persists as answer closed too quickly. Answer based on isolated fixations on data, can come to different conclusions with same data
Early Concrete (7-9 years)	Uni-structural	Low: cue and one relevant datum retained	Can generalize only in terms of one aspect	Consistency not reached, answer closes quickly. Conclusions may be formed based on one aspect forming inconsistency
Preoperational (4-6 years)	Pre-structural	Minimal: cue and response confused	Denial, tautology, transduction. Bound to specifics	Consistency not reached. Answers are closed without seeing problem

Table 2.5: SOLO taxonomy assessment

Source: Biggs and Collis (1982)

Numerous studies evaluate learning outcomes from qualitative sources with SOLO taxonomy (Watkins 1983; Lucas 1996; Cuthbert 2005). From these studies, a few criticisms have emerged. Watkins (1983) reported difficulty distinguishing between the higher levels of the taxonomy (4 and 5). Lucas (1996) noted that while SOLO taxonomy is useful to measure learning outcomes, its assessment of approaches to learning is unclear.

2.8 Sequence analysis

Novices and experts can be differentiated by various qualities of their GIS problem-solving strategies; one quality is the sequence of GIS functions used to approach a problem. To explore this concept further, a sequence analysis applied to the problem-solving process is discussed. Sequence analysis is commonly seen in genetics analysis using Deoxyribonucleic Acid (DNA) for paternity tests. This analysis is also applied outside of the sciences in such areas of tourism (Bargeman et al. 2002) and navigation wayfinding (Huynh et al. 2008). In education, a similar idea is developed by Kaminske (1997) where a complex concept is composed of elements (primitive) that are linked by relations. For example, in the case of windward rainfall, it is expressed (in formula form) by an expert as e-R-f-R-g-R-h-R-j-R-k-R-i. Each lower case letter represents an element such as wind (e), mountain range (f) and R is the relation that links these elements. A novice simply represents the same concept with h-R-a-R-c. From this coding, the generality of a novice's understanding is apparent.

A number of potential methods to organize sequence strings exist, one of which is cluster analysis. Cluster analysis encompasses factor analysis and multidimensional scaling. However, in this study, a process of unidimensional sequence alignment borrowed from biology was used because it could analyze data in nominal form. Unidimensional sequence alignment is a statistical technique that calculates the best match between sequence strings of nominal data which are then aligned to emphasize the similarities and differences along the sequence strings (EMBL-EBI 2007). Originally, this approach was developed to compare the sequence of amino acid strings in DNA and Ribonucleic Acid (RNA) (Durbin et al. 1999).

The GIS problem-solving sequence resembles that derived from a string of biological DNA. It is analyzed by a software, CLUSTALW (EMBL-EBI 2007), that matches clusters of identical sequence. There are some fundamental similarities and differences between DNA and sequences examined in this study. Both sequences are based on four building blocks (i.e., visual, primary, secondary, and tertiary GIS level functions); however, the GIS sequence has only one strand where a DNA strand is composed of two complementary strands. Despite these basic substantial differences, the similarities justify use of DNA software to analyze GIS problem-solving sequences.

2.9 Chapter summary

This chapter has given an overview of four main themes, namely the state of geographic and GIS education, spatial development in children, novice-expert research, and a review of two analytical methods. Although research on GIS education has increased and become more extensive over the years, researchers have concentrated on only a few areas. These studies examine how GIS affects students' geographic knowledge, geographic skills, problem-solving abilities, as well as attitudes. The consequence of such research is that potential areas are completely missed or ignored. For example, research on the fundamental knowledge and skills needed for effective GIS use have been neglected. In addition, past studies are grounded on a small scale, based in one classroom or within a grade level. Large scale research that can make general conclusions and develop widely applicable learning levels is needed.

In the next chapter, the data collection procedure is explained. This is followed by a discussion of task development including the affection scales, geospatial scale, geographic skills questions, and the GIS problem-solving task.

CHAPTER 3: METHODOLOGY

This chapter begins with an overview of the data collection procedure. Next, an explanation of participant recruitment is followed by an extensive discussion of the development process and pilot testing of each affection scale, geospatial scale, and GIS problem-solving task. Subsequently, evaluation methods for the scales and GIS task are explored, followed by a step-by-step transformation of transcribed verbal data into sequence analysis. This chapter concludes with an overview of the data gathered and the analyses applied to these.

3.1 Data collection procedure

The data collection process was different between high school and university students. Due to high school participants' rigid timetable, data were collected in the geography classroom at Huron Heights High school. For university participants, they were invited to the researcher's office on Wilfrid Laurier University campus. Aside from the location, the order of data collected differed slightly. Each step is explained below, highlighting differences between high school and university participants.

1. Recruitment of participants (see *section 3.2 for explanation)*

2. Completion of consent form (approximately 10 minutes)

i) Each university participant was interviewed individually in the researcher's office, a quiet space to work. Each participant was given the consent form to read and complete.

ii) Due to the time limit, all grade 9 students completed in silence the consent form in their geography classroom, over one lunch period (60 minutes).

iii) All participants were reminded that they were free to end the interview at any time. A thank-you souvenir was provided at the end of the interview.

3. Completion of computer, geography, and mathematics affection scales (approximately 15 minutes)

i) Participants were given three affection scales to complete in 15 minutes. While university students worked individually in the researcher's office, all grade 9 students completed the scales during their lunch period.

4. Completion of demographic survey and geospatial scale (approximately 45 minutes)

i) A demographic survey was appended to the geospatial scale. Participants completed questions on personal information (e.g., age, gender) and education background.

ii) Participants completed the geospatial scale in 45 minutes. They were told that pen, pencils, and erasers were allowed (no ruler or calculator). If there were any questions, the researcher was in the room to answer questions, otherwise, she was reading quietly within a short distance away. While university students worked individually, grade 9 students completed the scale together during their lunch period.

iii) Students were interviewed after the geospatial scale if one or more answer was different from the question confidence. For example, if a student answered a question incorrectly but indicated 'very confident' on the response, the interview was an opportunity to explore how misconceptions developed. The student was asked to explain, for each question that fell in this category, how they arrived at their answer. These responses provided insight into their thinking process, accessory information used to solve questions, and the potential gaps in geographic knowledge that may have created misconceptions.

iv) The interview process was flexible in nature which encouraged participants to speak openly. The interview was performed immediately after each scale period for university students. The same set of questions was posed to grade 9 students a week later when they came in individually to complete the GIS problem-solving exercise.

5. Completion of geographic skills questions (approximately 30 minutes)

i) Participants were given three geographic skills tasks, to be completed in 30 minutes.

ii) For university participants, the geographic skills exercise followed immediately after the geospatial scale. Grade 9s were given this assessment a week later, a meeting intended to complete the geographic skills and the GIS problem-solving task.

6. Completion of GIS problem-solving task (approximately 45 minutes)

i) Participants were introduced to the GIS interface and the GIS handbook. The preamble was given consistently to all participants, regardless of their GIS experience.

ii) For university participants, the GIS exercise followed immediately after the geographic skills questions. Grade 9s were given this assessment a week after the geospatial scale, a meeting intended to complete the geographic skills and GIS problem-solving task.

iii) During the exercise, each student was given a GIS handbook that contained eight explanation sheets to cover metadata for data files used, interface of ArcMap, Toolbox of basic tools needed, and GIS operations useful for solving the problem.

iv) The researcher was in the room as the participant was working on GIS. Questions on technical problems were answered but no aid was provided on the problem-solving approach.

v) The problem-solving process was audio-visually recorded by Camtasia to capture all the actions and operations selected on-screen as well as the verbal think aloud process. Think aloud forms of data have been used in other studies to compare novice and expert performance (Lawrence 1988; Ericsson and Smith 1991; Heyworth 1999; Anderson and Leinhardt 2002; Wigglesworth 2003; Eells et al. 2005; Hmelo-Silver et al. 2007) and the problem-solving process of expertise studies (Anderson and Leinhardt 2002; Hmelo-Silver et al. 2002; Virvou and George 2008).

vi) The researcher observed and listened as participants worked on the problem. Based on these observations, section 7.1 discusses teaching implications for similar research in the future.

7. Completion of data collection

i) The audio-visual and GIS file were saved

ii) Participants were asked if they had any question(s)

iii) Participants were thanked and given a thank-you gift.

3.2 Recruitment of participants

One hundred and four students were recruited from four education cohorts, from two different institutions. The students were from the following levels: grade 9 students (n=20) from Huron Heights C.I.; first-year university students taking either introductory physical geography or introductory human geography (n=24) studying at Wilfrid Laurier University (WLU); third and fourth year students taking geography as a major (n=30) from WLU; graduate students in the Wilfrid Laurier Joint Program in Geography (WLJPIG) program (n=30), split evenly between both Laurier and Waterloo campus students. Each student was asked to perform 5 tasks in the same sequential order which includes 1) reading and signing of the consent form, 2) completing three affection tests (computers, geography, and mathematics), 3) completing a geospatial scale, 4) completing three geographic skills questions, and 5) solving a real-world exercise on a GIS.

Grade 9 students were recruited from Huron Heights High School located in the City of Kitchener, Ontario. A fellow graduate student who teaches at Huron Heights allowed recruitment from his grade 9 geography class and convinced his colleague to open his class for recruitment. A presentation of the project overview and process was given to three grade 9 academic classes. As a token of appreciation, snacks and a small gift (paper pad and pen) were presented to each student. In addition, students were granted by the school 2 hours of volunteer time (high school students in Ontario require 40 volunteer hours in order to graduate). A total of 22 students participated, although two students did not complete the full study. In total, 20 students' complete data were collected.

University students were recruited from the Department of Geography and Environmental Studies at WLU in three different ways. The initial contact method was through email. A mass e-mail was sent from the WLU geography department to all first-year students, third, fourth year students, and graduate students. The second method was through posters. These were posted on departmental announcement boards in the Department of Geography and Environmental Studies at WLU. The third and most effective recruitment method was through personal contact. These are described further as they were tailored to each grade level.

First-year students were recruited from two first-year geography classes (GG102-human geography and GG101-physical geography). Two recruitment presentations, 5 minutes each, were given to the human geography class (class size of about 200 students) at the beginning of the fall semester and a second time half way through the term. Presentations to the physical geography class were conducted during laboratory sections (class size of 25) throughout October. Interested students completed a form with contact information to schedule a meeting. A total of 26 students participated, however 24 sets of complete data were collected.

A large number of third and fourth year students were recruited through personal contacts such as word-of mouth and past T.A.-student relations. A total of 30 complete student datasets were collected. Graduate students were recruited through personal contacts and collegial support. A total of 30 complete datasets were collected, 15 graduate students from each campus. At the end of the data collection, all participants were offered a 'thank-you' gift (paper pad, pen, and snacks) as well as a chance to win prizes (gift certificates, text books, waist pouches).

A few lessons were learned from this experience. First, immediate follow up with interested students secured their commitment. Second, due to students' busy schedule, it was helpful to send a reminder a few days before the appointment. Finally, the best time to recruit was at the start of the semester and just after midterms. The sample of 104 participants was not random as they volunteered for the interview rather than arbitrarily selected.

3.3 Pilot testing

Pilot testing was performed on the affection scales (computer, geography, and mathematics), the geospatial scale, and the GIS problem-solving exercise. Although it would be optimal for the same group of reviewers to validate all the tests across the different developmental stages, this was impossible due to time commitment. In general, six groups of students and staff assisted with the development of these measurement instruments, detailed below:

Dissertation committee (Team A),

First year geography students from GG102 (183 students) (Team B),

Graduate students (Team C),

Students from GG369 (37 students) (Team D),

Staff (Team E),

Mix of 3 senior undergraduate and 3 graduate students (Team F), and

Grade 9 students from Huron Heights (Team G).

The pilot test process and outcomes are described within each test development below.

3.4 Geospatial scale creation and reliability

3.4.1 Creation of the geospatial scale

Despite research efforts in the areas of geographic and GIS education, there is a paucity of assessments (e.g., student learning) (Rutherford 2002) in general and a shortage of "valid and reliable assessments for spatial thinking" (NRC 2006: 232). The geospatial scale was created in response to the void in assessment tools and satisfies the first research objective of the dissertation, to develop an instrument that assesses the level of geospatial thinking. Performance on a series of geospatial knowledge and skill-testing questions are measured.

The terms 'index' and 'scale' are sometimes used interchangeably in the social research literature (Babbie 1990). However, this dissertation will make a distinction between the two and introduce both measurement tools into the study. Index and scale are ordinal measures which are usually used to rank-order participants on a variable. The difference between index and scale can be regarded in the way that scores are assigned. Where an index usually assumes equal weighting between items and concludes with a simple accumulation of scores, a scale has a weighted structure such that the items may vary in importance (Babbie 1990). A scale is superior to an index because the scale score provides more information than an index score.

The geospatial questions are formulated so that students make inferences and analyze geographic data. Furthermore, each question is designed so that it is at one of Piaget's spatial development levels and elicits a corresponding action. Thus, at Piaget's preoperational level, the action is to describe, at the concrete operational level, to analyze, and at the formal operational level, to make inferences. The tasks span a range of different learning modes, so that no particular one is favoured. The tasks include drawing a diagram, multiple choice, short answer, and matching vocabulary to a diagram. Overall, the geospatial scale measures performance in geographic thinking with a spatial focus and follows a Guttman scaling format where some items of the scale are 'harder' indicators of the variable (Babbie 1990).

The geospatial scale development began with the identification of a list of core geospatial concepts. The extensive analysis was conducted on the Ontario geography curriculum from Kindergarten to Grade 12 (Sharpe and Huynh 2004). A second document was also examined, 'Geography Standards', which is a national curriculum for Geographic education. Sharpe and Huynh (2004) found fifty-eight concepts, ranging from those appearing only once to those repeated up to 48 times in the curriculum. Some of the most frequently appearing concepts included 'map', 'region', and 'place'. This list was further reduced based on careful examination of each geospatial concept. From this initial inspection, a number of concepts were excluded because it was felt that they were not clear, too general or did not explicitly contain spatial relations properties. These include demographics, symbol, legend, spatial, space, movement, geography, map projection, and resolution. A second set of categories included terms which were grouped together due to their similar meaning. These following terms have been merged as one due to their similarity: spatial distribution, forms of settlement, spatial organization, urban form, and distribution. A second cluster of terms included coordinates, longitude, latitude, spatial data, and geographic data while a third cluster included contour, and elevation. The final list was reduced to twenty terms whose frequency in the geography standards is listed in Table 3.1.

Geospatial term	Total concepts (geography standards and overall grades 9-12 curricula)	Geography standards	Geography grade 9	Geography grade 11	Geography grade 12	Representative questions in geospatial scale
Elevation	1	0	0	1	0	Question 5
Aspect	2	0	0	1	1	Question 6
Contour	2	0	0	1	1	Question 5
Buffer/buffering	3	0	0	2	1	Question 2 and 3
Choropleth	3	1	0	1	1	Question 27
Overlay	3	0	0	1	2	Question 11, 12 and 14
Urban forms, forms of settlement	5	2	2	0	1	Question 18
Geographic/spatial data	9	0	5	1	3	Embedded in all question
Direction, bearing	10	4	2	0	4	Question 8 and 10
Area	11	0	0	6	5	Question 13
Distance, distance Decay	11	5	0	1	5	Question 4, 9
Coordinates, latitude, longitude	13	4	0	8	1	Question 28-30
Symbol, cartography, classify, legend	18	2	2	6	8	Question 19-24
Navigation, movement	18	8	0	6	4	Question 8 and 10
Scale, resolution	19	3	2	4	10	Question 16 and 17
Spatial	43	21	2	5	15	Embedded in all questions
Distribution, spatial distribution	52	21	6	9	16	Question 18
Region	57	23	5	14	15	Integrated maps into questions
Map	116	76	5	14	21	Integrated maps into questions
Position, locate, location, place	119	46	21	17	35	Integrated implicitly into questions

Table 3.1: Summary of geospatial concepts

Sharpe and Huynh (2004)

The second stage of development was to link these core geospatial concepts to a series of skill testing questions. Reference was made to three widely used spatial tests in the psychology literature, Thurstone's Primary Mental Abilities (PMA) Space test, the Differential Aptitude Space Relations Test, and the Mental Rotations Test. Thurstone's PMA space test is a collection of sixteen individual assessments that measure seven abilities, of which space is one of them (Goodman 1943). The spatial ability is measured by 13 different tests with focus on visualization, orientation, and perception. Both the Differential Aptitude Space Relations test and the Mental Rotations Test evaluate visualization of objects in three dimensions. The three tests measure spatial orientation and spatial visualization, the two spatial ability factors recognized in psychology. However, these tests offer little guidance on geospatial or spatial relations question design.

Model questions were found in recent spatial skills tests in the geography research community (Lee 2006a) as well as academia (Battersby et al. 2006; Golledge 2006; Golledge et al. 2006a; Golledge et al. 2006b; Lee and Bednarz 2009). In particular, two questions regarding spatial terms were borrowed from Golledge et al. (2006b). Spatial terms are described as "words that describe how two or more objects in space relate to one another. Objects can be point features such as fire hydrants, line features such as streets, or area features such as cities" (pg. 185). The list of 34 spatial terms was modified to reduce repetition and to introduce missing spatial terms. The new list contained 48 spatial terms of which three original terms were removed, 'close', 'in' and 'on' since synonyms 'proximal', 'inside', 'on top/on bottom' were already present. Nine spatial terms were added including bottom, distributed, down, intersect, near, next, parallel, random, and tangent. Nine additional terms were included, area, aspect, bearing, buffer, classify, contour, coordinates, direction, and distribution. Finally, the word 'center' was modified to reflect a Canadian spelling, 'centre'.

The number of questions testing each concept was weighted and based loosely on their importance, as quantified in the last column of Table 3.1. Concepts that are integral and central to geography such as 'map' and 'position' are embedded into as many questions as possible. The rational is that core concepts should be included as a fundamental part of a question rather than to be tested explicitly. The remaining questions are created based on their significance in the curricula. A few exceptions are 'representation' and 'overlay', which have a disproportionately higher number of questions than the others with similar concept finds. The reason for this decision is because representation and overlay are fundamental to both geography and GIS thus it is more heavily weighted.

Overall, the core geospatial concepts tested agree with those proposed over the years from different countries such as the United Kingdom (Walker 1976) and the United States of America (Nystuen 1968; Papageorgiou 1969) to current thinking (Golledge 1995; Bednarz 2004; Gersmehl and Gersmehl 2006; Gersmehl and Gersmehl 2007). The common overlap in core geospatial concepts is listed with synonyms of the common concepts in bracket: location, distance, scale, change (e.g., distance decay), spatial representation (e.g., shape identification), spatial distribution and patterns (e.g., forms of settlement, choropleth, spatial correlation, spatial association), distance decay (e.g., spatial transition gradient), buffer (e.g., zone of influence, spatial aura, proximity), and frames of reference (e.g., direction, location, position). This is evidence that the concept list used to form the geospatial scale is at least similar to the spatial aspects noted in the literature.

The first draft of the geospatial scale contained seven categories and fourteen questions. It was presented to Team A for feedback on the clarity and format of each question, the order of question presentation, and the quality of diagrams (version 2). The second version was administered to Team B who answered with the clicker technology (version 3). Clicker technology is a handheld response system that engages students through real-time interaction, e.g., multiple choice questions, feedback, opinion poll.

Two spatial term selection questions were added to Version 3 although the number of categories remained the same. Team C was asked to read the scale thoroughly then to report any misunderstanding or unclear questions by describing aloud what they thought each question asked for. Observations were made as each participant attempted the questions. The visual and verbal information informed which questions were problematic and where obstacles were encountered. Finally, each question was reviewed together with the students. Where the answers were correct, no further comments were made. However, for an incorrect answer, the participant was asked to explain whether the incorrect answer was due to the wording, clarity of the question or whether it was a matter of content knowledge. If it was the former, the student was asked to make suggestions to clarify the question. Based on the observations and the students' comments, the geospatial scale was revised for greater clarity. This scale (version 4) was then given to Team E. This group recommended rewording of some questions, producing version 5.

In the next phase, Team D was given the three affection scales (discussed in section 3.5) and the geospatial scale. The geospatial scale took approximately 25 minutes with some students completing it in 10 minutes and most within 15 minutes. Five students formed a focus group to critique each question based on 1) clarity, 2) sequence order, and 3) test format. The principle outcome of this discussion was how to make the scale more challenging, both in the question and multiple choice answer design (version 6).

On close examination of the geospatial list, it was found that a number of concepts were not fully tested, including: choropleth mapping, representation, and geographic data. Seven questions were added to test students on their notion of symbol representation and spatial relationships between symbols. An additional navigation related question was added to the existing two and the diagram was modified to resemble a true street network. Three explanation questions were added for students to explain their problem-solving strategies. These were added to the end of more complex type questions (e.g., overlay questions). A total of eleven questions were added to form version 7. This scale was given to Team F. Their comments fell mainly in rewording to clarify meaning of questions (version 8).

Three additional questions to test coordinates (latitude and longitude) were added as none of the existing 27 questions assessed this concept explicitly. The number of questions totalled 30 across 10 categories. At the end of each question (explanation question excepted) a confidence indicator was added. Students were asked to indicate their level of confidence for each question; choices ranged from 'very sure' to 'not sure at all' (Version 9).

Team G was given Version 9 of the geospatial scale and the revised affection scales. The purpose was to confirm whether the language was at an appropriate level for grade 9 students. Two geospatial scales that differed in the language level were created. The test version contained simplified words and truncated sentence structures, keeping the questions and ideas the same as the original. Half a class was given the original scale while the other half received the test version. A difference of means t-test determined no statistically significant difference between the two sample groups. No difference was found in the first class of 15 students, $t = 0.842$, df = 13, $p = .415$. The same result was found in the second class of eighteen students, $t = 1.038$, df = 16, $p = .315$.

Table 3.2 summarizes the geospatial and non-geographic concepts required to solve each of the 30 questions.

Question number	**Geography elements**	**Non-geography elements**
Question 1	Location (Locate) Place Position Spatial recall Space Spatial distribution	Vocabulary
Question 2	Buffering Area Distance Scale	Scale calculation (mathematics)
Question 3	Buffer	English proficiency to convey concept
Question 4	Distance decay	Vocabulary
Question 5	Contour Elevation	Slope (rise over run)
Question 6	Aspect	
Question 7	Spatial vocabulary	English proficiency
Question 8	Navigation Direction Map	
Question 9	Distance Scale	Scale calculation
Question 10	Navigation Direction Map	
Question 11	Overlay Region Area	
Question 12	Overlay	English proficiency to convey concept
Question 13	Area Scale	Scale calculation (mathematics)
Question 14	Overlay Region Area Map	English proficiency to convey concept
Question 15	Geospatial vocabulary	English
Question 16	Scale Area Region Map	Mathematics
Question 17	Scale Area Region	Scale calculation (mathematics)

	Map	
Question 18	Geospatial vocabulary Forms of settlement	English proficiency to convey concept
Question 19	Geographic data Forms of settlement	Visualization
Question 20	Geographic data Forms of settlement	Visualization
Question 21	Geographic data Forms of settlement	Visualization
Question 22	Spatial distribution/ organization Spatial data Geographic data Area Region Map	Visualization Understanding of spatial term
Question 23	Spatial distribution/ organization Spatial data	Understanding of spatial term
Question 24	Spatial distribution/ organization Spatial data	Understanding of spatial term
Question 25	Spatial distribution/ Organization Spatial data Region Area	Understanding of spatial term
Question 26	Geospatial term	English
Question 27	Spatial distribution Choropleth	Visual comparison
Question 28	Coordinates (latitude/ longitude)	Mathematics
Question 29	Coordinates (latitude/ longitude)	Understanding of vocabulary parallel and perpendicular (English and mathematics)
Question 30	Coordinates (latitude/ longitude)	Approximation along a line (mathematics)

Table 3.2: Geospatial and non-geographic concepts used in each question

Geospatial questions were developed to range from easy to challenging. Table 3.3 shows that the questions were spread across different levels of Piagetian spatial development (1971) and Bloom's (1956) learning scale. Bloom's taxonomy is an object-based evaluation that has influenced education (Marzano and Kendall 2007); hence it is used throughout the dissertation as a framework.

Question number	Piaget level	Bloom's taxonomy
Question 1	Topological	Knowledge
Question 2	Euclidean	Application
Question 3	Euclidean	Knowledge
Question 4	Euclidean	Comprehension
Question 5	Projective	Analysis
Question 6	Projective	Application
Question 7	Projective	Knowledge
Question 8	Euclidean	Application
Question 9	Euclidean	Comprehension
Question 10	Euclidean	Application
Question 11	Projective/Euclidean	Analysis/ Synthesis
Question 12	Projective/Euclidean	Knowledge
Question 13	Projective/Euclidean	Comprehension
Question 14	Projective/Euclidean	Synthesis/ Evaluation
Question 15	Projective/Euclidean	Comprehension
Question 16	Euclidean	Application
Question 17	Euclidean	Application
Question 18	Projective	Knowledge
Question 19	Topological	Comprehension/application
Question 20	Topological	Comprehension/application
Question 21	Topological	Comprehension/application
Question 22	Topological/Projective	Comprehension/application
Question 23	Topological/Projective	Comprehension/application
Question 24	Topological/Projective	Comprehension/application
Question 25	Projective	Application/ Synthesis
Question 26	Projective	Comprehension
Question 27	Topological/Projective	Analysis
Question 28	Euclidean	Comprehension
Question 29	Euclidean	Application
Question 30	Euclidean	Application

Table 3.3: Cognition level by question

A revised edition of Bloom's taxonomy (Anderson and Krathwohl 2000) modified the label for each level and switched the order of the last two stages. Nevertheless, the original Bloom's taxonomy was used because the revised edition does not change any results in this study. Furthermore, it makes more sense that the thinking process 'evaluation' comes after a conclusion reached through 'synthesis' which is the original order in Bloom's taxonomy.

3.4.2 Marking of geospatial scale

The geospatial scale was marked shortly after it was completed. Three methods were used to evaluate the geospatial scales, out of a total of 30 points. First, correct multiple choice or explanation questions received a score of 1 while an incorrect answer received a score of 0. Second, explanation questions received either a mark of 0, 0.5 or 1 corresponding to the extent of correct information. The third method applies to three questions with multiple answers. Students who scored more than the average received a mark of 1; all others received a mark of 0. These questions are described below.

Question 1 (Task 1)

A total of 8 locations were shown to the participants. In order for a location to be correct, its name and location must both be accurately identified. Following this rule, each student's correct locations were marked out of 8.

These data were then used to find the mark dispersion. Students who scored in the upper quartile (75% of students) received a mark of 1, which in this case they need to have identified at least 7 locations correctly. A selection of 6 locations or less resulted in a mark of 0.

Question 3 (Task 3)

Students were asked to select five spatial terms that described the topological relationship between landforms. 'Topological' describes spatial relationships which are independent of a dimension or direction (Olson and Bialystok 1983). Students who scored in the upper quartile

(75.7% of students) received a mark of 1, which in this case correctly identified 4 or more spatial terms. A selection of 3 locations or less resulted in a mark of 0.

Question 7 (Task 1)

As this question is exactly the same as that of Question 3 (Task 3) the same method was applied. In this case, a benchmark at 70.3% was chosen as it was the closest to 75%. At this level, 4 or more spatial correct terms earned a score of 1, otherwise a score of 0.

3.4.3 Reliability score

The scores of 104 students produced a reliability of .777 Cronbach's Alpha score. The acceptable score in psychology is .700 while the optimal level is .800 or greater (Norusis 2005; Pallant 2005).

The geospatial scale has six subscales (further explained in section 4.3). A reliability score was calculated for each subscale, arranged in decreasing value below:

Comprehension: .683 (7 items)

Representation: .651 (5 items)

Analysis: .628 (8 items)

Application: .611 (5 items)

Scale: .343 (2)

Spatial thinking: .334 (3 items)

3.4.4 Lessons learned

The major milestones and lessons learned in the geospatial scale development are:

1. Identify fundamental concepts for question creation

2. Create questions that:

i) Provide pertinent information to solve a problem

ii) Ensure information from one answer does not unintentionally aid in the answering of another question

iii) Are well labelled, both in tables and figures

iv) Do not depend on memorization of facts, definitions or conventions (e.g., labelling, calculation)

3. Re-word questions for clarity

4. Check grammar

3.5 Affection scales (computer, geography, and mathematics)

The affection scale satisfies part of the fourth objective which is to understand the relationship between geospatial thinking with the level of attitudes towards computer, geography, and mathematics.

The common thread between these scales is that the questions inquire about the importance of these school subjects to an individual's education and application to life. Where the computer scale focuses on self perceived ability to install software and use hardware, the mathematics scale is focused on student affection towards the subject. The geography scale is a mixture of both affection to the subject and self perceived ability in geography tasks.

The first scale given to participants was computer anxiety, borrowed from Wood et al. (2002). The 15 questions examine one's reaction to computer and software use. A duplicated question was deleted resulting in 14 in the final draft. Data from this study (n=104) produced Cronbach's Alpha of .847.

A small collection of geography specific affection scales exist (Golledge 2000; Hegarty et al. 2002; Baker and White 2003; West 2003). Two different surveys, though with some overlap, have been selected to model after: Baker (2002; 2003) and West (2003). Baker's affection scale has a total of 28 questions whereas West's survey contains 27 questions. Twenty-seven were borrowed from West's scale; each question was modified to apply to the geography subject. An additional thirteen questions were added from Baker's survey, totalling to 40 questions. These questions were reviewed and revised by the author to follow closely suggestions of attitude scale construction (Edwards 1957).

Team A commented on the general format of all three scales. The suggestions were integrated to form version 2 which was pre-viewed by Team B. They noted questions that were either too similar, that appeared to be duplicates or that did not directly apply to graduate students. From this initial screening, three questions were omitted. This was administered to Team D and a focus group that identified ambiguous questions (version 4). A further 6 questions modified from Wood et al. (2002) were added to increase the understanding of student affection towards geography, but these questions were not found in either Baker (2002; 2003) or West's (2003) scales. The revised version of this scale was given to Team F. Their comments led to minor grammatical changes (version 6). The final scale has 21 questions with Cronbach's Alpha of .921.

The mathematics index has 15 questions which examine opinion towards mathematics. Five questions are negative items (#2, 3, 6, 10, 12), whose scores are reversed. This scale was first presented to Team F who added small grammatical corrections (version 2). Team G provided a few comments for revision (Version 3). The internal consistency is Cronbach's Alpha of 0.847.

3.6 Reliability and validity

Cronbach's alpha was used to measure reliability which is the internal consistency or interrelatedness of the items in a scale (Schmitt 1996). In particular, reliability tests whether a scale will provide the same results when given repeatedly to the same participant (Babbie 1990).

Validity examines how well a scale reflects the *real meaning* of a concept(s) investigated (Babbie 1990). Two methods of validity will be examined: face validity and content validity (Carmines and Zeller 1979; Babbie 1990). If a scale has face validity this means that the questions resemble what it is designed to measure. Content validity examines the extent to which concepts are being tested.

The scale has face validity because it tests geospatial relation concepts. Next, there is content validity because the scale is developed from a core list of geospatial concepts. A second way to examine content validity is the application of a spatial taxonomy to each question (Table 3.4). The taxonomy was developed by Jo (2007) to measure the nature and extent of spatial thinking in geography textbook questions. The taxonomy uses three categories from NRC (2006): concepts of space, tools of representation, and processes of reasoning. The category 'Concepts of Space' can be classified as 'spatial or 'non-spatial' and further described as primitive, simple or complex. 'Tools of Representation' is the second criterion which classified questions as either using representation or not. If the question required representation, it can either be external or internal. The final category is 'Reasoning Processes' composed of three levels: *input* (e.g., naming, defining, listing, labelling, completing, matching, reciting), *processing* (e.g., comparing, distinguishing, classifying, categorizing, organizing, summarizing, inferring), and *output levels* (e.g., evaluating, judging, predicting, forecasting, planning, creating, hypothesizing, generalizing, applying a principle).

Question number	Concept (spatial/non-spatial)	Representation	Reasoning process
Question 1	Spatial – simple	Diagram	Input
Question 2	Spatial – complex	Diagram	Processing
Question 3	Spatial – complex	None	Input
Question 4	Spatial – complex	None	Input
Question 5	Spatial – simple	Diagram	Output
Question 6	Spatial – simple	Diagram	Processing
Question 7	Spatial – simple	None	Input
Question 8	Spatial – complex	Diagram	Process
Question 9	Spatial – simple	Diagram	Processing
Question 10	Spatial – complex	Diagram	Process
Question 11	Spatial – complex	Diagram	Processing
Question 12	Spatial – complex	None	Input
Question 13	Spatial – simple	Diagram	Processing
Question 14	Spatial – complex	Diagram	Output
Question 15	Spatial - complex	Written	Output
Question 16	Spatial – simple	Diagram	Processing
Question 17	Spatial – simple	Diagram	Processing
Question 18	Spatial – simple	Diagram	Input
Question 19	Spatial – simple	Diagram	Processing
Question 20	Spatial – simple	Diagram	Processing
Question 21	Spatial – simple	Diagram	Processing
Question 22	Spatial – complex	Diagram	Processing
Question 23	Spatial – complex	Diagram	Processing
Question 24	Spatial – complex	Diagram	Processing
Question 25	Spatial – complex	Diagram	Output
Question 26	Spatial- complex	Written	Output
Question 27	Spatial – complex	Diagram	Processing
Question 28	Spatial – complex	Numerical	Input
Question 29	Spatial – complex	Numerical	Processing
Question 30	Spatial – complex	Diagram	Processing

Table 3.4: Summary of face and content validity

3.7 Geographic skills test creation and rubric development

Geographic skills satisfy part of the fourth objective which is to understand the relationship between geospatial thinking with the level of geographic skills. The National Geography Standards: Geography for Life (Geography Education Standards Project 1994) outlined five geographic skills and perspectives seen in geographically literate people. These are:

1. Asking geographic questions
2. Acquiring geographic information
3. Organizing geographic information
4. Analyzing geographic information
5. Answering geographic questions

The standard geographic skills are transformed into three tasks which take the form of query, data formation, and a GIS flow chart creation. Each student was presented with the GIS problem statement and a list of available data (section 3.8 below). They were asked to create 2 different questions from the GIS problem statement, based on the data available (geographic skill tested: asking geographic questions). The second task was to suggest additional datasets required to solve the questions posed (geographic skills tested: acquiring and organizing geographic information). Finally, they were asked to create a flow chart to describe their problem-solving strategy (geographic skills tested: analyzing and answering geographic questions). The flow chart also acted as a process worksheet (Kirschner et al. 2006) to guide students in their hands-on GIS application. Each skill was evaluated by a rubric that follows a qualitative assessment method.

The geographic skills rubric levels are derived from the hierarchy of Structure of the Observed Learning Outcome (SOLO) taxonomy, an evaluation of extended answers along a general sequence of cognitive growth for a concept or skill. The rubric content and expectations for each level follow the ideas of Bloom's taxonomy: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation. Each evaluation area is worth 5 marks for a total of 15 (Table 3.5).

Geographic skills scoring rubric: A guide to scoring written answers			
SOLO score	**Query**	**Data information**	**GIS flow chart**
	Demonstrates an analysis that result in the use of geographic knowledge and spatial principles that result in appropriate geographic questions	*Identifies significant data (data not already provided) that will aid in answering posed questions*	*Completes and applies logical steps that show a potential solution to the problem*
5	Synthesizes two original and different questions that effectively and clearly demonstrate an evaluation and application of spatial thinking	Evaluates and synthesizes all the important data to the questions, all of which are individually derived and demonstrate a clear analysis of geographic knowledge	Produces a complete flow chart that captures the problem from start to solution Demonstrates a thorough evaluation and synthesis of problem and given dataset
4	Synthesizes two different questions that demonstrate clear analysis and application of spatial thinking	Synthesizes the important data to the questions, all of which are individually derived and demonstrate an analysis and application of geographic knowledge	Produces a complete flow chart that captures the problem mostly from start to solution Demonstrates an analysis and application of the dataset to the problem
3	Synthesizes two somewhat different questions that demonstrate a comprehension of spatial thinking	Synthesizes some of the important data to the questions, some of which are given in the data list, demonstrating a general comprehension of geographic knowledge	Produces a somewhat complete flowchart. Demonstrates comprehension and knowledge of the dataset and problem to be solved
2	Synthesizes one question that demonstrates a knowledge of spatial thinking	Borrows data given in the data list and demonstrates a general knowledge of geography	Produces an incomplete flowchart Demonstrates some knowledge and comprehension for the data and Problem
1	No synthesis of questions attempted	No data suggested	No apparent strategy

Table 3.5: Geographic skills marking rubric

3.8 GIS exercise creation and rubric development

The development of a GIS problem-solving exercise and evaluation satisfies one component of objective five. A problem-solving activity was selected over other outcome tasks because it required participants to select relevant knowledge and principles to produce a solution (Gagné 1965), closely matching with Bloom's highest level of thinking, evaluation. In addition, the GIS problem is similar to exercises used in past GIS education research (Audet 1993; Keiper 1999; Baker 2002; Carver et al. 2004; Drennon 2005). The nature of GIS exercises is a problem based format where students solve increasingly complex spatial and non-spatial questions with given background information. The GIS exercise proposed is problem based, incorporating multiple data sets. The technological requirements are kept to basics as the study is interested in whether and how different levels of geospatial knowledge, skills, and perspectives influence effective problem solving with GIS, not the technical challenges identified in past research (Meyer et al. 1999; Edelson et al. 2006).

The problem-based learning (PBL) environment is in stark contrast to a traditional content-driven education. In the former scenario, the learning experience is in a constructive and flexible setting where students apply concepts learned in class to real world problems. The instructor is a facilitator where the curriculum becomes an experience rather than a prescription (Drennon 2005). When a solution is reached, there are two simultaneous outcomes. First, students are reinforcing prior knowledge and second, students learn something (e.g., concept, skills, thinking process) such that the ability is permanently changed (Gagné 1965). In particular, the GIS problem encourages exploration, defined by van Hiele (1986) as the stage of 'free orientation' where multiple solutions free of unexpected obstructions exist.

In developmental psychology, a limitation to research is their simplification and tightly controlled research design, the resulting data is then used to generalize about children's cognition of geographic space (Hart and Berzok 1982). In contrast, the GIS exercise is complex as there are multiple variables that reflect a real life situation, various solutions exist, and the participant has full control over the problem-solving approach. The collected data are a true reflection of participants' spatial thinking and problem-solving abilities instead of a generalization abstracted from a controlled experiment.

The GIS exercise was modelled after a problem-solving task designed by Dr. Bob Sharpe. The model question seeks to identify residential areas that are within a 2km distance from a grocery store to create a mailing list. The current GIS exercise focuses on a student-related issue, searching for rental housing (Figure 3.1). Some data are borrowed in original form from the model problem, some data are modified (e.g., selecting only bachelor/rental housing from the property points file), and some are created by the author through digitization (e.g., bus routes, location of the Faculty of Social Work, off-road bicycle lanes, and on-road bicycle lanes).

GIS problem statement

You are new to the City of Kitchener, Ontario and wish to find rental housing. You have some mandatory and optional criteria in mind.

You want to live within a 4 Km bike ride to the Faculty of Social Work and a 3 Km bike ride to a grocery store. You also want to live close to the Grand River Transit bus system. Since your main transportation is a bicycle, you would also like to live close to roads with a bicycle lane.

Some optional criteria are to live by nature (e.g., rivers, parks), bicycle trails, banks, and department stores.

You have a budget of $750.00/month for rent and you understand that the housing cost is directly proportional to the distance away from downtown Kitchener. The starting price for a bachelor apartment in downtown Kitchener is $800.00/month and decreases by $50.00 for every 1.0 Km distance away.

Please select two potential rental areas (approximately 1 Km^2 in area) that would satisfy the above criteria. Talk aloud as you are thinking and reasoning through this task.

Figure 3.1: GIS problem-solving exercise

The data are presented as core and optional dataset so as to not overwhelm participants with too much information. They are given the choice to choose any dataset(s) they preferred.

Core dataset:

- Downtown Kitchener
- Grand River Transit bus routes
- Grocery stores
- Housing
- On-road bike trail
- Street network in Kitchener

Optional dataset:

- Banks
- Department Stores
- Off road bike trail
- Parks
- Rivers
- Water features (ponds)

Team F read the GIS task for clarity, logical flow of ideas, and the sufficiency of dataset provided. Comments were integrated and retested on a second group. The second group tried the task on GIS using a handbook. Finally, revisions were made by going through the problem by self, anticipating where confusion or uncertainty may be prompted by language, presentation, and question format. A few different solutions were also tested (e.g., measuring, eye-balling, and a combination of spatial queries, and buffers/intersections) to confirm that similar solutions could be reached by different means.

The GIS problem-solving rubric, like the geographic skills rubric, is a combination of the SOLO and Bloom's taxonomy. The rubric expectations were created from student observations, contrasting and comparing between the strategies of those who exhibit trial and error (novice) versus systematic solutions (expert). The rubric is adapted from an assessment of extended responses in mathematics, evaluating mathematical knowledge, strategy used, and explanation of outcome (Graham and Naglieri 2003). The rubric is illustrated in Table 3.6, with three main areas of evaluation: geospatial knowledge, problem-solving strategies, and the outcome and explanation. Each area is worth 5 marks, for a total of 15 points.

GIS problem solving scoring rubric: A guide to scoring GIS task			
SOLO score	**Geospatial Knowledge** *Knowledge of geography and spatial principles used to reach a correct solution*	**Problem-solving strategies (GIS operations)** *Identification of relevant information; correct application of GIS operations, geography, and spatial principles to systematically represent and integrate concepts*	**Outcome and Explanation** *Verbal explanation of rationale and steps taken to reach solution*
5	Shows complete understanding of the problem's geography and spatial principles Anticipates or predicts all the outcome of GIS operations based on knowledge of spatial understanding Evaluates the given geographic knowledge and synthesizes new information	Evaluates and identifies all the important elements of the problem and shows complete understanding of the relationships among elements Gives clear evidence of a complete, appropriate, and systematic solution process Executes GIS operations completely and correctly Attempts to use a wide range of GIS operations from simple to advanced	Explains fully and in detail the reasons for each step taken Selects two 'correct' locations for housing and satisfy all mandatory criteria Has a high command of geography and spatial vocabulary Integrates human/social dimension to solve problem
4	Shows nearly complete understanding of the problem's geography and	Analyses and identifies most of the important elements of the problem and shows	Explains the reasons for each step taken Selects two 'correct' locations for

	spatial concepts and principles Anticipates or predicts most of the outcome of GIS operations based on knowledge of spatial understanding Analyzes the given geographic knowledge and synthesizes new Information	general understanding of the relationships among them Reflects an appropriate strategy for solving the problem and solution process is nearly complete Executes GIS operations completely; application of GIS operations generally correct but may contain minor errors Attempt to use a range of GIS operations from simple to advanced	housing and satisfy most mandatory criteria Has a command of geographic and spatial vocabulary Integrates human/social dimension to solve problem
3	Shows some understanding of the problem's geography and spatial concept and principles Applies the given geographic knowledge and comprehends information	Comprehends and identifies some important elements of the problem but shows only average understanding of the relationships among them Appears to reflect an acceptable strategy but the application of strategy is unclear, or the strategy applied is not logical and consistent throughout May contain major applications errors of GIS operations Attempt to use different GIS operations	Explains somewhat the reasons for each step taken One 'correct' locations for housing and satisfy some mandatory criteria Has some command of geographic and spatial vocabulary Integrates some human/social dimension to solve problem
2	Shows limited to no understanding of the problem's geography and spatial concepts and principles Little application of given geographic knowledge and poor comprehension of information	Fails to identify important elements or places too much emphasis on unimportant elements May reflect an inappropriate or inconsistent strategy for solving the problems Misuses or fails to use GIS operations completely Use of GIS operations is limited	Difficulty explaining the reasons for each step taken No 'correct' locations for housing; satisfy a few mandatory criteria Has a poor command of geographic and spatial vocabulary May attempt to use irrelevant or incorrect outside information to solve problem

1	No answer attempted	No apparent strategy	No explanation of the solution process is provided

Table 3.6: GIS problem-solving marking rubric

The SOLO taxonomy is one method to examine GIS problem solving. Another way is to assess the solution accuracy. However, the solution alone gives little insight on the problem-solving processes and offers only broad differentiation between participants. To gain an in-depth understanding of thinking processes, sequences are analyzed. Each sequence represents an active decision expressed as a GIS operation. The sequence string is unique to each person and offers a novel analytical approach in geographic education research. Sequence analysis is described in section 3.9 below.

3.9 Preparation for sequence analysis

Cluster analysis of the GIS operation sequence categorizes similar problem-solving methods together. The aim is to reveal any relationship(s) between geospatial expertise and the sequence of GIS actions (Objective five).

A transcription and a sequence of problem-solving steps were created from each participant's audio-visual recording. Each GIS function reflects a level of spatial thinking, categorized into one of four groups: visualization (visual tactic), primary (primitive), secondary, and tertiary order GIS functions. Each group is described below and accompanied by a list of sample operations.

Visualization or visual tactic is the derivation of information based on visual inspection of the GIS layer(s).

The *primitive or primary* level functions are tools that represent spatial facts in a way that is more easily understood. In addition the facts created are spatially unilateral or one dimension at any one time such that if a distance were to be measured, the restriction is that only two points (in one direction) can be measured at one time, e.g., point A to point B. These include four tools applicable to the problem:

1. Measure tool: provides distance between two points, in a specified direction from each other
2. Zoom in/out: enlarge or decrease size of view
3. Symbology change: increases or decreases visibility of layers
4. Pan: move around the map to see other extents or areas

The *secondary order* functions, also identified here as intermediate tools, provide facts that are in transition to becoming information, showing a unilateral relationship between layer and its surrounding or other layers. These operations include:

1. Buffer: shows the areal extent of a radius around the point of interest
2. Union: combines two layers into one
3. Clip: cut out the shape of a layer based on another layer
4. Erase: take away part of a layer based on the intersection with another layer
5. *Intersection: Isolate common overlaps between two or more layers

*On its own, the intersection tool may be an intermediate tool but when multiple intersections are performed in sequence such that the previous intersection result is used to intersect with another layer, this theoretically is the same as what a spatial query does and so becomes a tertiary tool (see below). The same concept can be extended to multiple clip or erase actions.

Tertiary operations are advanced tools which create information about the spatial relationship(s) between layers, in one or more direction. This includes spatial query, a selection of features from one or more layers that satisfy a spatial relationship with another layer.

Spatial query can be considered a higher-order GIS function because this operation alone can provide a solution in the fewest steps. Hence, the spatial query tool provides an eloquent and simple way to solve the solution.

In a transcription, a letter (V, F, S or T) is assigned to each problem-solving tactic described above. For example, the following GIS action will have a sequence as exemplified in the problem-solving transcription as:

Merge bike trails since they are the primary transportation routes (*merge = secondary*)

Select bicycle trails that are 'within a distance of' 4Km from SW (*spatial query = tertiary*)

Select merged bicycle trails that are 'within a distance of' 3Km from grocery stores (*spatial query = tertiary*)

Select Housing that 'are completely within' downtown buffer (*spatial query = tertiary*)

The resulting sequence will be 'STTT'.

The sequences are input into CLUSTALW software, specifically chosen for this purpose because it has, in addition to the standard alignment output of results, a better graphic representation of the results than other alternatives. CLUSTALW groups participants into categories based on the similarity of their sequence string.

3.10 Nature of dataset and analytic methods

Five sets of tests are employed to differentiate between novice, intermediate, and expert characteristics in GIS problem solving. The quantitative data support statistical calculations (such as t-test of means and post-hoc anova) to explore the levels reached by students across grade levels. A regression model was performed to learn possible relationships and generalized patterns between geographic knowledge, skills, and problem solving with GIS. Observations explain patterns and surprises revealed in quantitative data such as the mechanisms of problem solving and student misconceptions. A description of each dataset is detailed below, followed by an overview of the analytical methods performed.

Dataset 1: Demographic data

Personal information were collected:

i) Age

ii) Gender

iii) History of geographic education (geography major/minor/elective, number of geography courses taken in high school, number of geography courses taken in university)

Dataset 2: Perspectives (Affective attitude)

The affection scales apply a Likert scale that range from 1 to 5. A low score represents a positive affection while a high score is indicative of poor perceptions of a subject. The data allow for descriptive statistics (mean and standard deviation) as well as one-way post-hoc anova tests, and t-tests of means.

Dataset 3: Geospatial scale

The geospatial scores were evaluated numerically; a score of 1 was assigned for every correct answer and 0 for an incorrect answer. Two exceptions apply. In the case of explanation questions, a complete answer received a score of 1, an incorrect answer was given a score of 0 while a satisfactory response received a mark of 0.5. The second case is where multiple answers are correct. Students who scored above the average received a mark of 1, all others were given 0 (see section 3.4.2). At a statistical level, descriptive data, one-way post-hoc anova tests, t-tests of means, factor component analysis, and regression models were performed.

Dataset 4: Geographic Skills (Inquiry, Data Acquisition and Organization, Analyzing and Answering Geographic Questions)

Responses to the geographic skills assessment were written answers, which were evaluated against a rubric (Table 3.5), with possible scores ranging from 1 to 5. The statistical analyses included descriptive statistics, one-way post-hoc anova, and t-tests of means.

Dataset 5: Problem solving with GIS

The GIS problem-solving task was audio-visually recorded, which was then transcribed, giving rise to two analytic methods: cluster analysis and an evaluation of spatial thinking process with the SOLO taxonomy (Figure 3.2).

The GIS exercise was measured against a rubric (Table 3.6) resulting in an assigned score. Specifically, geospatial knowledge, problem-solving strategies (e.g., geographic theories, rules, order of operations), and outcome explanations are integral to the process. Statistical analyses include descriptive statistics, one-way post-hoc anova, and t-tests of means.

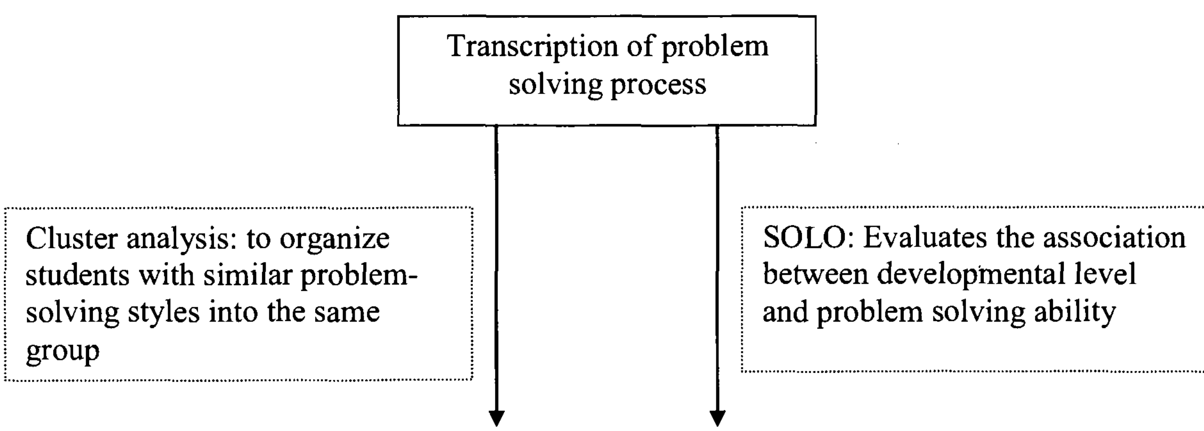


Figure 3.2: Qualitative data analysis of GIS problem-solving tasks

Figure 3.3 provides a summary overview of all the analytic methods used.

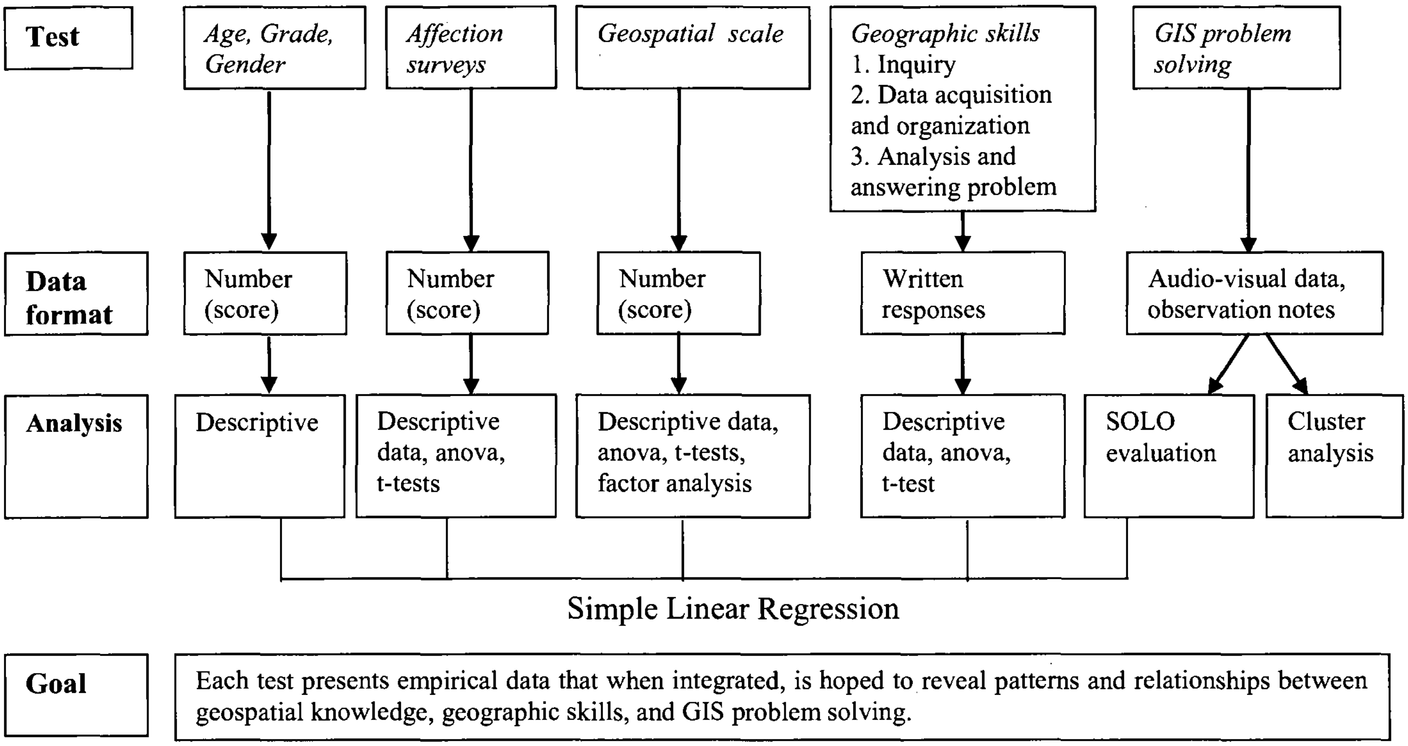


Figure 3.3: Structure of data and analyses

3.10 Chapter summary

This chapter presented a comprehensive view of the data collection process, from the recruitment process to the creation of scales through the scoring of the GIS exercise. Together, these exercises are sufficient to collect qualitative and quantitative datasets accumulated from written, verbal, and video records to support a range of different and rigorous analyses.

Four datasets were collected from each participant, including the affection scales, geospatial scale, geographic skills, and an audio-visual recording of the GIS problem-solving process. The scales have acceptable levels of Cronbach's alpha, in particular the geospatial scale is robust for advanced statistics such as factor analysis. While the scales provide a quantitative dataset, this is complemented by qualitative data from the GIS exercise.

CHAPTER 4: RESULTS

This chapter includes the results of statistical analyses and qualitative data interpretation, presenting results in the order of objectives as outlined in Chapter One.

4.1 Geospatial scale development

Objective 1: The first research objective is to develop a research instrument, in the form of a scale, to measure the level of geospatial thinking based on performance on a series of geospatial, knowledge-based questions. The figures and tables below provide an exploratory analysis of the geospatial scale.

The analysis here first explores the descriptive statistics of the geospatial scale overall and by expertise levels. This is followed by examining the performance and observations of student misconceptions.

As a starting point, Figure 4.1 displays a frequency distribution histogram of the geospatial scores (n=104), which approximates a normal distribution. Score range from a minimum of 5 to a maximum of 27 out of a total of 30 points. The mean is 17.6 with a standard deviation of 4.8.

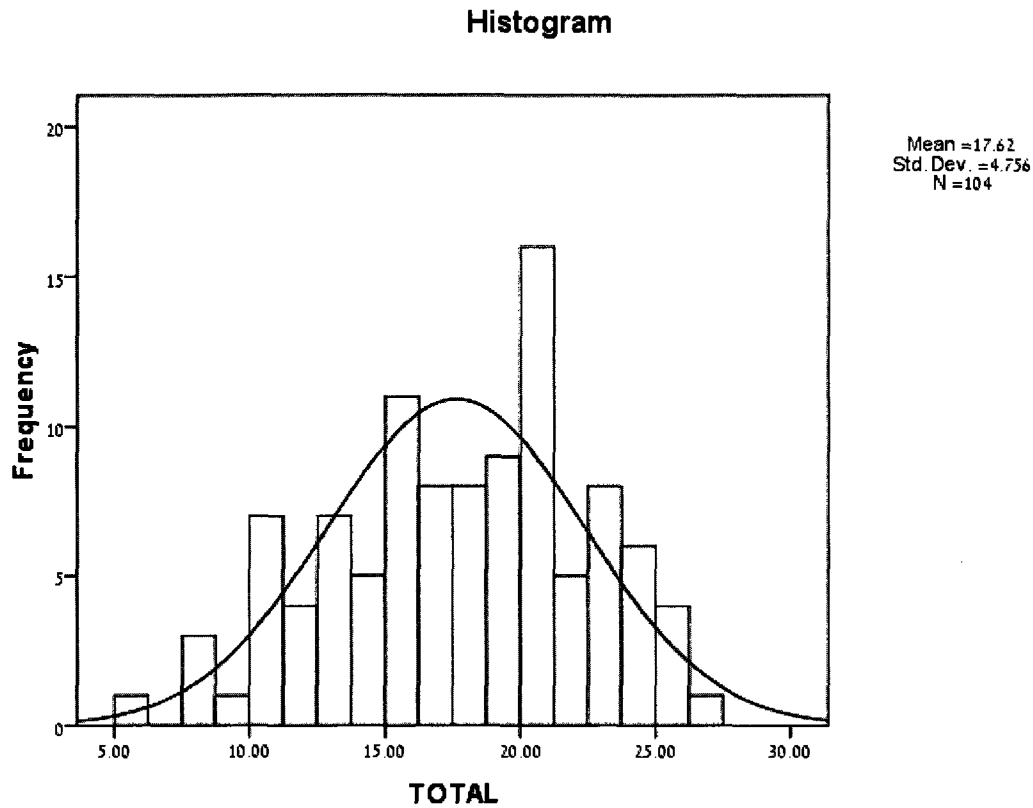


Figure 4.1: Distribution of geospatial scores

The geospatial scores provide a way to group participants, other than the traditional categories of age or grade cohorts. Based on their performance on the geospatial scale, participants are categorized on the expertise continuum into novice, intermediate, and expert groups. The resulting expertise categorization grouped students with geospatial scores greater than one standard deviation above the mean (score greater than 22) as experts, one standard deviation less than the mean (score less than 13) as novice and a range in between the two standard deviations as intermediates (scores between 13.01 to 21.99). Since the distribution is approximately normal, the standard deviation technique is appropriate to partition students with like scores.

In Table 4.1 experts are shown to perform better than intermediates, who perform better than novices. The one-way anova test confirms that there is a statistically significant difference among the three expertise levels (F = 195.702, df = 2, sig = .000). However, this test does not suggest where the difference lies so t-tests of means are applied. T-tests show that statistically significant differences at the .05 level exist for novices versus intermediates (t = 12.416, df = 81, p = .000); novices versus experts (t = 24.769, df = 40, p = .000) and intermediates versus experts (t = 10.628, df = 81, p =.000).

Grouping	n	Minimum	Maximum	Mean	Std. Deviation
Novice	21	5.0	13	10.6	2.0
Intermediate	62	13.5	21.5	17.9	2.4
Expert	21	22	27.0	23.9	1.4

Table 4.1: Average geospatial score across expertise levels

An item analysis was performed on each question to illustrate the frequency of correct response by expertise levels (Figure 4.2). In general, experts exhibit a higher frequency of correct answers than intermediates and novices, across questions. A t-test of means was conducted on the average score for each question at each expertise level. Differences of means by expertise levels were found in 24 of the 30 questions (Table 4.2). Table 4.2 is a summary of performance by question across expertise levels. The last column offers explanations for observed differences.

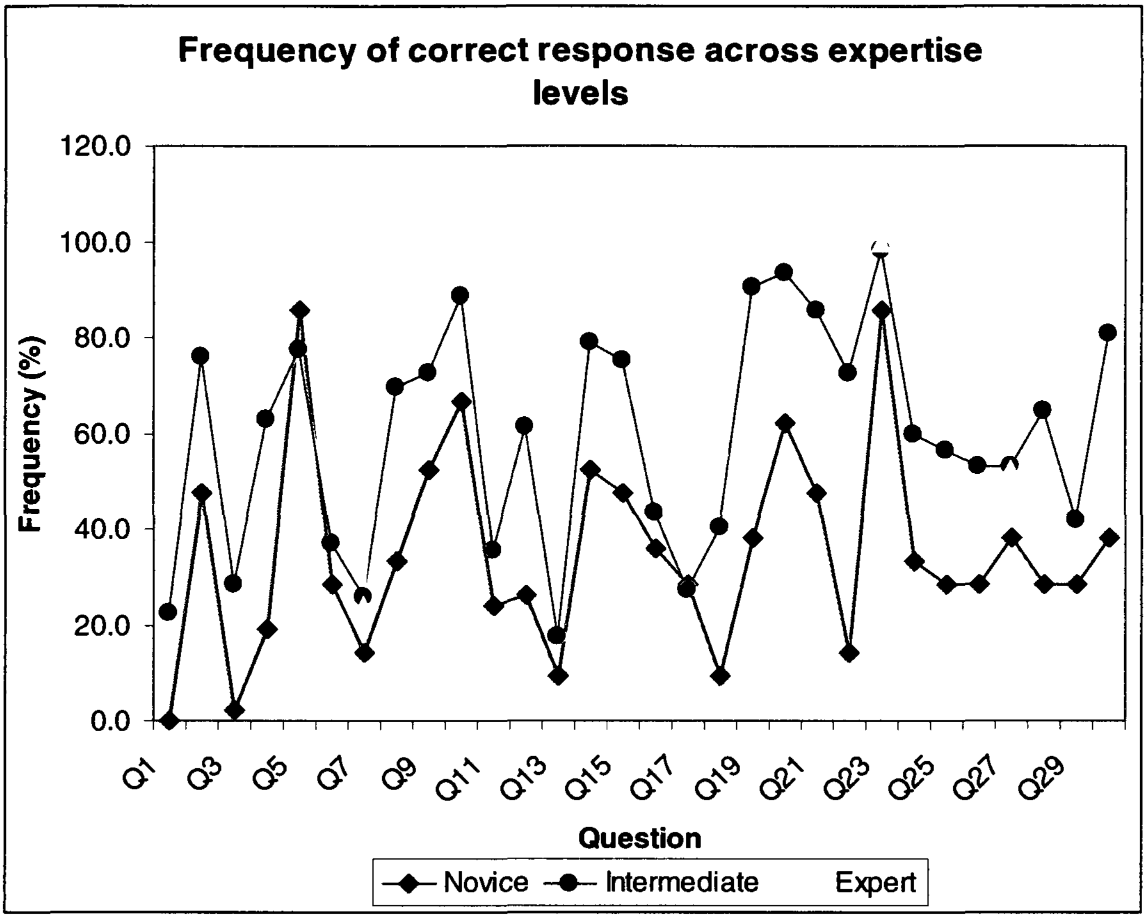


Figure 4.2: Frequency of correct responses across expertise level

Question	Statistical difference between groups	Primary geospatial concept	Hypothesis for observed differences
Q1	Experts and intermediates (.029); experts and novices (.000); novices and intermediates (.017)	Spatial location of landmarks	Memory capacity
Q2	Experts and intermediate (.012); experts and novices (.000); novices and intermediates (.016)	Buffer	Lack of knowledge from formal education
Q3	Experts and novices (.000)	Buffer	Lack of knowledge from formal education
Q4	Experts and intermediates (.017); experts and novices (.000); novices and intermediates (.000)	Distance decay, terminology	Lack of knowledge from formal Education
Q8	Experts and intermediate (.003); experts and novices (.000); novices and intermediates (.003)	Navigation, direction	Cognitive development; practise in daily activities

Q9	Experts and intermediates (.003); experts and novices (.001)	Calculate distance travelled	Mathematics; scale conversion
Q10	Experts and intermediates (.020); experts and novices (.018)	Navigation, direction	Cognitive development; practise in daily activities
Q11	Experts and intermediates (.034); experts and novices (.012)	Overlay	Cognitive development; lack of knowledge from formal education
Q12	Experts and intermediates (.017); experts and novices (.000); novices and intermediates (.000)	Explanation of how overlay was achieved	Lack of knowledge from formal education
Q13	Experts and intermediates (.002); experts and novices (.001)	Area estimation	Mathematics; scale conversion
Q14	Experts and intermediates (.022); experts and novices (.000); novices and intermediates (.018)	Overlay, distance approximation	Lack of knowledge from formal education; cognitive development
Q15	Experts and intermediates (.006); experts and novices (.005); novices and intermediates (.005)	Explanation of how overlay was achieved	Cognitive development; lack of knowledge from formal education
Q18	Experts and novices (.001); novices and intermediates (.009)	Spatial terms	Lack of knowledge from formal education; lack of practise and exposure to geography vocabulary , cognitive development
Q19	Experts and novices (.000); novices and intermediates (.000)	Representation and symbols	Lack of knowledge from formal education to maps; practise in daily activities
Q20	Experts and novices (.001); novices and intermediates (.000)	GIS symbol, representation	Lack of knowledge from formal education to maps; practise in daily activities
Q21	Experts and novices (.002); novices and intermediates (.000)	GIS symbol, representation	Lack of knowledge from formal education to maps; practise in daily activities
Q22	Experts and intermediates (.007); experts and Novices (.000)	Representation, spatial relationship	Lack of knowledge from formal education to maps; practise in daily activities
Q23	Novices and intermediates (.019)	Representation, spatial relationship	Lack of knowledge from formal education to maps; practise in daily activities
Q24	Experts and intermediates (.002); experts and novices (.000); novices and intermediates (.037)	Representation, spatial relationship	Lack of knowledge from formal education to maps; practise in daily activities
Q25	Experts and intermediates (.001); experts and novices (.000); novices	Overlay, spatial distance	Lack of knowledge from formal education; practise in daily activities; cognitive development

	and intermediates (.027)		
Q26	Experts and novices (.001); novices and intermediates (.016)	Spatial relationship	Lack of knowledge from formal education
Q28	Experts and intermediates (.023); experts and novices (.000); novices and intermediates (.004)	Format of latitude and longitude	Practise in daily activities
Q29	Experts and intermediates (.000); experts and novices (.000)	Latitude, longitude, selection and application	Practise in daily activities
Q30	Experts and novices (.001); novices and intermediates (.000)	Latitude and longitude	Lack of knowledge from formal education; practise in daily activities

Table 4.2: Statistical difference by question across expertise group

Student performance is different on 11 distinct geospatial concepts (position, buffer, distance decay, navigation, overlay, scale, spatial terminology, GIS symbol representation, representation of spatial distributions, latitude and longitude, distance and area estimation) where there is none detected in the other nine (elevation, aspect, contour, urban forms/forms of settlement, geographic/spatial data, symbol representation, region, map, correlation) (Figure 4.2). These differences may be attributed to errors and misconceptions described in Table 4.3. Each category is adapted from Bloom's taxonomy, 1) lack of knowledge, 2) incomplete comprehension, 3) incomplete application, 4) incomplete analysis, and 5) general misconceptions.

Error classification	**Error explained**	**Example**
Lack of knowledge	This level is concerned with the knowledge of terminology and facts. Students have not been formally exposed to a geospatial concept or its application.	Definition of concept buffer
Incomplete comprehension	This level is associated with an understanding of concepts. Students have received formal education on a topic, but do not	Latitude and longitude identification

	understand it well enough to describe, locate or explain it.	
Incomplete application	This level of learning applies relevant information to a new situation. Students can correctly answer a question directly relating to a concept, such as identifying the steepest mountain using contour lines, but are less successful using the concept of contour lines in an applied situation.	Select landscape visible from a particular point based on contour lines
Incomplete analysis	Analysis is the ability to identify the components of a question to deduce and make inferences to reach a solution. Students have difficulty putting multiple pieces of information together to arrive at an answer. This may be due to cognitive overload.	Selection of the best campsite based on four criteria
Misconception	Misconception is an incorrect understanding of a concept. Students apply a concept that has not been fully developed or incorrectly understood in their mind.	Confusion between a large and small scale

Table 4.3: Summary of misconceptions and common errors in the geospatial scale

4.2 Relationship between geospatial scale, age, grade, gender, and formal geographic education

Objective 2: The second objective is to examine the scale's relationship to age, grade, gender, and number of formal geography courses taken. Among the advantages of this scale is that it is based on actual performance and avoids assumptions about the uniformity of expertise within groups.

The analysis here first explores the relationship between age, education level, and gender with expertise groupings. This is followed by an examination of the geospatial scale as an alternative to grouping students based on expertise rather than age and/or grade expected performances.

Age (grade or education level as a corollary) has traditionally been a determinant of spatial development such that an improvement of performance is expected with increased age and education level. The average age across the whole sample is 21.9 with a standard deviation of 6.2, the youngest at 14 years old and the eldest at 45 years old. Table 4.4 summarizes the mean score at each grade, progressing in performance with age and education levels.

Results of an anova test is summarized in Table 4.4 which shows statistical differences in geospatial scores across age groups (F = 2.309, df = 22, sig = .004). Since the age variable is continuous rather than allocated into groups, a post-hoc test was not possible.

Grouping	Mean Age	N	Minimum score	Maximum score	Mean score	Std. Deviation Score
Grade 9	14.7	20	5.0	20.5	13.3	4.1
First year	18.9	24	10.0	23.5	17.0	3.2
Seniors	22.1	30	8.5	27.0	17.6	4.8
Graduates	29.6	30	10.0	26.0	21.0	3.6

Table 4.4: Mean geospatial scores across grade levels

To explore how geospatial scores differ across age-grade continuum, a one-way anova test was performed. There is a statistically significant difference at the .05 level between the four participant groups (F = 15.124, df = 3, sig = .000); however, this test does not suggest where the difference lies. T-tests were run to better illuminate the differences across grade levels (Table 4.5). Differences in geospatial scores are found between grade 9 with all higher levels; first year with graduates, and third and fourth years with graduate students. Generally, geospatial score improves with age and education level.

Geospatial scores	Grade 9 (n=20)	First year (n=24)	Third and fourth years (n=30)
First year	t = -3.351* df = 42 p = 0.002		
Third and fourth years	t = -3.231* df = 48 p = 0.002	t = -.475 df = 52 p = .637	
Graduates (n=30)	t = -7.065* df = 48 p = 0.000	t = -4.279* df = 52 p = 0.000	t = -3.163* df = 58 p = 0.002

*The mean difference is significant at the .05 level.

Table 4.5: Anova post-hoc test to determine within group differences

No significant difference in the scoring between gender was found (t = .504, df = 102, p = .616). However, when gender is considered per question, some differences are observed. Of the 30 geospatial questions examined, two questions proved to be significantly different across gender: Question 24 (t = 2.367, df = 102, p= .020, two tailed) and Question 26 (t = 2.707, df = 102, p= .008, two tailed). In these questions, females performed better than males. For question 24, females averaged .7222 while males scored a mean of .5000. For question 26, females averaged .6296 while males scored a mean of .4100.

If geospatial performance is positively related to increasing age and grade level (Table 4.4 and Table 4.5) and the same is true of geospatial performance with expertise levels (Table 4.1), then it is expected that expertise levels are related to age and grade level. This relationship is explored in the following analyses.

Figure 4.3 shows the age distribution across expertise levels, showing that the variability in age is larger in the experts compared to novices and intermediates. The typical age for novices and intermediates is late teens whereas that of experts is in the mid-twenties. The lowest and largest age for each group increases with expertise level, except for the lowest age for the intermediates. All expertise groups are positively skewed (higher values).

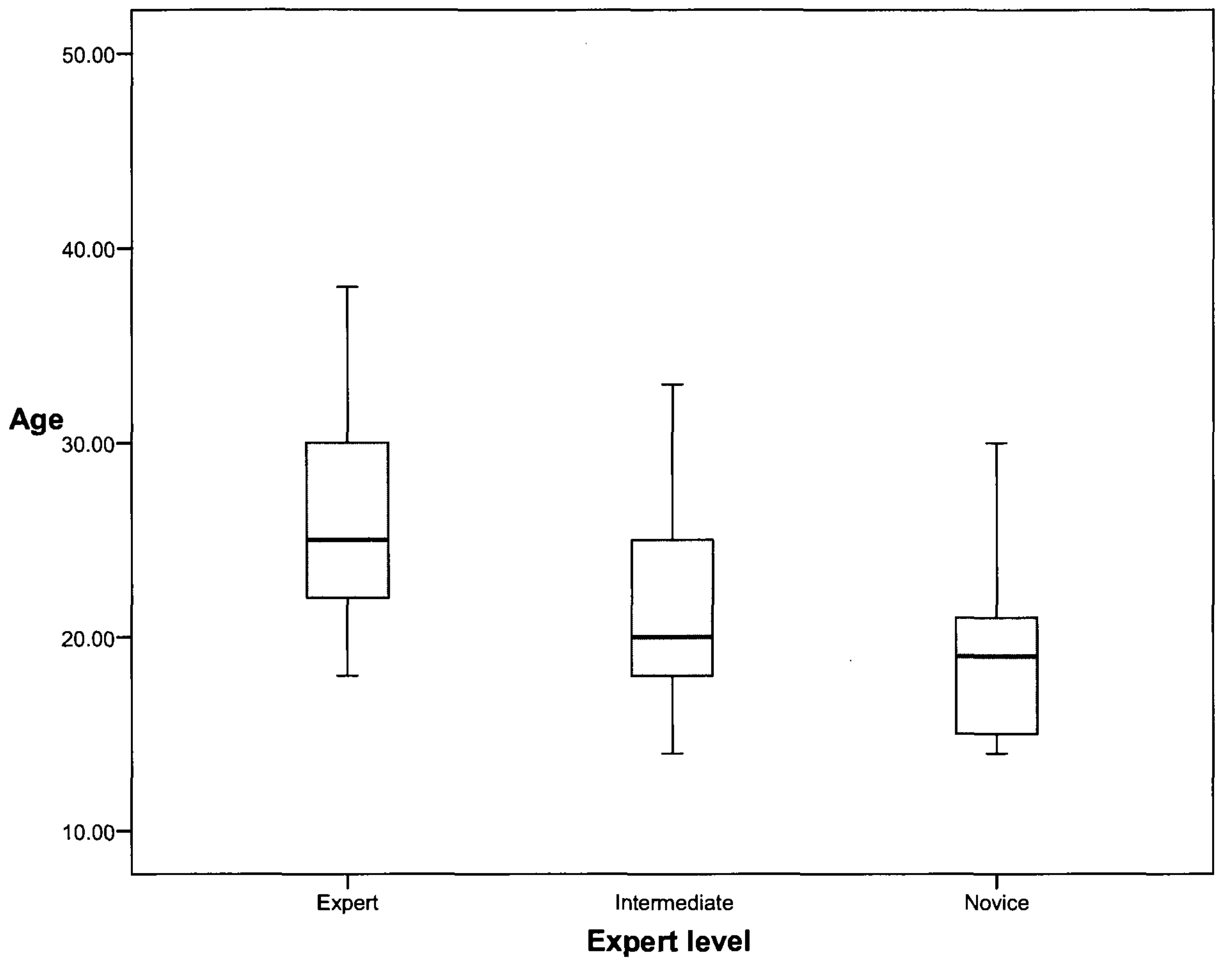


Figure 4.3: Boxplot showing the range of age in each expertise levels

Age, grade level, and gender are not normally distributed; thus the Spearman's correlation is used to explore their associations with expertise level. Table 4.6 shows a moderate correlation between age and expertise levels whereas Table 4.7 shows a moderate correlation between grade level and expertise levels. However, there is no statistically significant correlation between gender and expertise ($r = .061$, $p = .541$).

Correlations

			Age	Expert code
Spearman's rho	Expert code	Correlation Coefficient	1.000	.416(**)
		Sig. (2-tailed)		.000
		N	104	104
	Age	Correlation Coefficient	.416(**)	1.000
		Sig. (2-tailed)	.000	
		N	10	10

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.6: Correlation between age and expertise level

Correlations

			Expert code	Grade level
Spearman's rho	Expert code	Correlation Coefficient	1.000	.398(**)
		Sig. (2-tailed)		.000
		N	10	104
	Grade level	Correlation Coefficient	.398(**)	1.000
		Sig. (2-tailed)	.00	
		N	10	104

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.7: Correlation between grade level and expertise level

Figure 4.4 shows that the variability in grade level is smallest in the experts, a group that primarily includes third and fourth year as well as graduate students. The intermediate group membership comprises first year students and above whereas the novice group is dominated by third and fourth year students and younger. Except for the expert group, novices and intermediates show symmetry in the composition of grade levels.

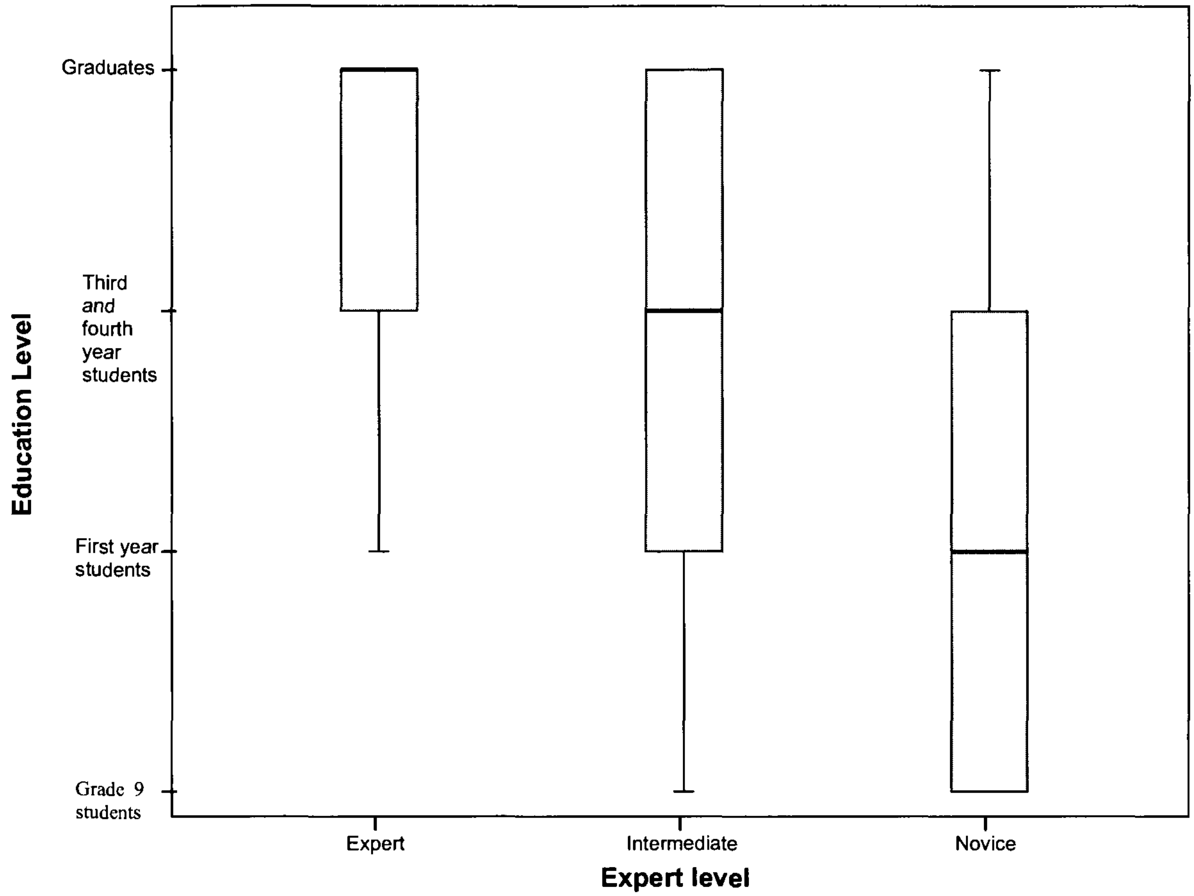


Figure 4.4: Boxplot showing the range of grade levels in each expertise levels

Table 4.8 summarizes the number of students at each education level within an expertise category. The data match closely with performance expectations associated with age and education levels such that the novice group is composed primarily of grade 9 students where the expert groups are dominated by graduate students. The number of students in each group is shown in Table 4.8, with percentages in brackets. The number of geography courses taken ranges from 7.0 at the novice level to approximately 20 at the expert level.

Levels	Grade 9 n (%)	First year n (%)	Third year n (%)	Graduates n (%)	Average age	Gender	Mean geography courses taken
Novice	10 (50%)	2 (8.3%)	7 (23.3%)	2 (6.7%)	19	11 females 10 males	7.0
Intermediate	10 (50%)	19 (79.2%)	17 (56.7%)	16 (53.3%)	21.7	32 female 30 males	10.4
Expert	0 (0%)	3 (12.5%)	6 (20%)	12 (40%)	26.3	12 females 9 males	19.8

Table 4.8: Percentage of expertise levels in each grade level

The number of geography courses taken ranges from one to 44 with four natural breaks in the data (Figure 4.5). The natural breaks are used as categories (category 1: 0-10 courses; category 2: 11-20; category 3: 21-30 and category 4: 31 or more courses). An anova test finds statistically significant difference between the number of geography courses taken and performance on the geospatial scale (F = 7.139, df = 3, sig = 000).

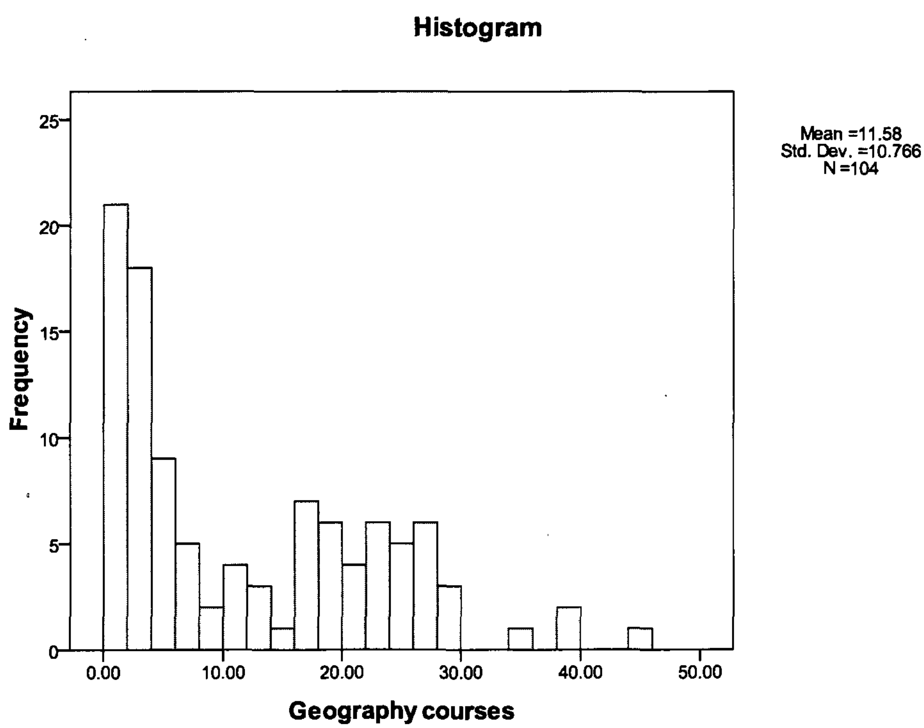


Figure 4.5: Histogram of geography courses taken by sample group

A post-hoc test identified statistically significant difference between the geography course categories with the geospatial scale performance (Table 4.9). Participants who take more geography courses perform better on the geospatial scale. In particular, participants who take 21 or more geography courses, high school and universities level, do better than those who take fewer.

Expertise level varies across age (level of cognitive development) and grade level (extent of formal instruction); thus both are important influences on the level of geospatial thinking. Table 4.4 through to Table 4.9 as well as Figure 4.3 and

Figure 4.4 are empirical evidence that the geospatial scale is an alternative way to group students' geospatial thinking and knowledge that is reflective of their age and grade level.

(I) Geography course grouped	**(J) Geography course grouped**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
Less than 10 courses (Novices)	10 to 20 courses	-2.27510	1.08776	.163
	21 to 30 courses	-3.42727*	1.10505	.013
	More than 30 courses	-8.42727*	2.26853	.002
10 to 20 courses (Intermediates)	Fewer than 10 courses	2.27510	1.08776	.163
	21 to 30 courses	-1.15217	1.30635	.814
	More than 30 courses	-6.15217	2.37311	.053
21 to 30 courses (Experts)	Fewer than 10 courses	3.42727*	1.10505	.013
	10 to 20 courses	1.15217	1.30635	.814
	More than 30 courses	-5.00000	2.38108	.160
more than 30 courses (Experts)	Fewer than 10 courses	8.42727*	2.26853	.002
	10 to 20 courses	6.15217	2.37311	.053
	21 to 30 courses	5.00000	2.38108	.160

* Correlation is significant at the 0.05 level (2-tailed)

Table 4.9: Comparison of grade, expertise, and geography courses taken

4.3 Dimensions of the geospatial scale

Objective 3: A third objective is to identify the principal dimensions or factors of the geospatial scale that differentiate novice-intermediate-expert levels of geospatial thinking.

The analysis here identifies, through factor analysis, the dimensions of the geospatial scale. Prior to the factor analysis, the Kaiser-Meyer-Olkin (KMO) measure and Barlett's test of Sphericity were conducted to ensure the data were of a robust nature for the following statistical procedures.

The KMO measure of sampling adequacy is considered to be acceptable at .600. This value determines whether the dataset is large enough for factor analysis. The KMO calculated for the dataset is .595. Barlett's test of Sphericity, which tests whether the correlation between items is appropriate for factor analysis, as items should correlate well ($r > .20$) but not too well ($r > .80$). Barlett's test is statistically significant at $p = .000$.

The initial factor analysis revealed 11 possible subscales, which explain 65.86% of the total variance. Upon examining the items in the subscales, common themes were not found. So, a series of factor analyses were performed, each one looking at a set of subscales that was one less than the last. A total of 8 reiterations were calculated, which produced 11 to four subscales. Each time, the items for each subscale were examined for common processes or geospatial themes. Subscale consistency was observed; items within a group remained within that group from the 8th or 7th subscale onwards. At these subscale levels common themes began to emerge.

However, it was found that the most convincing and logical common threads emerged with six subscales. Each of the six themes follows the concept of the most highly loaded item in each factor. In turn, each item in the factor was compared against this concept and compared as a group to confirm that all items exhibited this idea (Table 4.10). The six subscales found are:

analysis, comprehension, representation, application, scale, and spatial relationship (Table 4.11 and Table 4.12).

Factor	Highly loaded item	Theme
1	Question 14 Participants select the best campsite that satisfies four criteria	Analysis
2	Question 4 Participants select a term to describe the relationship between distance from the outbreak source and risk of infection	Comprehension
3	Question 20 Participants identify the real-world objects best represented by the symbols presented in a diagram	Representation
4	Question 18 Participants select five spatial terms from a list that best describes a diagram	Application
5	Question 17 Participants select a map that is large-scale	Scale
6	Question 6 Participants identify the order in which mountains are seen from a given location	Spatial representation

Table 4.10: Geospatial subscales

The six identified factors include geospatial concepts as well as processes of thinking. Subscales 1, 2, and 4 relate to thinking processes which are based on Bloom's Taxonomy: analysis, comprehension, and application, respectively. The remaining three subscale, 3, 5, and 6, relate to representation, scale and spatial relationships, respectively. The three spatial thinking subscales found address Newcombe's (1982) query on whether spatial tests are able to effectively differentiate between one or more constructs. The six subscales explain 45.11% of the total variance (Table 4.11) and is evidence that the geospatial scale tests for core geospatial terms as well as processes of thinking (Table 4.12). In fact, the scale seems to measure thinking more successfully than geospatial concepts which inspire a question for further thought – what kinds of questions provide meaningful tests of geospatial concepts?

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.621	15.404	15.404	4.621	15.404	15.404	2.830	9.432	9.432
2	2.047	6.825	22.229	2.047	6.825	22.229	2.480	8.266	17.698
3	1.925	6.417	28.647	1.925	6.417	28.647	2.463	8.211	25.909
4	1.730	5.767	34.414	1.730	5.767	34.414	2.109	7.029	32.938
5	1.682	5.606	40.020	1.682	5.606	40.020	1.864	6.212	39.151
6	1.528	5.092	45.112	1.528	5.092	45.112	1.788	5.962	45.112
7	1.426	4.753	49.865						
8	1.330	4.433	54.298						
9	1.263	4.210	58.508						
10	1.142	3.806	62.314						
11	1.063	3.542	65.856						
12	.976	3.253	69.109						
13	.878	2.928	72.037						
14	.840	2.798	74.836						
15	.805	2.683	77.519						
16	.729	2.429	79.948						
17	.686	2.288	82.236						
18	.659	2.198	84.434						
19	.632	2.108	86.542						
20	.592	1.975	88.517						
21	.545	1.816	90.333						
22	.487	1.622	91.954						
23	.445	1.484	93.438						
24	.411	1.371	94.810						
25	.346	1.153	95.962						
26	.293	.978	96.941						
27	.278	.926	97.867						
28	.237	.792	98.659						
29	.228	.761	99.420						
30	.174	.580	100.000						

Extraction Method: Principal Component Analysis.

Table 4.11: Total variance and Eigenvalues of geospatial scale

Rotated Component Matrix(a)						
	Component					
	1	2	3	4	5	6
Geospatial14	0.78975278					
Geospatial15	0.71967835					
Geospatial30	0.52549763					
Geospatial8	0.40838089					
Geospatial23	0.40752347					
Geospatial1	0.3926297					
Geospatial2	0.33898906					
Geospatial10	0.30332196					
Geospatial4		0.697279029				
Geospatial24		0.663502675				
Geospatial9		0.613402899				
Geospatial28		0.506010839				
Geospatial22		0.465653336				
Geospatial3		0.427028285				
Geospatial13		0.377142774				
Geospatial20			0.724288445			
Geospatial19			0.677643837			
Geospatial21			0.652049803			
Geospatial12			0.443505473			
Geospatial11			0.429570858			
Geospatial18				0.70477499		
Geospatial5				0.60004071		
Geospatial29				0.58287421		
Geospatial25				0.58240425		
Geospatial26				0.41700664		
Geospatial17					0.71192979	
Geospatial16					0.60001397	
Geospatial6						0.724037836
Geospatial27						0.636394932
Geospatial7						0.189844720
	Analysis	**Comprehension**	**Representation**	**Application**	**Scale**	**Spatial relationships**

Table 4.12: Factor analysis – rotated components of geospatial scale

4.4 Relationship between geospatial scale with affection and geographic skills

Objective 4: The fourth objective is to examine the geospatial scale's relationship to subject affection and geographic skills.

The analysis here first explores the descriptive statistics for the affection scales and the geographic skills tasks by expertise groups. This is followed by a regression model that explores the relationships between demographic predictors (age, education level, and gender), affection scale, and geographic skills outcome with geospatial scale performance. The logic here is that an individual's geospatial thinking is also partially influenced, according to both literature and practice, by their level of skill in geographic learning (inquiry, organization, analysis), and by their attitudes towards computers, geography, and mathematics. To take these influences into account several research instruments are developed.

Affection scale

Each affection scale uses a Lickert format from 1 to 5. The total questions are 14 in the computer scale, geography has 21, and mathematics has 15. Table 4.13, Table 4.14, and Table 4.15 summarize results of the affection scales by expertise levels. The only statistical difference between groups is found for mathematics (F = 3.905, df = 2, sig =.023); no statistically significant difference is found in computer affection (F = 1.208, df = 2, sig = .303) nor geographic affection (F = .519, df = 2, sig = .121). In mathematics, experts have a statistically higher score, at a .05 level, than both novice (t = -2.628, df = 40, p = .012) and intermediates (t = -2.642, df = 81, p = .010) with little difference between novices and intermediates (t = .442, df = 81, p = .660).

Expert code/Computer affection	n	Minimum	Maximum	Mean	Std. Deviation
Novice	21	1.3	3.1	2.4	0.5
Intermediate	62	1	3.7	2.3	.6
Expert	21	1.3	3.0	2.1	0.5
Total	104	1.4	3.6	2.1	0.96

Table 4.13: Descriptive data of computer affection by expertise levels

Expert code/Geographic affection	n	Minimum	Maximum	Mean	Std. Deviation
Novice	21	1.6	2.9	2.2	0.4
Intermediate	62	1	4.2	2	0.5
Expert	21	1.1	2.5	1.8	0.4
Total	104	1.5	2.8	2	0.79

Table 4.14: Descriptive data of geographic affection by expertise levels

Expert code/Math affection	n	Minimum	Maximum	Mean	Std. Deviation
Novice	21	1.5	4.3	2.9	0.7
Intermediate	62	1.7	4.2	2.9	0.6
Expert	21	1.8	3.4	2.5	0.4
Total	104	1.7	3.8	2.8	1

Table 4.15: Descriptive data of mathematics affection by expertise levels

Skills

Each geographic skill is graded out of 5. Descriptive data of the three geographic skills by expertise groups are illustrated in Table 4.16, Table 4.17, and Table 4.18. Statistical difference between groups is found in the inquiry (F = 3.542, df = 2, sig = .033) and analysis skills (F = 3.142, df = 2, sig =.000), with no statistical differences in the data collection (F = 1.704, df = 2, sig = .187) component.

Inquiry	n	Minimum	Maximum	Mean	Std. Deviation
Novice	21	1	5	3.2	1.3
Intermediate	62	1	5	3.3	1.3
Expert	21	1	5	4.1	1.3
Total	104	1	5	3.4	1.3

Table 4.16: Descriptive data of inquiry skills by expertise levels

Data collection	n	Minimum	Maximum	Mean	Std. Deviation
Novice	21	1	5	3.5	1.4
Intermediate	62	1	5	3.4	1.5
Expert	21	1	5	4.1	1.3
Total	104	1	5	3.6	1.5

Table 4.17: Descriptive data of data collection skills by expertise levels

Analysis	n	Minimum	Maximum	Mean	Std. Deviation
Novice	21	1	5	2.4	1.0
Intermediate	62	1	5	3.2	1.2
Expert	21	2	5	4.1	0.78
Total	104	1	5	3.2	1.2

Table 4.18: Descriptive data of analysis skills by expertise levels

Inquiry (geographic skill) scores differ across expertise levels. Experts perform significantly better, at the .05 level, than intermediates (t = 2.483, df = 81, p = .015) and novices (t = 2.312, df = 40, p = .026) where there is no difference between novices and intermediates (t = .252, df = 81, p = .802) (Table 4.16).

Analysis (geographic skill) scores differ across expertise levels. Experts perform significantly better, at the .05 level, than intermediates (t = 3.414, df = 81, p = .001) and novices (t = 6.096, df = 40, p = .000), while intermediates perform better than novices (t = 2.632, df = 81, p = .010) (Table 4.18).

Subsequent analysis integrates various traits of the individual to examine their relative effects in determining geospatial thinking. Six variables were selected to build the regression model. Since the number of geography courses is strongly dependent on grade level, from here on the latter variable will substitute the number of courses taken. The variables are explained below.

1. Grade level: this is an ordinal variable that differentiates between the grade levels, separating students from grade 9, first year, third and fourth year, and graduate students.
2. Age: this is a ratio datum that captures the age of each student
3. Gender: this is nominal datum that labels females as 1 and males as 2
4. Computer affection: this is a ratio datum that is the total of each participant's score on the computer affection survey. The lowest possible score is 14 and the highest is 70. The lower the score, the more affection one shows towards computers.

5. Geographic affection: this is a ratio datum that is a total of each participant's score on the geographic affection survey. The lowest possible score is 21 and the highest is 105. The lower the score, the more affection one shows towards geography.
6. Mathematics affection: this is a ratio datum that is a total of each participant's score on the mathematics affection survey. The lowest possible score is 15 and the highest is 75. The lower the score, the more affection one shows towards mathematics.

To determine the best method to enter predictors, three common ways were tested: enter, forward elimination, and backward elimination. The models produced by the 'enter' and 'backward' elimination methods have the same R-squared value (Table 4.19). For simplicity, the model produced by the enter method was selected (Table 4.20).

Selection Method	**R square**
Enter	.355
Forward	.323
Backward	.355

Table 4.19: Data entry methods (geospatial scale)

Model	R	R square	Adjusted R square	Std. Error of the Estimate
1	.596 (a)	0.355	0.315	3.93656

a. Predictors (constant), Math affection, Grade level, Gender, Geographic affection, Computer affection, Age
b. Dependent Variable: Geospatial

Table 4.20: Regression model summary of geospatial scale

The R-squared value is .355 and the independent variables together explain 35.5% of the variance in the geospatial score (Table 4.19 and Table 4.20). The null hypothesis that there is no linear relationship between geospatial scores and the 6 independent variables can be rejected (F-value = 8.891, sig = .000). Of the six predictor variables, only grade level has a significant impact on the geospatial scale performance (t = 2.838, sig = .000). This suggests that geographic knowledge is dependent on formal learning that advances by grade rather than by age (cognitive development) (Table 4.21).

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	18.953	3.602		5.262	.000	11.804	26.102
	Grade level	1.998	.704	.459	2.838	.006	.601	3.395
	Age	.072	.119	.095	.608	.544	-.164	.309
	Gender	-1.273	.849	-.134	-1.500	.137	-2.958	411
	Computer affection	-1.595	.828	-.186	-1.926	.057	-3.238	.049
	Geography affection	-.125	.927	-.013	-.135	.893	-1.964	1.714
	Math affection	-.916	.728	-.114	-1.257	.212	-2.361	.530

a Dependent Variable: Geospatial

Table 4.21: Predictors of Regression model

The residuals reveal that the regression model fits the data. The standardized residual results range from a minimum of -2.446 to a maximum of 2.216. Since the residuals fall within -2.58 and 2.58 where 99% of standardize residuals should be, the distribution of residuals is approximately normal. If a model fits the data well, approximately 5% of the cases have standardized residuals greater than 2 in absolute value (Norusis 2002). In this study, the percentage is 4.8% (5 / 104 students) which translates to a model that fits the data well.

4.5 GIS problem solving task

Objective 5: The fifth objective is to develop a research instrument in the form of a computer-based exercise to measure performance on a GIS.

The analysis here examined the problem-solving process across expertise levels by 1) the time of task completion and 2) GIS performance level across expertise levels.

Time of completion

There is a statistically significant time difference between novice, intermediate, and expert groups (df = 2, F = 5.201, sig = .007). Table 4.22 shows that experts and intermediates take longer to complete the GIS task than the novices. Experts take statistically longer, at .05 level, than novices (t = 3.319, df = 40, p = .002) and intermediates longer than novices (t = 2.529, df = 81, p = .013). However, no difference is found between experts and intermediates (t = 1.275, df = 81, p = .206).

Proficiency Groups	n	Minimum (minutes)	Maximum (minutes)	Mean (minutes)	Std. Deviation (minutes)
Novice	21	8.3	42.6	18.8	8.5
Intermediate	62	6.2	45.5	25.1	10.2
Expert	21	15.3	46.4	28.4	10.1
Total	104	6.2	46.4	24.5	9.6

Table 4.22: Descriptive data of time completion on GIS task

GIS score

GIS performance is summarized in Table 4.23. Post-hoc anova suggests differences between the groups (F = 20.594, df = 2, sig = .000). Experts perform statistically better, at the .05 level, than intermediates (t = 3.381, df = 81, p = .001) and novices (t = 9.373, df = 40, p = .000); while intermediates perform better than novices (t = 3.993, df = 81, p = .000).

Proficiency Groups	n	Minimum	Maximum	Mean	Std. Deviation
Novice	21	6.5	10.5	8.3	1.2
Intermediate	62	6.5	15	10.5	2.4
Expert	21	10	15	12.3	1.6
Total	104	6.5	15	10.4	2.4

Table 4.23: Descriptive data of GIS scores

4.6 Relationship between geospatial scale and GIS problem-solving exercise

Objective 6: The sixth objective is to examine the relationship between the performance on the geospatial scale and performance in GIS problem solving. How do different dimensions of the geospatial scale relate to problem solving? What does a problem-solving sequence tell us about the spatial thinking process?

The analysis here first explores the relationship between geospatial and GIS scores. This is followed by a sequence analysis which examined how the process of problem solving may be related to one's spatial thinking. Finally, the third analysis combines demographic data (gender), affection scales, geospatial factor scores, and geographic skills as predictors to explain one's GIS performance.

GIS problem solving

The geospatial and GIS scores are normally distributed hence the Pearson correlation will be used. Table 4.24 shows a positive correlation which is statistically significant at the 0.01 level (2-tailed value of .603). Figure 4.6 illustrates the correlation between geospatial and GIS scores across all students.

		GIS score	Geospatial
GIS score	Pearson Correlation	1	.603 (**)
	Sig. (2-tailed)		.000
	n	104	104
Geospatial	Pearson Correlation	.603 (**)	1
	Sig. (2-tailed)	.000	
	n	104	104

** Correlation is significant at the 0.01 level (2-tailed).

Table 4.24: Correlation between GIS and geospatial scores

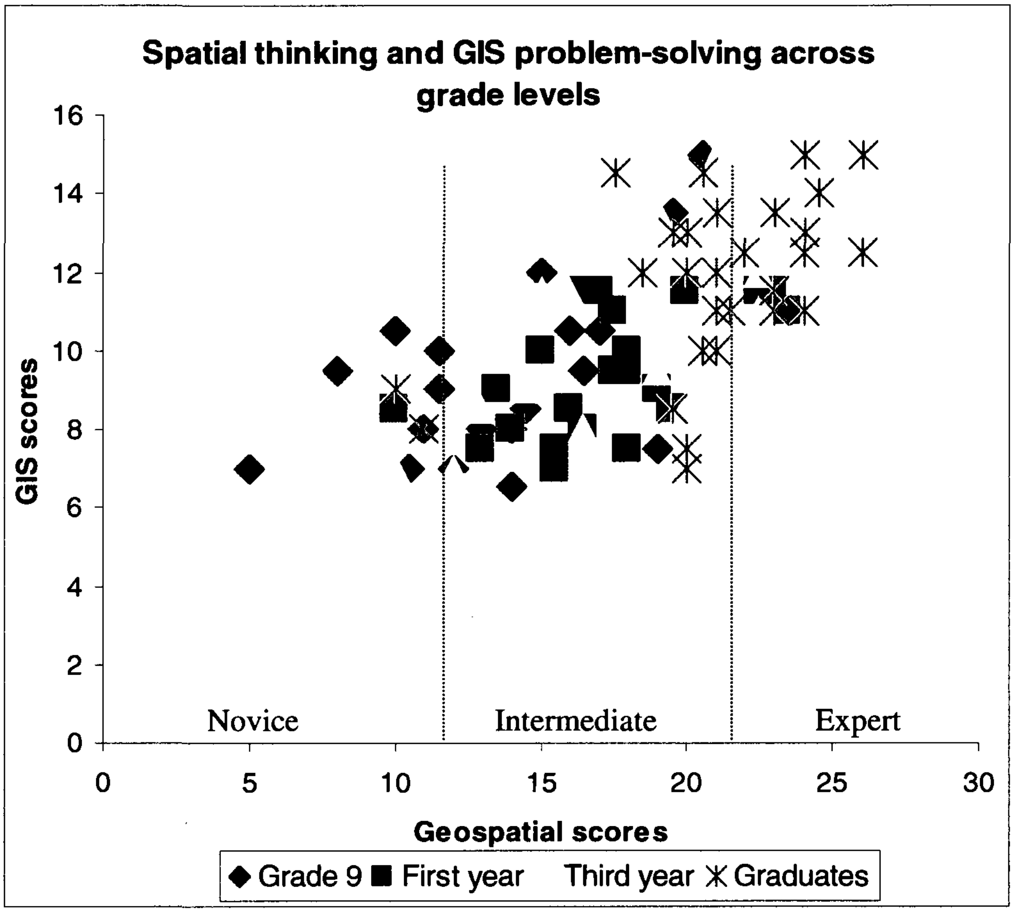


Figure 4.6: Geospatial and GIS scores across expertise levels

The next step of the analysis seeks to understand how the geospatial subscales may influence the way one performs and approaches a GIS problem-solving task. A Pearson's correlation between the GIS score and each of the six subscales was conducted. Four of the six subscales were significantly correlated to the GIS scores which include analysis, comprehension, representation, and application (Table 4.25).

	Analysis	Comprehension	Representation	Application	Scale	Spatial relationships
GIS Score	r = .390* p = .000	r = .511* p = .000	r = .304* p = .002	r = .466* p = .000	r = .131 p = .185	r = .082 p = .409

*correlation is significant at the .01 level (2-tailed)

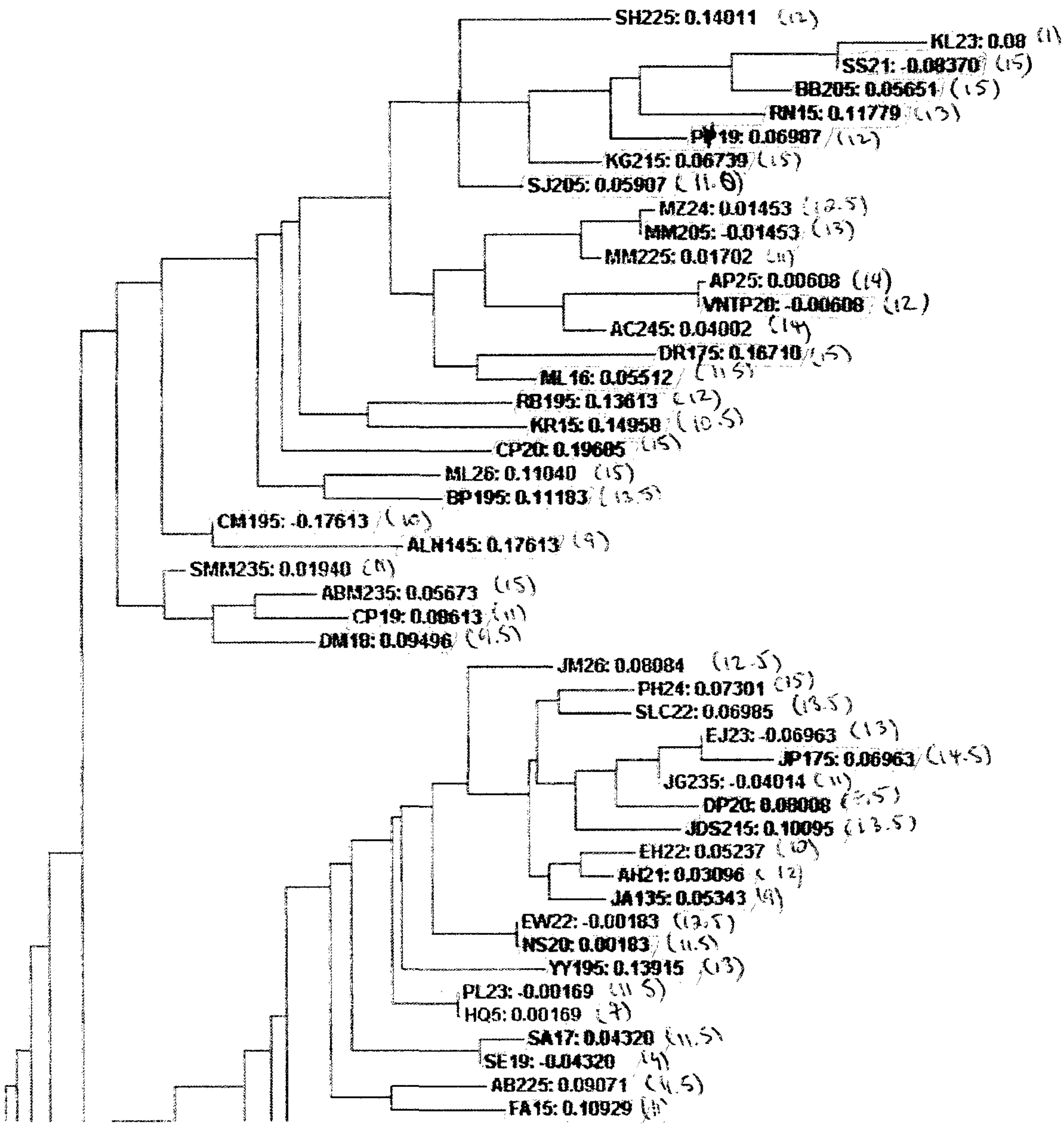
Table 4.25: Correlation between GIS score and geospatial factors

Sequence analysis

The GIS solutions or the clusters of housing selected vary little between expertise groups, in that they generally fall within the same neighbourhood. However, the methods used to reach solutions vary greatly. Hence, a closer analysis of the problem-solving process is undertaken. First, the sequence of action orders is identified for each participant and then entered in CLUSTALW. The resultant phylogram identifies four major groups and two minor groups, for a total of six problem-solving styles.

The phylogram was colour coded; a participant with a geospatial score greater than 22 was highlighted yellow, a score less than 13 was pink, and a score between 13-22 green (Figure 4.7). Based on the colour code, the first and the second group of the phylogram include participants whose spatial score fall in the highest and intermediate range. This suggests that participants with similar spatial thinking evaluation score also solve the problem in a similar manner. In the third group, the number of high geospatial scorers diminishes while the number of low scoring participants increases. This trend continues throughout the fourth to sixth group where low scores abound.

Phylogram



SH225: 0.14011 (12)
KL23: 0.08 (11)
SS21: -0.08370 (15)
BB205: 0.05651 (15)
RN15: 0.11779 (13)
PT19: 0.06987 (12)
KG215: 0.06739 (15)
SJ205: 0.05907 (11.0)
MZ24: 0.01453 (12.5)
MM205: -0.01453 (13)
MM225: 0.01702 (11)
AP25: 0.00608 (14)
VNTP20: -0.00608 (12)
AC245: 0.04002 (14)
DR175: 0.16710 (15)
ML16: 0.05512 (11.5)
RB195: 0.13613 (12)
KR15: 0.14958 (10.5)
CP20: 0.19605 (15)
ML26: 0.11040 (15)
BP195: 0.11183 (13.5)
CM195: -0.17613 (10)
ALN145: 0.17613 (9)
SMM235: 0.01940 (11)
ABM235: 0.05673 (15)
CP19: 0.08613 (11)
DM18: 0.09496 (9.5)
JM26: 0.08084 (12.5)
PH24: 0.07301 (15)
SLC22: 0.06985 (13.5)
EJ23: -0.06963 (13)
JP175: 0.06963 (14.5)
JG235: -0.04014 (11)
DP20: 0.08008 (7.5)
JDS215: 0.10095 (13.5)
EH22: 0.05237 (10)
AH21: 0.03096 (12)
JA135: 0.05343 (9)
EW22: -0.00183 (12.5)
NS20: 0.00183 (11.5)
YY195: 0.13915 (13)
PL23: -0.00169 (11.5)
HQ5: 0.00169 (7)
SA17: 0.04320 (11.5)
SE19: -0.04320 (4)
AB225: 0.09071 (11.5)
FA15: 0.10929 (11)

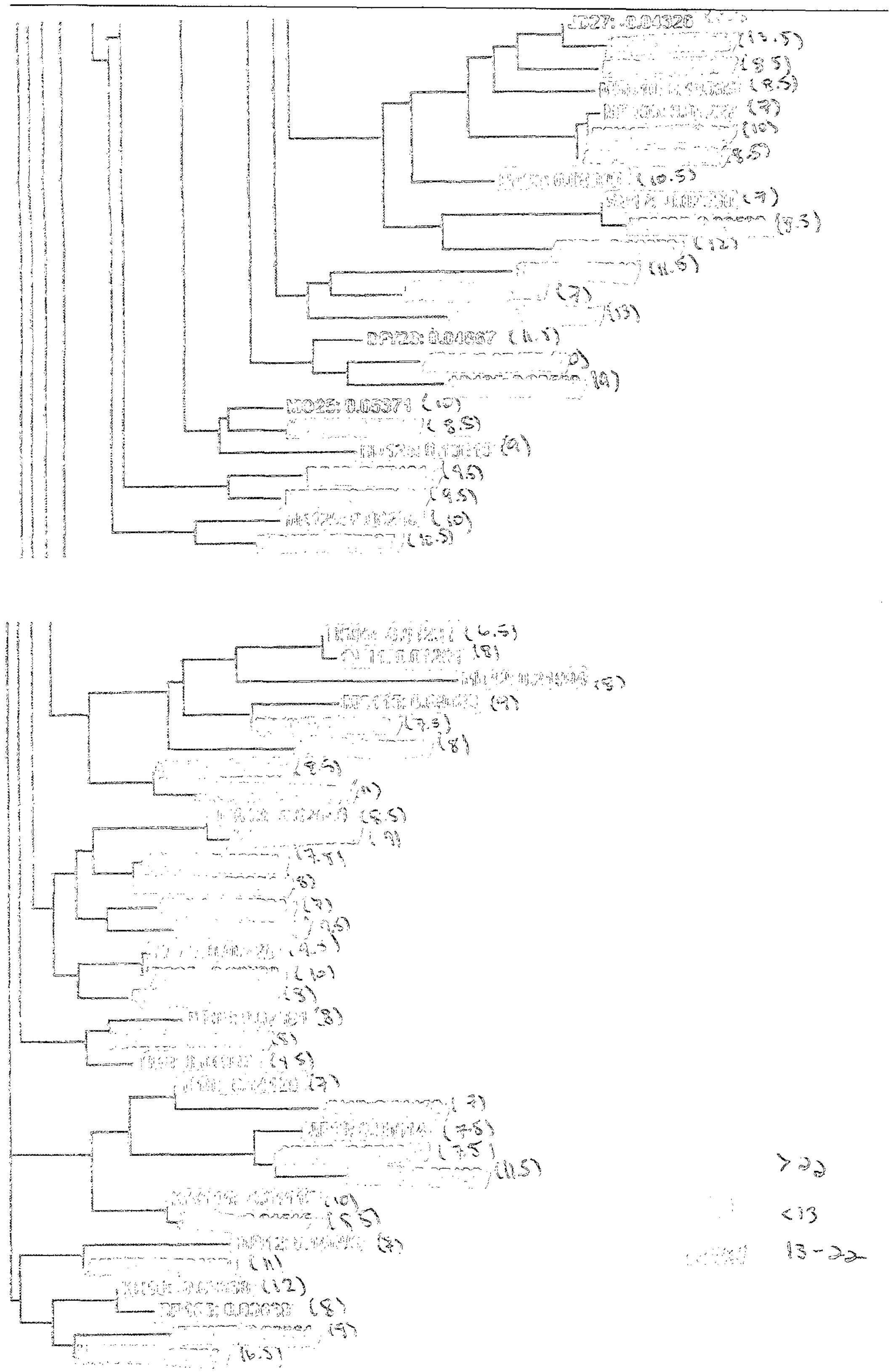


Figure 4.7: Phylogram of GIS problem-solving strategies

The average correlation score for each of the six sequence groups is above 60% which is an acceptable value in social studies (Huynh et al. 2008). Group 1 (n=27) is 64.4%, Group 2 (n=20) is 76.4%, Group 3 (n=24) is 62.7, Group 4 (n=20) is 71.8%, Group 5 (n=7) is 86.7% and Group 6 (n=6) is 88% (Table 4.26). Figure 4.8 compares geospatial scores with the six sequence groups. Participants, who score in the expert range, are found in sequence groups 1 or 2, the equivalent of expert groups in GIS problem solving. This pattern is consistent amongst novice and intermediate students. GIS sequence groups 1 and 2 exhibit structured, logical deduction problem-solving methods (experts), groups 3 and 4 exemplify semi-structured exploration (intermediates), and groups 5 and 6 illustrate visualized trial and error (novices).

	Novice	*Intermediate*	*Expert*
Group 1	0	18 (29%)	9 (42.9%)
Group 2	0	10 (16.1%)	9 (42.9%)
Group 3	6 (28.6%)	15 (24.2%)	3 (14.3%)
Group 4	9 (42.9%)	12 (19.4%)	0
Group 5	3 (14.3%)	4 (6.5%)	0
Group 6	3 (14.3%)	3 (4.8%)	0

Table 4.26: Number of novices, intermediates, and experts in each sequence group

Table 4.27 shows a correlation between the total number of GIS functions (first, second, third or visualization) with the GIS score. In this case the GIS score is a sum of two rubric components, geospatial knowledge and outcome.

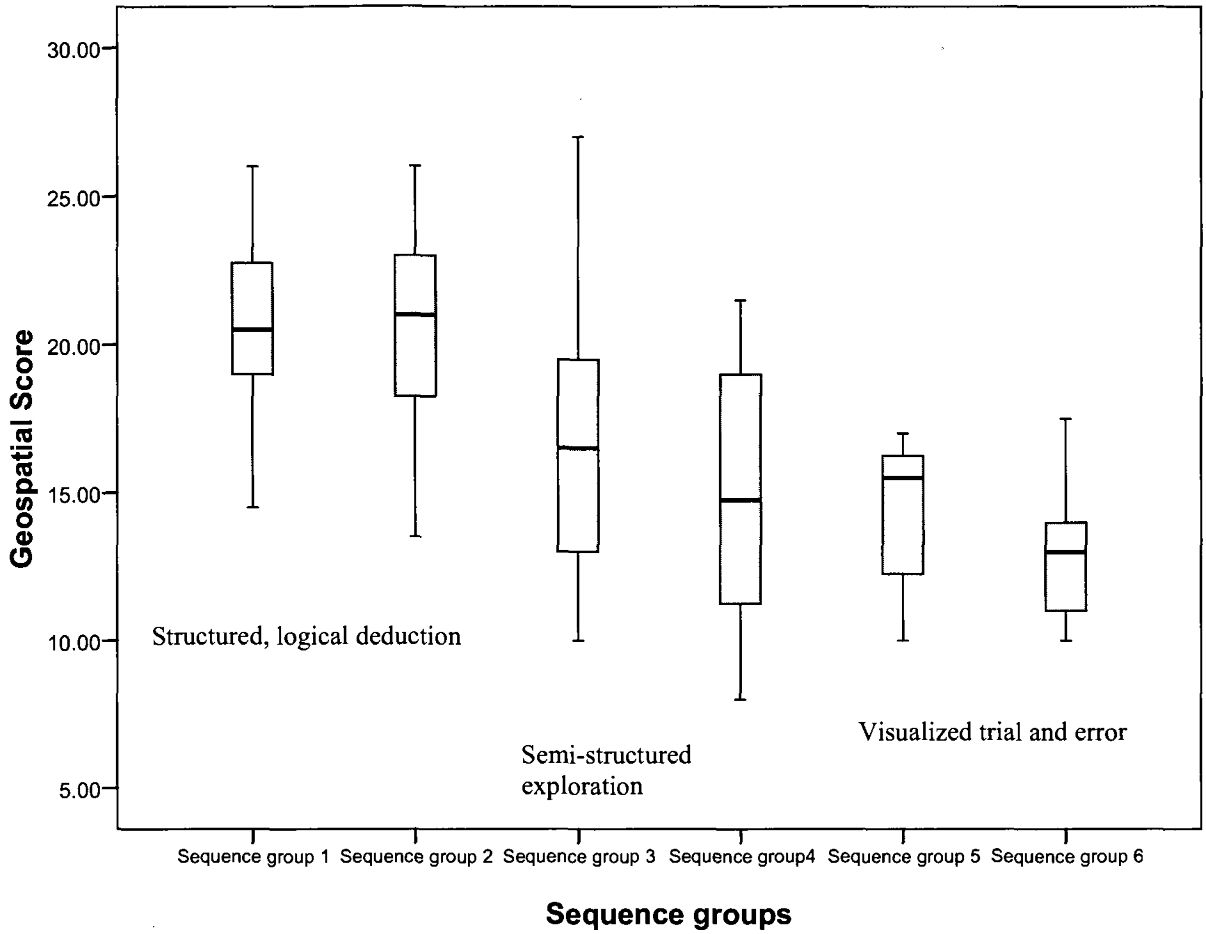


Figure 4.8: Expertise levels grouped by geospatial scores and sequence analysis

An inverse relationship between frequency of first-order and visualization GIS operations with the GIS score exists. Hence, the greater the number of first-order and visual actions used to problem solve, the lower the GIS score. The reverse is true of second and third order actions; the greater the number of these actions, the higher the GIS scores. This supports the notion that simple tools are less effective in GIS problem solving and are used by participants with a developing spatial knowledge and thinking processes.

	Total sequences	First order	Second order	Third order	Visualization
GIS score (minus strategic problem-solving component)	.126	-.224*	.414**	.250*	-.471**

*Correlation is significant at the 0.01 level (2-tailed)
**Correlation is significant at the 0.05 level (2-tailed)

Table 4.27: Comparison of GIS score with GIS tactics

Linear regression modelling is used to better understand how geospatial knowledge, geographic skills, and affections define GIS performance. The dependent value includes GIS scores, while the predictors or independent variables include factor scores calculated from the factor analysis of the geospatial questions. Factor scores, rather than geospatial scores were applied in the model in order to gain an understanding of how each subscale contributes to GIS problem solving. It was found that the most comprehensive model was calculated by the 'backward' elimination method (adjusted regression is .485) where the 'enter' (adjusted method is .466) and 'forward' methods (adjusted regression is .451) trailed behind. Table 4.28 summarizes the R square value obtained from each regression model.

Selection Method	**R square adjusted**
Enter	.466
Forward	.451
Backward	.485

Table 4.28: Data entry methods (GIS problem-solving exercise)

Fifteen predictors are used in the model; four are repeated from the geospatial regression model (gender, computer, geography, and mathematics affection). Only the nine new predictors are explained below.

1. Analysis subscale factor score: Analysis is a subscale of the geospatial score which is a factor score produced in the factor analysis calculation.

2. Comprehension subscale factor score: Comprehension is a subscale of the geospatial score which is a factor score produced in the factor analysis calculation.
3. Representation subscale factor score: Representation is a subscale of the geospatial score which is a factor score produced in the factor analysis calculation.
4. Application subscale factor score: Application is a subscale of the geospatial score which is a factor score produced in the factor analysis calculation.
5. Scale subscale factor score: Scale is a subscale of the geospatial score which is a factor score produced in the factor analysis calculation.
6. Spatial relationship subscale factor score: Spatial relationship is a subscale of the geospatial score which is a factor score produced in the factor analysis calculation.
7. Geographic skills (inquiry): this is a ratio datum that captures the evaluation score for the first geographic skills exercise, asking geographic questions.
8. Geographic skills (data acquisition and organization): this is a ratio datum that captures the evaluation score for the second geographic skills exercise that examines data acquisition and organization.
9. Geographic skills (analysis and answer): this is a ratio datum that captures the evaluation score for the third geographic skills exercise which is to create a flow-chart to analyse and answer the GIS problem-solving task on paper.

The independent variables together explain 52.5% (adjusted R square = 48.5%) of the variance in GIS score (Table 4.29). The null hypothesis that there is no linear relationship between GIS scores and the 13 independent variables can be rejected (F= 13.105, sig. = 000).

The regression model selected uses a stepwise functionality known as 'backward' elimination. This strategy finds the best predictors from a larger pool to increase the explanation power of the model. For this reason, eight of the thirteen factors were selected predictors: factor scores (subscales 1 through 4 only), the geographic skills inquiry, and analysis as well as the math affection (Table 4.30).

Model Summary(h)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.730	.534	.466	1.74637
2	.730	.534	.472	1.73683
3	.730	.533	.477	1.72878
4	.729	.531	.480	1.72295
5	.726(e)	.527	.482	1.72049
6	.724	.525	.485	1.71610
7	.715	.512	.476	1.73040

e Predictors: (Constant), subscale6 factorscore, subscale4 factorscore, subscale3 factorscore, subscale2 factorscore, subscale1 factorscore, Question, Gender, Math affection, Analze
h Dependent Variable: GIS score

Table 4.29: Regression model summary of GIS problem-solving exercise

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients			95% Confidence Interval for B		Correlations			Collinearity Statistics	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound	Zero-order	Partial	Part	Tolerance	VIF
6	(Constant)	9.051	1.107		8.175	.000	6.853	11.249					
	Question	.278	.136	.155	2.051	.043	.009	.547	.359	.206	.145	.875	1.142
	Analze	.564	.174	.285	3.237	.002	.218	.911	.585	.315	.229	.644	1.554
	Math affection	-.508	.300	-.126	-1.695	.093	-1.103	.087	-.223	-.171	-.120	.901	1.110
	subscale1 factorscore	.384	.178	.161	2.155	.034	.030	.738	.256	.216	.152	.899	1.112
	subscale2 factorscore	.549	.187	.230	2.945	.004	.179	.920	.379	.289	.208	.822	1.217
	subscale3 factorscore	.382	.176	.160	2.173	.032	.033	.730	.224	.218	.154	.927	1.079
	subscale4 factorscore	.597	.189	.250	3.160	.002	.222	.973	.383	.308	.224	.800	1.250
	subscale6 factorscore	.274	.170	.115	1.614	.110	-.063	.610	.123	.163	.114	.994	1.006

a. Dependent Variable: GIS score

Table 4.30: Predictors of GIS problem-solving exercise

The standardized residual results range from a minimum of -2.187 to a maximum of 2.294. Since the residuals fall within -2.58 and 2.58 where 99% of standardize residuals should be, the distribution of residuals is approximately normal. If a model fits the data well, approximately 5% of the cases have standardized residuals greater than 2 in absolute value (Norusis 2002). In this study, the percentage is 6.7% (7 / 104 students). Thus, the model fits the data well. An analysis of the case wise diagnostic residuals and a plot of the residual errors show normal distribution, demonstrating that no systematic errors were found.

4.7 Profile of GIS problem solvers across expertise

Objective 7: The seventh objective is to examine and discuss the differences between expert, intermediate, and novice levels of thinking. First, a profile of each expertise level is described followed by a discussion of the misconceptions, GIS use, problem solving, and errors across each expertise level.

A summary of the expertise characteristics are presented in Table 4.31, highlighting differences in geospatial knowledge and thinking, geographic skills, and affection. Some of the qualitative observations are similar to those summarized by Salthouse (1991).

Characteristics	***Novice***	***Intermediate***	***Expert***
Age	14 to 22	18 to 24	22 and above
Education level	Grade 9/first year students	Third and fourth year students	Third and fourth year students, graduate students
Average number of geography courses taken	7.0	10.4	19.8
Gender	Equally distributed across gender		
Geospatial score (total of 30)	13 and under	13.01 to 21.99	22 and greater
Geographic skills score	Inquiry and analysis show statistical significance between the groups. Experts perform better on these geographic skills than intermediates and novices.		
Affection (computer, geography, and mathematics)	Mathematics is the only affection to show statistical significance between the groups. Experts have a more positive affection toward mathematics than other expertise groups. The logical thinking required in mathematics may be applied to the systematic problem solving method.		
GIS problem-solving score (total of 15)	8.3	10.5	12.3
GIS problem-solving strategy	Visual, trial and error	Combination of visual strategies and strategic deduction	Structured and logical deduction
Qualitative observations	Not knowing: 1. What to do 2. When to or which GIS functions to apply 3. Relevancy of information and reason for this	1. Unable to predict or know what to expect from GIS actions 2. Difficulty interpreting outcomes of GIS functions	1.Proficient and efficient application of GIS functions 2. Understanding of the interrelations among GIS functions and spatial relationships
Time to complete GIS problem	18.8	25.1	28.4

Table 4.31: Profile summary of expertise groups

Quantitative measures are but one way to identify expertise levels; observations can add to this differentiation. Observations of each expertise levels have subtle but different qualities and characteristics that were analyzed using the grounded theory method. In this section, four themes emerge from observing students problem solve. These include 1) misconceptions or points of confusion during the exercise, 2) GIS use, 3) problem-solving strategies, and 4) errors made.

Novice participants

Novices were puzzled about overlaying layers. For example, one student asked "how do I know where to put the layers?" and another student was confused by the location, asking "is this where the grocery store and Social Work are in real life?" Although novices understand primitive map elements, formal instruction is required and repeated at higher grades.

Besides visualization, language posed a challenge. For example, the problem-solving language was confusing, e.g., distance away from grocery store on bike trail. Some participants thought they were to measure the distance from a bike trail to a grocery store.

Within a short while students became fluent with the tool, developing confidence to change symbology characteristics (e.g., colour, size) or reordering the layers in the table of contents. Novices were more apt to add non-necessary layers and less likely to differentiate between layers added. In addition, participants who have prior experience with GIS have more advantage in the basic visualization techniques (e.g., how to customize layer properties, how to change the order of layers in the table of contents) and knowledge of simple functions (e.g., zoom).

Novices used different methods to solve the problem, concentrating on visual tactics and simple tools (e.g., measurement or zoom tools). Some common tactics used are:

-turn layers on and off to see location of amenities

-use certain layers as anchor points, e.g., grocery store

-select location then measure to confirm

-use known distance as anchors to estimate for other distances

-visually select houses on-screen that appear correct

A common error was misreading the information (3 instances) such as measuring an incorrect distance. Another student confused the layers applied in the spatial query function.

Intermediate participants

Like the novices, a small number of intermediates were unsure how create a map from data layers. A solution to reduce misconceptions is to encourage questions from participants. Seemingly, participants who were unfamiliar with GIS but asked questions did better than counterparts who asked no questions but rather assumed information. In addition, participants' thinking process is revealed in their questions. For example, a participant made links between location, travel patterns, and road use when she inquired about the traffic flow along roads.

Many intermediate participants were competent with GIS such as familiarity with basic GIS tools (e.g., symbol changes, and layer reordering) learned from a cartography class (GG251). A range of GIS operations were used, varying from simple tools, to buffer, to spatial query. Normally, intermediates applied GIS tools learned from previous GIS exposure and reused tools they were most familiar with.

Unlike novices, intermediates were diverse in their problem-solving styles and were more likely to try new tools to experiment with (primarily third and fourth year students). One strategy applied was to choose multiple housing clusters then assess whether the mandatory/optional criteria were satisfied around these neighbourhoods. This method produced results in a non-systematic way and randomly selected amongst 7000 and more housing locations. Yet another strategy was to work forward with the given data, applying GIS operations and decisions together to reach a solution. Finally, participants with prior experience over complicated the problem by using too many advanced GIS tools and did not know how to interpret the results.

The range of error was greater in this group, possibly due to a higher variety of problem-solving strategies used. One misconception was related to logic, five students selected incorrectly the order of layers in the spatial query function. The second logical error was an omission of certain factors due to incorrect judgement, e.g., exclusion of a grocery store due to its distance from the Social work buffer. The third error was a creation of incorrect buffers. The final logical error was that participants did not fully understanding overlay, resulting in unexpected results when two layers were merged.

Expert participants

Experts exhibited few misconceptions because they were more likely to ask for clarification. A common misconception was found in the spatial query tool; experts understood its function but some had difficulty differentiating between the spatial relationship options.

The majority of students in this group have taken a GIS course (e.g., GG391) thus they are quite fluent with the tool, e.g., operations and changed order of table of contents. Occasionally, participants recalled a GIS operation but did not remember how to execute it, e.g., switch selections in a table. Nevertheless, prior GIS experience helped participants combine past knowledge with new options to form a solution (e.g., spatial query to find houses within 1000m away from downtown then, switch selection to find houses that are greater than 1000m away). In a few exceptions, participants were generally plagued by the issue of linking what one knows and want (spatial knowledge/logical application) with knowing how to get there (technical).

A large proportion of experts applied related knowledge about a topic, in addition to the given information to make decisions. They were less likely to trivialize the problem because they understood there was a large amount to consider while novice users underestimated the problem and quickly used visualization to solve it, missing out on the intricate relationships between elements in layers.

Experts solved in a **specific** manner such that they were systematic and narrowed their housing options by examining each criterion whereas novice solved in a **general** manner such that they initially located houses that may not be known to satisfy any criterion, only to find such supporting evidence later. Experts personalized the exercise by integrating their own house searching experience and their familiarity of Kitchener into the problem-solving tactics. Another characteristic is that they were more likely than the novice to display only the necessary layers such that they were selective in what pieces of information they were showing on screen.

The types of error seen in experts were mainly assumptions. Although rare (one instance), a participant created a buffer of an incorrect distance. Another error is less an error than a trial and error of functions. Although the participant knew what result was desired, the subject experimented with different functions due to a lack of familiarity with the GIS operations. Finally, the most cited error (4 instances) is the exclusion of a grocery store due to an incorrect assumption.

4.8 Chapter summary

This chapter presented and described results of the analyzed data. Four major findings are highlighted. First, the mathematics affection is the only one that is statistically different between expertise groups. The second finding is that the geospatial scale is an effective instrument to differentiate between geospatial knowledge levels, separating participants into novice, intermediate or expert groups. A closer examination of the geospatial scale revealed six factors including analysis, comprehension, representation, application, scale, and spatial relationships.

The third result concerns GIS problem-solving strategies. Three different approaches are identified from the transcriptions, structured, logical deduction; semi-structured exploration; and visualized trial and error. The fourth analysis explores the relationship between the above problem-solving methods and expertise. Although outliers exist, the general trend showed that novices are more dependent on the visualized trial and error method than any other groups. Experts exemplify logical deduction while the intermediates alternate between these strategies. Chapter Five will discuss these findings in relation to past research and theories of geographic education, GIS education, as well as cognitive development.

CHAPTER 5: DISCUSSION

Chapter Five discusses interesting and unexpected findings from participant performance. First considered are surprising results arising from the geospatial scale. This is followed by a discussion on how affection and geographic skills may influence the geospatial scale outcome. The third section review findings from the GIS problem-solving task, specifically the sequence of problem solving, as a criterion for grouping participants along the geospatial expertise continuum. The concluding section provides a holistic exploration of additional factors that may provide deeper understanding of how the geospatial scale and the GIS problem-solving experience work in tandem.

5.1 Geospatial scale: A method to identify the novice-intermediate-expert continuum

The geospatial scale is explored on several fronts, by initially examining gender differences in the geospatial sale. Next, performance on the geospatial scale is explained by expertise level. Finally, participant misconceptions are documented.

5.1.1 Geospatial performance by gender

It was anticipated that spatial abilities and reasoning increase with age, grade level, and amount of geographic education. This was supported by the data, however, no gender difference in the geospatial scores was found. The literature is split on this topic; there is support for gender differences in spatial abilities (Signorella and Jamison 1978; McGee 1979; Self et al. 1992; Self and Golledge 1994; Voyer et al. 1995; Kaufman 2008) although gender difference accounts for only five percent of the variance in sampled spatial tests (Hyde 1981). Other studies argue that such differences are disappearing over time (Feingold 1988) while statistically significant gender differences are found in some but not all spatial abilities tests (Linn and Petersen 1985; Beatty and Tröster 1987). Self and Golledge (1994) explained that males perform better on geometric rotation tasks while females surpass on some spatial relational tests. Perhaps the focus of the geospatial scale on spatial relations explains a lack of gender differences which are traditionally found in visualization and orientation tasks.

5.1.2 The relationship between expertise with performance on geospatial scale

A comparison of geospatial test scores between expertise levels shows statistically significant differences on 24 questions (Table 4.2). Differences are explained by observations, student rough notes, and post-test interview responses. Three areas will be discussed, mathematics, geographic knowledge, and spatial development. Finally, five geospatial questions that do not follow the expertise trend are explored.

Mathematics plays a role in geospatial thinking as a number of questions require either explicit or implicit mathematic skills (e.g., calculation of distance, area, and scale conversion). Novices tend to have poor mathematics skills. For example, they have difficulty converting a unit from kilometres to metres and do not fully understand the use of a numeric scale in a map context. For this reason, the scale and size of objects may not be correctly understood leading to confusion of spatial relations.

Experts exhibit two observable traits. The first trait is the high level of confidence in their calculations. The second is their ability to estimate and use simple mathematical principles, even if the exact equation is forgotten. In general, experts are not only knowledgeable in the core topics of geography but are equally able to apply different disciplines to resolve a spatially based question, such as mathematics.

The second difference is in geographic knowledge. Experts may not have all the relevant facts and conventions memorized; however, they understand the basic principles that make up a geospatial knowledge structure from which they can work out a solution given sufficient information. Similarly, the literature supports this notion where experts possess a body of knowledge that is both domain specific, extensive, and easily integrated with relevant knowledge presented in the problem (Carter et al. 1988; Ericsson and Smith 1991; Patel and Groen 1991). Even if novices and experts are presented with the same amount of knowledge, the meaning and information that each generate may make it useful for experts but mean little to the novice (deGroot 1978). In the case of identifying a map as 'large' or 'small' scale, participants who simply memorized the definition in class but failed to develop a knowledge structure around the concept were not successful in answering the question. Experts seem to possess a large knowledge structure rather than fragments of memorized information. Meaning is created through the depth, extent, and complexity of interconnected domain knowledge (Leinhardt and Greeno 1986; Glaser and Chi 1988; Anderson and Leinhardt 2002; Hmelo-Silver et al. 2002; Livingstone and Lynch 2002).When a part of the structure is forgotten, the remaining parts can help one recover (van Hiele 1986). To this end, a participant with more knowledge can draw out obvious and embedded relationships to form a full picture of the question.

How does one develop a knowledge base? Observations suggest that at least the foundational ideas of geography should be explicitly taught because an appropriate comprehension of fundamentals support understanding of advanced concepts (van Hiele 1986; Nakhleh 1992). Until the lower order element is understood higher order concepts will not be fully developed (Case 1980). For example, a participant who has not learned of the concept 'buffer' is not able to correctly answer a question that directly relates to it. Instead, participants will either use informal knowledge of the concept, unique personal experiences, or put into the context of another domain. For example, a participant defined his understanding of 'buffer' as "physically becoming larger because of gym work outs" while another thought of 'buffer' as "shining one's car." Similar support for misconception is found in the science literature (e.g., chemistry, physics) where scientific terms and laws are interpreted with everyday meanings (e.g., heat and temperature or gravity) (Fredette and Clement 1981; Nakhleh 1992).

From a teaching perspective, students need a structure to understand geographic knowledge, without which subject matter can very easily be forgotten and tasks incomplete (van Hiele 1986). Extending this idea, geographic knowledge is not simple or innate; if that were the case the differentiation of novice and expert would not exist. Rather, it is likely that experts develop and accumulate geographic knowledge through a combination of formal and informal avenues. This suggests that geographic learning should be part of an explicit and strategic education (Golledge 2002) to ensure a complete rather than fragmented knowledge base.

In addition to education, memory plays a role in knowledge accumulation. Research shows that experts possess both greater memory quantity and superior memory quality than novices (Chase and Simon 1973; Chi et al. 1981; Ericsson and Polson 1988; Glaser and Chi 1988; Staszewski 1988; Hmelo-Silver et al. 2002) thus increasing their references to prior knowledge (Hmelo-Silver et al. 2002). The integration of knowledge may be a factor to experts' structured thinking strategies. They work through a question by utilizing existing 'knowledge structure', which is a framework of related information or facts. For example, a number of participants had difficulty with the latitude and longitude questions. However, they worked out the correct answers from their general understanding of how the Earth is divided into grids and the maximum/minimum degrees possible around a circle.

The third area discussed is spatial development. Piaget and Inhelder (1971) described spatial development as a sequence of cognitive changes starting from sensorimotor to the formal operational stage such that an immature level of spatial development impedes participants from reaching a correct solution if spatial abilities from a higher level are required. For example, questions 11 and 14 of the geospatial test require participants to first visualize the spatial associations and interactions to determine a solution. Experts are able to solve these problems because they have developed higher-order geographic concepts such as overlay. In corollary, unlike experts, novice participants have not acquired all the prerequisite concepts and subtle discriminations underlying complex principles to fully reach the solution.

Spatial development progresses with age such that the average age is distinctly different across expertise levels, increasing from 19 years old for novices to 21.7 for intermediates and 26.3 for experts. This differentiation follows closely to other research where spatial development increases with age through successive developmental sequences (Eliot 1970; Laurendau and Pinard 1970; Hart and Moore 1973).

Piaget and Inhelder (1971) hypothesized that children as young as 9 years old reach the highest level of spatial thinking (formal operational period); however a number of anomalies question this assertion. For example, two graduate students (undergraduate degrees outside of geography), ranked in the range of novice, with geospatial scores of 10 and 11. Although they are currently studying geography, their undergraduate degree was in another discipline. It appears that the omission of an undergraduate degree or formal geography courses translate to a lack of foundational geospatial background needed to excel on the geospatial scale. These cases, similar to the literature results, reflect older participants' immature understanding of projective and Euclidian concepts. On the opposite extreme, one grade 9 student scored very close to the expert range at 20.5. She thoroughly enjoys geography and excels in her study skills and performance in geography classes, as reported by her geography teacher. An emerging question is whether there is an appropriate age at which geography needs to be explicitly instructed. A follow-up question is whether the ability to understand spatial association increases or decreases after this age.

Generally, experts performed better than intermediates and novices while intermediates did better than novices on the geospatial scale. Five geospatial questions (5, 7, 17, 23, and 27) were an exception to this pattern (Figure 4.2). Novices did better than intermediates on Question 5 (determine slope from contours) likely because they recently learned about contours in class. In the remaining questions, intermediates performed as well as experts. The question themes include map scale, representation, spatial correlation, and spatial terms. Map reading is a skill present in young children but formal instruction is required to teach primitive (representation) and first-order (map scale) concepts (Table 2.1). It is likely that intermediates and experts have developed through repeated use of maps in formal education, a deep understanding of these two themes, thus perform equally well. Next, spatial correlation is a fourth-order geographic concept (Table 2.1). Perhaps intermediates and experts have developed an understanding of higher-order spatial relations through formal education and cognitive maturation. Finally, spatial terms are learned formally in school and informally from daily experiences. Perhaps intermediates and experts have more exposure and application of spatial terms at the post-secondary level.

Exceptions to the spatial development trend suggest that factors in addition to age or cognitive maturation attribute to learned concepts. Another factor may relate to the length of time participants require to move through each learning stage until it is completely understood (Bruner 1963; van Hiele 1986). This study finds that spatial development is an on-going process and is not fully reached even at the graduate level.

5.1.3 Misconceptions of the geospatial scale across expertise levels

Student misconceptions, also known as alternative frameworks, are incomplete understandings of a concept. Five categories of misconception summarize observations: a lack of knowledge, incomplete comprehension, incomplete application, incomplete analysis, and overall misconceptions of concept (Table 4.3). While novices, intermediates, and experts exhibit errors that fall into all five categories, some are more associated with certain expertise levels. Examples are used to describe each type of misconception. This section ends with general conclusions about misconceptions.

A *lack of knowledge* represents two scenarios. Either participants have not yet learned the concept or they have forgotten what they have learned. A number of strategies were used in this scenario such as drawing on personal experience, on memory, and making an educated guess. Question 28 on latitude and longitude challenged students' knowledge of how the Earth is divided into coordinates. In this example, students who simply memorized the format had difficulty working out the solution.

Students who experience *incomplete comprehension* have difficulty understanding what the question is asking. This may be related to one's stage of spatial development, extent of geographic knowledge or factors not yet identified here. Question 2 requires a buffer to be drawn around a given radius of a disease outbreak. The range in answers suggests that some students understand the question but basic characteristic of a buffer is only partially recognized (e.g., illustration of a square rather than a circle).

Incomplete application may occur when there is too much demand on the memory or there are too many pieces of information to consider. In Q11, two diagrams are shown; one illustrates the regions of beetle infestation while the second shows areas dominated by pine trees. The solution requires a mental overlay of these two layers, taking into consideration scale and given landmarks. The partially correct solutions suggest that participants did not take into consideration all the factors.

In an *incomplete analysis*, participants make assumptions which impede an analysis that considers all factors. Question 5 is a complex question because it integrates visualization, understanding of contour lines, spatial relationships, and direction. Errors are found where students make assumptions or fail to consider one or more of these factors.

General misconception is seen across all levels. This is exemplified by a question on spatial terms. Novices, intermediates, and experts all selected incorrect terms based on misconceived meanings, such as the vernacular rather than the specific geographical meaning of the term.

Two insights are garnered from post-interviews. The first is that participants understand and use spatial relations explicitly by grade 9. However, one barrier to development seems to be exposure to formal education, theories or concepts of geography. Regardless of age, informal learning cannot substitute a systematic presentation of knowledge. Second, knowledge of discipline-specific vocabulary is important for communication. Participants can generally describe what they are thinking but do not yet possess a domain-specific lexicon to communication complex ideas. For example, vocabulary is a limitation for novice students as they are not always able to articulate geographic concepts, found in similar research (Bednarz and Bednarz 2008). For example, a student said "houses between *these* areas" where one could say (more correctly) houses where housing buffers *intersect.*" A lack of geography lexicon and ideas may lead to partial explanations of problem-solving approach. Like other disciplines, geography has a language and vocabulary specific to the spatial nature of the discipline (Marsh et al. 2007). Experts convey easily ideas and explanations grounded in geospatial terms, matching with Marsh et al. (2007)'s work that show people's ability to identify and generate spatial relationship terms increased with grade level. For example, a novice explained overlay in simple and colloquial phrases of "I put this on top of that and look for the areas where they meet." However, an expert would likely say "I will overlay the work buffer with the grocery store buffers. Where they intersect is an area of interest".

In summary, this first discussion attempted to understand the lack of gender difference in the geospatial scale. Next, performance on the geospatial scale can be improved by enhancing mathematics skills, depth of geographic knowledge, and spatial development. Finally, the knowledge gap, between what participants know and may learn later may contribute to misconceptions. These are found across all participants, although more common in novices than experts. The following section extends the discussion to explore how affection scales, and geographic skills contribute to expertise performance.

5.2 Mathematics affection: Contributing factor to geospatial expertise

The previous section discussed surprising results from the geospatial scale as well as misconceptions across expertise levels. The expertise continuum is furthered explored in this section with mathematics affection; the relationship examined is between geospatial expertise test scores and participants' affection towards mathematics.

5.2.1 Relationship between geospatial expertise and mathematics affection scale

Of the three affection scales, the only statistically significant difference between expertise groups is in mathematics where experts express more affection than both intermediates and novices. The experts are positive in their attitude; as well they appreciate and have greater confidence in mathematics. The affection scores suggest that experts who view this subject in a positive light also do well in the geospatial task, which has six questions that require some level of mathematical application (4 questions require direct mathematics and 2 require indirect application). Mathematics generally requires logical, step-by-step solutions; perhaps students who enjoy mathematics applied a similar logical approach to successfully solve the geospatial questions.

Experts' greater positive attitude in mathematics suggests that affection plays a role in learning (Nakhleh 1992; Songer et al. 2006; Immordino-Yang and Damasio 2007). Immordino-Yang and Damasio (2007) recognize emotions and cognition as the two prongs of human function. While cognitive development furthers problem solving of geospatial questions, emotions affect attention focus, information recall, and learning the associations between events and outcomes (Immordino-Yang and Damasio 2007). Specific to this study, observations suggest that affection encourages curiosity and inquiry, gaining additional information to solve the question.

5.3 GIS problem solving: Differences along the expertise continuum

The previous section discussed mathematics affection amongst expertise groups. Building on these findings, this section examines GIS problem solving across expertise groups. The first part focuses on GIS problem-solving strategies, followed by the sequence of GIS operations applied. In both discussions, the role of domain-specific knowledge (geographic concepts) and problem-solving skills (GIS tools) (Downs 1994a) are examined.

5.3.1 Relationship between geospatial expertise and effectiveness of GIS problem solving

Marked differences exist between novices, intermediates, and experts on the GIS problem-solving task. Differences are discussed in two sections, first in the strategic approach and second in the time of completion.

Problem-solving strategies

Novice, intermediate, and expert participants reached similar solutions in their selection of best housing locations. However, the thinking and problem-solving process varied widely, consistent with other studies (Hmelo-Silver et al. 2002). The strategies varied from application of personal experiences (e.g., mental map of downtown), primitive means (e.g., distance measurement, visualization) through to using multiple spatial relationships (e.g., overlaid buffers, intersection, and spatial query). Table 5.1 is adapted from a mathematics scoring rubric developed by Graham and Naglieri (2003). A summary of GIS problem-solving characteristics at each expertise level are presented; the left most column separates participants into expertise levels which is described further in terms of three criteria: geospatial knowledge, problem-solving strategies, and detail level of explanation.

Experts share numerous qualities such as application of a systematic and logical approach (Eells et al. 2005), use of appropriate GIS operations, and envisioning potential outcomes pre-execution of GIS operations. For example, experts and intermediates both displayed data that were necessary and changed the table of contents to gain maximum visualization. Similar qualities found in other research corroborate that experts use schema-based pattern recognition to differentiate between relevant and irrelevant information (Elstein 1994; Kirschner et al. 2006). In this study, experts demonstrated a logical sequence of non-redundant GIS operations, based on the ability to anticipate multiple spatial interactions at different scales. From this insight, they developed a systematic plan to reach a solution, cognizant of the purpose behind each decision, and able to predict outcomes resulting from the operations executed. Experts demonstrated meaningful learning, defined by Mayer and Moreno (2003) as a deep understanding of material through recognition and organization of pertinent pieces of information. Learning occurred when the structured information is integrated with existing knowledge. This is in contrast to novice and to a lesser extent intermediates, who have difficulty separating out irrelevant information (Patel and Groen 1991). In essence, experts were able to monitor, evaluate, and reflect on the problem-solving situation (Glaser and Chi 1988; Hmelo-Silver et al. 2002; Eells et al. 2005; King et al. 2008).

Summary of similarities across GIS problem-solving strategies			
Geospatial scores	**Geospatial Knowledge**	**Strategic Problem-Solving Knowledge (GIS operations)**	**Outcome and Explanation**
Scores < 13 Novice	**Address to a less extent the characteristic and importance of spatial location** and association between features	Frequent use of **simple tools** and visualization; trial and error of functions	**Incorrect assumptions** of spatial relationships and information about layers were made
Scores 13 > 22 Intermediate	A mixture of skills	**Combination** of simple tools and advanced tools	Mixture of explanation; quick to reach a solution
Scores > 22 Expert	**Understand the spatial** relationship between layers; identify simple and higher-level spatial relationships between layers	Frequent use of **advanced and intermediate** tools; diverse use of GIS functions	**Anticipate the outcome** before they are produced; take time to examine multiple perspectives or solutions

Table 5.1: Summary of GIS problem-solving strategies

Experts were more likely to use deduction and analysis but may have used strategic visualization and informal deduction to paint a general picture to frame the problem. In situations where experts were less familiar with the GIS tool, they applied geospatial knowledge with reference to the GIS handbook to approach the problem systematically. In the process, they gained insight into additional rules or methods to further understand the problem. Another similarity is that experts examined the potential solutions from multiple perspectives, a characteristic found in experts of other activities (Carter et al. 1988). A common perspective incorporated peripheral information, such as personal knowledge of the Kitchener area, specific reference points, or personal experiences (visits to local restaurants).

Experts are flexible in their problem-solving strategies (Chi et al. 1981; Ericsson and Polson 1988; Johnson 1988; King et al. 2008) and go beyond a purely structural understanding of the immediate question (Hmelo-Silver et al. 2007). An example of flexibility is that experts may have a working method, but if this does not work, they search for other options. This is in contrast to novices who continue along a decided solution despite erroneous outcomes. At the intermediate level, some students insist on using certain GIS operations (e.g., spatial query, intersection) which takes them in circles.

Experts' motivation is not necessarily to reach the correct answer as they rarely confirm their solution with the researcher. Instead, as Anderson and Leinhardt (2002) describe, experts work out the most plausible answer constrained by theory, knowledge, and known rules. The process of problem solving associated with experts is known as 'working forwards strategy' (Owen and Sweller 1985; Sweller 1988; Heyworth 1999) where the solver begins by understanding the problem statement followed by performing operations until a solution is reached. For example, experts apply appropriate data and GIS operations to narrow the housing options until a small number of locations are revealed. The final selection is refined by examining optional criteria or personal experiences. The competing strategy associated with novices is known in the literature as 'means-ends analysis strategy' (Sweller 1988; Ayres 1993). Novices first take the given information and work backwards until the goal is reached (Sweller 1988; Heyworth 1999). For example, novices often select two locations based on visual inspection and then make measurements to ensure that these locations satisfy the criteria.

Novices commonly explore the data through visual and informal deduction in the trial-and-error process (Audet and Abegg 1996; Hmelo-Silver et al. 2002). However, visualization strategies only create weak or incorrect representations of the problem (Anderson and Leinhardt

2002). Where some novices apply the means-ends analysis, others use a working-forwards strategy, although only a simplified version. Novices perform less well because they are unfamiliar with rules pertinent to the problem or develop incorrect rules (Anderson and Leinhardt 2002). However, they also tend to use a larger number of tactics to reach a solution (e.g., visualization, various primary tools), mixing together secondary and/or attempts with tertiary tactics. This behaviour is also reported by Anderson and Leinhardt (2002) who found that novices use all resources they have access to. Perhaps, without a strategy or logical solution, they are aimlessly searching for a solution, using any means available.

Novices apply a second method known as 'localized thinking'. In the context of writing, localized thinking is where novice writers use the previous sentence as the cue for the next one (Smith 2008). Similarly, in a GIS context, novices usually decide the following GIS operation or tactic based on the outcome of the previous. This method differs from experts who have a strategy and are able to envision and predict the outcome of their actions.

A third type of strategy is exhibited by a subgroup of novice participants. They used 'visual intuition' to identify potential locations, finding a solution that 'simply appears correct' to the eye. This rigid approach may be due to cognitive overload which occurs when the amount of information is in excess of a participant's cognitive processing capabilities (Fayol et al. 1994; Mayer and Moreno 2003). Four factors affect cognitive overload of which two directly apply to this study, these include too much information supplied and demanded (Kirsh 2000). Novices who are confronted with too much information may choose to lessen the cognitive load by using the most direct problem-solving method. van Hiele (1986) argued that visual intuition may be just as reliable as discursive thinking, the process of reaching a conclusion by logic and reasoned thinking. Visual intuition is a structure, just one that is different from discursive thinking (van Hiele 1986).

Table 5.2 provides a general overview of problem-solving strategies applied by participants. Each approach is described by the key strategy used, the associated GIS operations applied, and its level in Bloom's taxonomy. For example, a simple strategy used by many participants is identified as 'Visualization', where primary visual inspection is applied to gain knowledge.

Problem-solving Strategies*	**Strategy**	**Associated GIS actions**	**Bloom's taxonomy**
Visualization*	Random selection through trial and error	Visual inspection	Knowledge
Informal deduction* (intuition)	Colour code symbols Label potential areas	Primary order tools: Organize layers, measure tool, zoom in/out, change size/colour of attributes	Comprehension
Deduction*	Smallest to largest distance	Secondary order functions: Buffer, intersect, erase	Application
Analysis*	Mathematical inquiry (e.g., spatial query)	Tertiary order functions: Spatial query, create information	Analysis
Location selection	Integrative thinking	Visual inspection of resultant housing options	Synthesis
Evaluation	Integrative thinking	Integration of periphery information to make judgments to select first and second location choices	Evaluation

*Adapted from van Hiele model of geometric thought (1986)

Table 5.2: Typology of problem-solving strategies

Time of completion

Experts took longer to complete the GIS task than intermediate and novice problem solvers. Where novice reached a solution in 18.8 minutes, intermediates in 25.1 minutes, experts took 28.4 minutes. There is a statistically significant difference in the completion time between experts with novices and intermediates with novices.

Time is a factor discussed in the novice-expert literature as a differentiating characteristic (Chase and Simon 1973; Glaser and Chi 1988; Ericsson and Smith 1991) such that experts require less time to complete a task correctly, compared to novices. Observations suggest that novices and experts approach the GIS task in different ways and these methods influence time of completion. In this study, experts were more likely to take the time to read through the question sheet, ask questions, and seek forms of feedback to clarify uncertainties leading to a deeper level of representation, observations consistent with those found by Glaser and Chi (1988). In addition, experts spend proportionally more time developing a framework and representation of a problem before searching for a solution (Chi et al. 1982; Glaser and Chi 1988; Lesgold et al. 1988).

This is in contrast to novices who are quick to search for a solution and ask few clarification questions. Similar findings are found in physics research and writing where novices tend to underestimate and oversimplify the complexity in solution methods (Chi et al. 1981; Kozma 1991; Eells et al. 2005; Smith 2008). This approach usually results in a single solution method whereas experts use a variety of methods to gain perspective and narrow down solutions, which in this study takes more time to implement. Some explanations are offered for this behaviour. First, the GIS task may be beyond novices' zone of proximal development (ZPD) (Vygotsky 1978). The ZPD is the gap between a student's current ability and the potential knowledge gained from guided instruction. Although all students possess a level of knowledge and ability, that of novices is insufficiently developed. Another explanation is that novices who are inexperienced with a computer, such as a GIS software, are anxious and have phobia (Lou et al. 2001). These negative affections may lead to defence mechanisms where students either exaggerate or underestimate the difficulty level of a task leading to simple resolution methods.

5.3.2 Relationship between geospatial expertise and the sequence of actions in GIS problem solving

The sequence of GIS actions is defined as the order of each step (GIS operation or visualization) taken to reach a solution. The sequence for each participant was generated from the transcript and input into ClustalW for sequence analysis. Six groups of problem-solving styles were found; participants in each group are more similar in their GIS approach and expertise level than with participants of other groups.

Group 1: participants are able to solve the problem in few steps, the majority use spatial query as a primary tool. Other tools used are buffer, intersection or clip. The problem-solving approach is strategic; the application of GIS function is consistent and lack redundancy. Participants can usually predict the possible outcomes of the GIS operation selected. In most cases, optional criteria are also considered. Participants apply newly learned GIS tools/operations to a complex and new situation, gaining 'insight' in the process. Participants in this group use forward strategy. Group 1 is labelled as 'Structured, logical deduction'.

Group 2: participants problem solve with a mixture of spatial query, secondary tools, mixed with some primary operations. An awareness of both optional and core criteria is present, in many cases the optional criteria are considered. The answers are accurate and carefully narrowed down. Participants' have a developed strategy and selection of GIS functions is sequential and logical. Participants in this group use forward strategy. Group 2 is labelled as 'Structured, logical deduction'.

Group 3: Participants focus heavily on secondary level tools such as buffer, erase, clip, and intersection. These participants have a strategy which leads to a sequential execution of GIS functions but sometimes repetition occurs. For example, both buffer/intersection and spatial query are used to satisfy the same criteria. These participants are in transition between trying the forward strategy and moving away from the means-ends analysis. Group 3 is labelled as 'Semi-structured exploration'.

Group 4: Participants begin to use secondary level tools such as buffer and intersection to narrow the data, although primary tools are also used. Answers are selected from a smaller pool of options and satisfy most or all of the mandatory criteria and in some cases optional criteria are considered. These participants are reliant on the means-ends analysis. Group 4 is labelled as 'Semi-structured exploration'.

Group 5: Participants limit their tactics to visualization and primary tools. Some trial with secondary level tools is seen although participants exhibit little understanding of the GIS operations. There is little evidence of a thought out plan within a repetitive and non-sequential set of actions. The answers are often chosen from a large selection then compared against the criteria to narrow the options. Participants in this group are more apt to use localized thinking method. Group 5 is labelled as 'Visualized trial and error'.

Group 6: The general approach taken concentrates on a few primitive tools. The answers satisfy the distance criteria between housing with work and grocery stores but few others are fully considered. The common approach is based on intuition rather than discursive thinking. Participants in this group are more apt to use localized thinking method. Group 6 is labelled as 'Visualized trial and error'.

Observations from this study agree with those found by Wigglesworth (2003) and Audet (1993). These studies found that novices use trial and error as well as visual strategies to negotiate a GIS problem. Intermediates apply transitional strategies such as buffering where experts have a logical approach whether through spatial query or logical expressions with spatial query (Audet 1993).

Each expertise level may have multiple tiers. For example, the tactics used by groups 1 and 2 are consistent with expert performance, whereas groups 3 and 4 are representative of intermediates and groups 5 and 6 show novice traits. These findings suggest that even within a single level of expertise, participants approach the solution in different sequential ways.

The mixed research methods applied in this study offer new ways to examine and interpret the thinking processes used in problem solving and more specifically in a GIS environment. Recordings of participant behaviours and thinking processes demonstrate that there are distinct differences between how an expert approaches a problem based activity compared to novices. Experts take longer than novices to complete the task, but in the time frame, they clarify misconceptions, gain a better understanding of the question, and reason in a logical fashion. Experts are able to predict the outcome of a GIS operation and are flexible in their solution search. Although visualization methods are applied, experts have a larger range of techniques and approaches than do novices.

A second analytical method, sequence analysis, was used to examine the order and nature of steps taken to reach a solution. The results show six problem-solving methods ranging from trial-and-error to deduction. The following discussion presents a holistic view of factors that influence performance on the geospatial scale and the GIS problem-solving exercise.

5.4 A holistic view of geospatial scale, GIS problem solving, and associated factors

Problem solving with a GIS is a layered and intricate exercise, involving at least three components: geospatial knowledge, problem-solving skills, and GIS knowledge. This study aims to understand how these factors contribute to GIS performance in a two part discussion. The first part explores the factors that influence geospatial scale performance. This is followed by a discussion of GIS predictors as well as different problem-solving strategies.

5.4.1 Predictor of geospatial scale: Grade level

In the regression model, only grade level was statistically significant. The significance of grade level (formal education), rather than age, as a predictor of geospatial score was a surprising result. Since cognitive development progresses with age, its prominence was anticipated. Nevertheless, grade level supports the notion that formal education (nurture rather than nature) is pivotal to spatial thinking. This finding suggests that the amount of geography exposure (length of time in school and number of geography courses taken) and complexity of geography materials learned (taking different geography courses) are foundational and may even increase geospatial thinking skills overtime. Similar conclusions are found; some studies argue that education and training develop spatial skills in young children (Huttenlocher et al. 1998) and adults (Baenninger and Newcombe 1989; Baenninger 1995).

5.4.2 Predictors of GIS performance: Geographic skills and geospatial subscales

A second regression model was used to understand how personal factors, geospatial knowledge, and geographic skills predict GIS problem solving. Six factors were significant in the model including geographic skills (inquiry, analysis), and the geospatial subscales analysis, comprehension, representation, and application.

Geographic skills

Novices and experts differ in their inquiry and analysis skills. In the inquiry exercise, experts asked more geographic and complex questions than did novices, possibly due to their interest in the subject and experience with research projects. The second observable difference was the analysis or creation of a flow chart. Experts' GIS analysis on paper was systematic and logical; in many cases, experts' hand-drawn flow charts were so accurate and logical that it was used as a guide to reach the solution. Conversely, novices' flow charts contained general ideas and vague logical steps, similar to 'flat' descriptions and lacked information depth found by other researchers (Carter et al. 1988).

Geospatial subscales

Four subscales influence GIS problem solving; these are analysis, comprehension, representation, and application. The emergence of thinking processes and a geospatial concept suggest that spatial thinking is an activity that draws on multiple thinking dimensions. Participants rely on the comprehension subscale to understand what they are asked to solve before they can develop a plan to proceed. The next step is application, which is to apply geographic knowledge to a situation. Analysis is the ability to integrate knowledge to problem solve. Finally, as the layers of information are visually displayed, an understanding of representation is important.

Observed GIS problem-solving factors

GIS learning can be compared to riding a bicycle because to do it well, one needs multiple and complementary components that are coordinated (van Hiele 1986). If a participant possesses one or an incomplete combination of the components, partial solutions will result. Participants are quick to develop a mastery of the GIS tool, as supported in similar research (Marsh et al. 2007; Bednarz and Bednarz 2008) but are slow to incorporate relevant geospatial concepts and spatial reasoning. When GIS is introduced to participants without sufficient spatial knowledge, they are more apt to use 'buttonology' or point-and-click procedures to reach an outcome. This research adds to the discussion that geospatial concepts and cognitive development influence effective

GIS application. Table 5.3 aims to predict the potential problem-solving approach if a participant possessed one competent ability compared to a combination of the three broad abilities namely geospatial thinking, problem-solving skills, and GIS knowledge.

The left column of Table 5.3 identifies the ability as a single contributing factor as well as in a combination with others. The right column describes how the problem-solving approach may look like when a single or a group of abilities is utilized. Situations which have been directly observed are indicated with a lone asterisk where those that are deduced from overall observed patterns are indicated with two asterisks.

Abilities	**Problem-solving outcomes in a GIS environment**
Single ability exhibited	
Problem-solving skills	**Ability to produce logical flow-chart
Geography and spatial thinking	**Ability to visualize geographic datasets
GIS knowledge	**Ability to use GIS functions
Combined abilities exhibited	
Problem solving and geospatial thinking	*Use of visualization or primitive tools to solve problem (intuition)
Problem solving and GIS knowledge	*Inability to predict outcome of GIS operations or understand interrelated geographical/spatial significance; difficulty selecting correct GIS operation to answer question
Geospatial thinking and GIS knowledge	*Use trial and error methods as unable to identify the problem and appropriate sequence to solution
Problem solving, geospatial thinking, and GIS knowledg	*A sequential and coherent method that uses the least number of GIS functions and knowledge of geographical relations to reach solution (discursive and consistent)

Table 5.3: Skills required for effective GIS problem solving

An integrative model is developed to capture the interrelationships between three aspects of effective GIS problem solving: geospatial knowledge, problem-solving skills, and knowledge of GIS (Table 5.4). Within every component, each level (1 to 5) is described, providing clear expectations as well as knowledge and skills required to advance. GIS, a tool, is only one component of effective spatial analysis. For participants to benefit from this technology, they need to understand the geospatial concepts that form the base of GIS operations, and that are inherent to spatial analysis. Combined with developed problem-solving strategies, GIS can become an effective support system for teaching, learning, and analyzing spatial problems (Marsh et al. 2007).

Geospatial thinking	GIS manipulation	GIS problem solving
Level 5 – Spatial evaluation: To reflect on the geospatial knowledge applied for problem solving	Level 5 – Spatial evaluation: To reflect on the GIS operations selected for problem solving	Level 5 – Spatial evaluation: To reach a conclusion from critical thinking criteria
Level 4 – geographic perception: Knowledge of interrelations of phenomenon *(Comparative)*	Level 4 – geographic perception: Ability to interpret results from GIS tools *(Comparative)*	Level 4 – geographic perception: Double check results with criteria *(Comparative)*
Level 3 – sequence: Principles of geographic knowledge phenomenon *(generalization of rules)*	Level 3 – sequence: Selective in the sequence and number of GIS tools performed and ability to predict results *(generalization of rules)*	Level 3 – sequence: Narrow and select most direct and least steps approach to problem solve *(generalization of rules)*
Level 2 – associations and scale: Communication using geographic language *(rules)*	Level 2 – associations and scale: Knowledge of GIS tools functions and application *(rules)*	Level 2 – associations and scale: Identify relevant dataset *(rules)*
Level 1 – relevance and significance: Knowledge of background geographic language; representation of symbols and terminology *(Perceptions of patterns)*	Level 1 – relevance and significance: Knowledge of foundational GIS tools structure and arrangement *(Perceptions of patterns)*	Level 1 – relevance and significance: Identify problem to be solved *(perception of patterns)*

Table 5.4: Levels of GIS problem-solving skills

The overall level structure is borrowed from van Hiele (1986) who identified each level of a structure as a 'thinking level' and intermediate levels between as 'periods'. The organization within each level is adapted from Denos and Case (2006), from the elementary to higher level: relevance and significance, associations, order, geographic perception, and evaluation. Each level is tailored to the specific ability. For example, at the foundational level of GIS manipulation, an understanding of representation, in particular how real world objects are simplified and symbolized in a digital manner is important. Hence, cartography is a fundamental knowledge base. Moving one level beyond cartographic skills, scale becomes significant. Since GIS supports different areas and allows one to zoom in and zoom out, the relevance of scale is important to understand both the large and small scale implications of findings. The content and details of the thinking levels are derived from observations of participant problem-solving behaviour. As a whole, the importance of this system is to anticipate, to model thinking processes, and to help participants move to a higher level of thinking.

Each level is distinguished by a distinct learning outcome. At each level, foundational similarities are observed across all abilities and indicated in brackets. Beginning with Level 1, students begin to form a *perception of patterns* and how the basic elements of each ability interconnects and develop a larger pattern network in the higher levels. Taking GIS problem solving as an example, a student may perceive a pattern as a collection of primary and secondary criteria to fulfill. At Level 2, repeated patterns develop into *rules*. A simple problem-solving rule may be to first resolve the most important criteria before considering the less significant. One level higher is where participants advance to develop general rules.

The formation of general rules frees participants from memorizing multiple, detailed, and intricate rules. Rather, general rules provide a framework to approach the problem. The fourth level is where participants compare emerging findings in order to move on to Level five where an evaluation is made on the solution that best answers the question.

Mindset and profile of expertise levels

The expertise literature offers little discussion on two areas, first on how one's mindset influences expertise and second, the profile of an expert working in a GIS problem-solving environment. First, two mindsets are defined: fixed and growth (Dweck 2006). Dweck (2006) defined a growth mindset as one that thrives on improvement, inquiry, and potential to change. A fixed mindset relies on innate talent rather on improvement, it fears failure, and is static. Experts generally have a growth mindset while novices possess a fixed mindset. Students with a growth mindset enjoy the challenge of problem solving, with or without prior GIS experience. These students possess strong inquiry skills, little fear of failure, persistence to reach a solution, and enjoy the process. Students with a fixed mindset are less likely to try new GIS operations, quickly reach conclusions, and seem occupied with searching for the correct solution. Although similar to affection, mindset is more broad and complex than how one feels about a subject, which would make for interesting research.

Second, the purpose of the profile aims first to highlight the multiple aspects of expertise as they relate to GIS problem solving. Second, the profile provides a guideline to create expertise level appropriate material. Table 5.5 is a profile that summarizes novice and expert characteristics.

Novice	Expert
Affection	***Affection***
Neutral or lack of enjoyment toward GIS exercise/subject	Enjoy learning of GIS exercise/subject
	See GIS exercise/subject as applicable to personal life
Knowledge	***Knowledge***
Limited theoretical and experiential knowledge	Abundant theoretical and experiential knowledge
Decisions based on intuition more than knowledge	Work out answer by applying domain-specific knowledge
Use only information provided to solve question	Link information from data with peripheral knowledge or personal experience
Assumptions are made about information	Regular referral to GIS booklet
	Ask questions to understand and clarify
Skills	***Skills***
1. Geography	***1. Geography***
Difficult to visualize data on paper	Detail in flow chart creation
General flow chart created	Strategy consistent with the steps in flow chart
2. General skills	***2. General skills***
Communication about process is vague and lack detail	Strong communication skills to describe the thinking process and decision making
Use only a limited number of tools, particularly those that are familiar	Flexible and open minded about problem-solving options, weighing best methods to apply
A limited approach is taken, using primarily one method to reach a solution, either GIS operations, visualization or intuition but less likely all in balanced proportions.	Balanced approach to the solution, using geospatial knowledge, GIS operations, personal experience, and logical thinking to reach a solution
Mindset	***Mindset***
Quick read through of questions resulting in missed o misinterpreted information	Careful reading of questions
Lack confidence in solution and little review of answer	Confidence in problem-solving approach; constant or regular reflection of decisions
GIS use	***GIS use***
Assumptions are made	Inquisitive and open to ask questions
Select a solution (intuition/visual solution) then search for proof to support answer	Explore available tools
	Work from given information to reach solution. Use information to narrow solutions that satisfy mandatory criteria. Final solutions are narrowed to satisfy optional criteria

Table 5.5: Profile of expert and novice GIS users

5.5 Chapter summary

This chapter discussed the results within the context of an expertise framework, divided into two broad parts. The first discussion is around the geospatial scale. Surprisingly, there is no gender difference in the geospatial scale performance although the approach is affected by mathematics affection, geographic knowledge, and spatial development. Grade level is statistically significant as a predictor of geospatial performance. The second discussion is dominated by findings related to the GIS exercise. The GIS performance is confounded by geographic skills (inquiry and analysis) and four dimensions of the geospatial scale (analysis, comprehension, representation, and application). This is evidence that a problem-solving task requires multiple abilities, at a minimum domain specific skills and related knowledge. Experts show greater fluency in their skills and geospatial knowledge than novices. Surprisingly experts take longer to complete the task than do novices, a finding that departs from the consensus of the expertise literature. Furthermore, six different strategies are identifiable from the problem-solving sequence. Groups 1 and 2 are labelled as 'Structured, logical deduction', Groups 3 and 4 are known as 'Semi-structured exploration', and Groups 5 and 6 are 'Visualized trial and error'.

A thorough conclusion follows in the next section. First, an overview of the study is provided followed by a consideration of challenges and limitations throughout the study. Finally, future research directions are suggested in hopes of addressing gaps that surfaced and questions unanswered in this study.

CHAPTER 6: CONCLUSION

6.1 Research summary

For two millennia, geography was valued and recognized as one of the pre-eminent spatial disciplines, along with astronomy (Dobson 1993). The underlying force, space, made it possible to makes connections of phenomena over the Earth's surface. This study attempts to isolate an understanding of space in the mind through thinking processes.

A geospatial scale was developed to measure spatial thinking and to examine whether in combination with other factors (affection, geographic skills), how it influences the way a problem-based GIS exercise is solved. An overall assumption questioned here is that GIS teaches geographic knowledge. The findings from this study are novel in that no empirical data of this robustness and nature are found in the geographic education literature. In addition, the dataset supports past theories founded on ad-hoc studies, and draws out nuanced understandings of widely accepted learning and teaching patterns about GIS. This concluding chapter highlights the main contributions of the dissertation, followed by a discussion of methodological limitations, and ends with some research questions related to this study.

The discussion begins with major findings, starting with participant affection towards computers, geography, and mathematics. The extent that one feels positive or negative feelings towards a subject plays a role in the level of interest and persistence spent on problem solving.

The second finding is that the geospatial scale is a useful tool to measure spatial thinking and spatial principles used in geography. However, the scale is complicated by the influence of nature and nurture. While spatial thinking abilities develop with age (nature) formal geographic education also plays a role (nurture). It is found that an expertise framework can be used to represent the collective influence of age, grade, and formal geographic education. The expertise framework shows that spatial thinking abilities increase with age, although anomalies exist. For example, a grade nine student performs close to the expert level while some first year students are novices.

The third finding is that geographic skills, similar to spatial thinking, progress with age. Taken together, affection, spatial thinking, and geographic skills give rise to different GIS approaches. The fourth finding relates to the analysis of problem-solving sequences. Three major strategies are used to problem solve with a GIS, namely structured-logical deduction, semi-structured exploration, and visualized trial and error. Experts are more likely to apply a structured-logical deductive approach where novices rely on visualized trial and error.

The geographic and GIS education literature embraces GIS as a tool that teaches geography. However, the transmission of geographic knowledge from GIS use is over simplified. The findings suggest that effective problem solving with GIS is a complex process that depends on affection, spatial thinking, and geographic skills. The four major findings are a result of the methodological approach built on past research designs from geographic education and psychology. The methods are described below as they may be potential contributors to the short and long term research agenda.

Four methodological developments are identified in this study. The first is the creation of a geospatial scale that surpasses acceptable internal consistency. The geospatial scale serves to differentiate between novice, intermediate, and expert spatial thinkers; a working concept that agrees well with the statistical results and qualitative observations throughout. By applying the expertise levels to a classroom setting, an educational model that favours differentiated learning can be developed. Students are introduced to spatial activities that complement their individual level of background knowledge. These students can be paired or grouped with other students working at a similar level within a constructive learning environment.

The second methodology is the development of tasks that measure geographic skills identified in the geographic education literature. Three questions explicitly test for geographic skills; the process was completed on paper, although a field-based exercise would provide a realistic situation. The third is a creation of a GIS exercise that distinguishes between types of strategies common to distinct geospatial expertise. Separate rubrics were created to measure the level of geographic skills and performance in the GIS exercise. No similar evaluation methods are found in the geographic education literature.

The quantitative and qualitative data, the number of students interviewed, the range of grade levels, and the tasks developed for this study make a large and complex collection of data. The benefit of this dataset is that further additional research questions can be explored such as the level of spatial vocabulary across expertise levels or gender differences across geographic skills. Despite its extent, this dataset has limitations that can be improved upon for future data collection. One such future refinement includes interviewing students from different disciplines (e.g., science, engineering, English) to provide a large scale understanding of spatial thinking and its use across different subject areas. A second possible extension of the study is to interview professional geographers and GIS users to compare with expert geospatial thinkers. A final addition is to interview student outliers a second time to better understand their learning journey.

Overall, the findings raise as many questions worthy of future research as they answer. Until more information about geographic learning and teaching are streamlined into the formal education system, geospatial knowledge will continue to be learned informally through daily interactions with the environment and thus produce different levels of spatial thinking and misconceptions of geography amongst young adults. Further research is needed to help untangle the complex relationships between transferring geospatial knowledge from paper to applying them in a GIS problem-solving exercise. The following section is a reflection of challenges and limitations encountered in this study.

6.2 Challenges and limitations

Three general challenges and limitations were encountered in this study: 1) developing scales and evaluation rubrics, 2) balancing sample size with time available, and 3) recognizing psychological effects of exercises (e.g., training effects and cognitive overload).

The first challenge was finding examples of scales, GIS-problem-solving tasks, and evaluation rubrics in the literature to build upon. It was quickly evident that available sources were not sufficient. The affection scales and the GIS exercise were adapted from existing publication while the geospatial scale was loosely modelled after fragments of published tests. The rubrics were developed solely for this study as no qualitative evaluation methods completely fit.

The time commitment and busy schedule of university students was an obstacle to recruitment. A sample of 104 participants is a satisfactory size for a dissertation although a larger sample pool would give statistical robustness and allow general findings to be more widely concluded. Aside from size, the sample was not random as students volunteered rather than arbitrarily selected by the researcher. Solutions for future data collection exist. The first amendment is to recruit students during less busy times of the semester. The second resolution requires negotiation with the course instructor. The agreement would reward student volunteers a grade incentive such as bonus marks. This method is beneficial in at least two ways; students can learn about the subject by being actively involved in the research process and the sample will be random.

The final limitation, psychological effects, is a result of the data collection method. The data collection process differed slightly between high school and university students because of timetable conflicts and travel distance to data collection site (Wilfrid Laurier University). University level participants were asked to complete three sets of scales (affection, geospatial, and geographic skills) and one GIS problem-solving task consecutively. This may have produced a training effect; participants subconsciously think deeply about geography due to the series of tests. Conversely, high school students completed the affection and geospatial scales during lunch so they may have been under pressure to complete all the tasks before the next period commenced. Finally, participants may have experienced cognitive overload from completing multiple scales, geographic skills questions, and GIS exercise in a short period of time.

6.3 Recommendations for future work

The geographic education literature has moved from dominance in ad-hoc to empirically grounded studies. Renewed interest in geographic education and spatial thinking may be due to the efforts of researchers (Golledge 1995; Battersby et al. 2006; Golledge et al. 2006b; Lee and Bednarz 2009), recent publication of seminal work (NRC 2006), and strong interdisciplinary research between geographers and psychologists (Liben and Downs 1989; Liben and Downs 1994; Liben and Downs 2001). A stable education structure involves three traits borrowed from the idea of a stable gene (Bassett 1990). These include longevity, hybridization, and application. Longevity refers to geography's ability to sustain student interest and play a role in formal education indefinitely. Hybridization is to extend geographic and spatial thinking principles across related disciplines. Finally, application extends from the hybridization process where geographic principles are applied to different ideas and models outside of geography.

Although research is a component of geographic education, at least four other actors play a role: government and funding agencies, education curricula, publication outlets, and public outreach. Their relationship forms a pyramid (Figure 6.1).

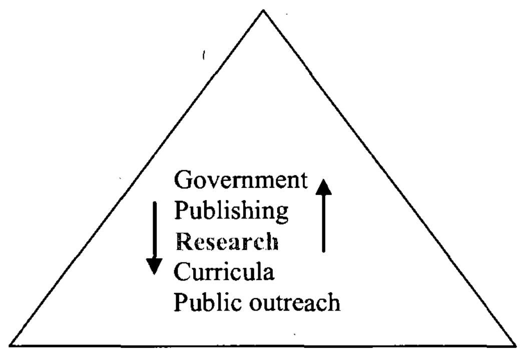


Figure 6.1: Future direction of geographic education

Research is centrally placed in Figure 6.1 because of its pivotal role; replicable data give credibility to research studies and to the field in general. Rigorous peer review is critical in the process of developing theories, of equal importance is a solid foundation of data to refute findings, retest, and redesign methodological approaches. Interdisciplinary research collaboration can then inform and contribute to two polar but equally significant players.

At the pyramid base is public outreach and curricula. The public can benefit from easy to manipulate technology (e.g., GPS, online GIS) or intuitive paper publications (maps) that have incorporated geospatial thinking principles. In formal education, education curricula K-16 and teaching methods benefit from established theories and learning models found in research. Since these applications benefit a wide and large population, they are located at the base or foundation of the pyramid (Figure 6.1).

The second role of research is to share findings with the immediate research community as well as granting agencies. More than a decade ago, Downs (1994b) invited geographic education researchers to collect empirical data so that conclusions can be verified. Nevertheless, data not only provide robust evidence for a field, it is also an avenue to publishing and to securing funds.

The envisioned research direction for geographic education involves heightened empirical data collection, and strong research networks with related disciplines to develop a broad understanding of geographic learning and teaching. Seven broad research directions, loosely related to this study, but directly linked to geographic education are proposed below.

Research direction 1: How might the geospatial scale be modified to provide meaningful tests of geospatial concepts?

The geospatial scale is useful to delineate participants into groups of different levels of spatial thinkers. However, the scale can be improved. The first area to consider is the representation of diagrams since an illustration is required for 26 of the 30 geospatial scale items. All diagrams are abstract in nature such that symbols and colour are representations of the real world. Marsh et al. (2007) found that the diagram, whether portrayed as abstract or real-life, has little impact on the extent of correctness. To build on this finding, some research questions that arise include:

i) How does the representation of a diagram, (real or abstract; familiar or foreign; coloured or black and white) affect the effectiveness of a geospatial question?

ii) What types of questions (e.g., problem solving, visualization, factual) provide meaningful tests of geospatial concepts?

Research direction 2: How reliable is the geospatial scale in different cultures?

The geospatial scale was created based on core geographic concepts primarily identified from the Ontario geography curricula. What if this instrument was applied to different places in the world, in communities with different geography curriculum? To refine and make the geospatial scale sensitive to geographic education some questions are posed below:

i) To what extent is geographic knowledge formed by culture?

What aspects of the geospatial scale can be changed to reflect cultural differences?

Research direction 3: How, when, and what types of geospatial misconceptions exist?

Participants reason through a problem with a range of methods including 1) content knowledge gained from formal education, 2) knowledge developed from personal experiences, and 3) an extrapolation of related knowledge. Unlike science education where misconceptions are measured with standard tests, no research on this topic is found in geographic education.

i) How do misconceptions in geography begin?

ii) At what learning stage do misconceptions appear?

iii) What forms do misconceptions in geography take and can these be generalized into groups or like-clusters?

iv) How does one measure the existence, nature of, and frequency of misconceptions?

v) What teaching methods can reverse misconceptions about geospatial concepts?

vi) What concepts are easily misconceived?

Research direction 4: When is it appropriate to introduce GIS to the classroom?

The geographic education literature seems to answer this question unanimously – GIS can be introduced starting at the kindergarten level. However, until the literature can support these claims with empirical data, more work is needed to guide how technology is most effectively incorporated into the classroom. The current state of desktop GIS is for professional use, and is simply too complex for young students. Although GIS can serve as a powerful visualization tool, much can still be demonstrated with static maps. When GIS is used to promote problem-based learning, a strong foundation in geospatial knowledge, GIS operations, and problem-solving strategies are mandatory. Without first building core and related knowledge, skills and affection, GIS is of limited value in the classroom. This suggests further research dedicated to the following questions:

i) How can problem solving with GIS be used as an assessment tool of geography and geospatial thinking skills?

ii) What peripheral and core knowledge, skills, as well as affection are needed to use GIS?

iii) What role do paper (non-digital) and digital devices have in geospatial thinking across the grade levels?

Research direction 5: What additional factors enhance a GIS application?

This study establishes that effective GIS problem solving is positively related to the extent of one's geospatial knowledge, problem-solving approach, and geographic skills (inquiry and analysis). Although not substantiated by statistical means, observations suggest that a number of additional factors play a role in GIS use. Affection is a significant factor but not easy to measure. Some research areas are proposed:

i) Compare and contrast different methods to capture realistic and holistic affection

ii) Does gender have any influence on GIS use?

In addition, a number of ad-hoc studies suggest that GIS helps students learn geography, (more specifically, spatial thinking) and mathematics (Furner and Ramirez 1999; Kerski 2006; NRC 2006). However, little research examines the reverse, how other subject knowledge areas advance or support GIS problem solving. A growing curiosity is to explore how interdisciplinary courses might strengthen problem solving and technology application.

Research direction 6: What does a successful GIS learning environment look like?

This question encourages a wider discussion on the physical, emotional, and social learning spaces that might be specific to learning technology in general or GIS in particular. Through observations, students who interact by asking questions generally perform better. If students work with a partner they may gain different perspectives through discussion and use collaborative skills amongst other social benefits. The overarching question is concerned with a holistic learning approach that encourages the development of knowledge, skills, and affection. Some related questions are posed below.

Physical space

i) How might the physical space be organized to induce collaboration, team teaching, and data sharing?

ii) What essential digital and non-digital tools are needed for the classroom?

Emotional space

i) How can a student's impression and assumptions about geography and GIS be changed positively?

ii) To what extent and how should students' interests be incorporated into the curriculum or daily instruction?

Social space

i) What is the role of problem-based learning and inquiry-based learning in GIS?

ii) How does grouping students (expertise level, gender, interests etc) affect learning?

iii) How does working alone and in groups advance geography and GIS application?

iv) Does feedback (from classmates and instructor) influence problem-solving skills? If so, how can this be used as a teaching technique in GIS learning environments?

v) What is the role of differentiated learning in a geography classroom?

Research direction 7: How is geographic knowledge learned?

In the Canadian education system, all students are taught geography in school, albeit the depth and extent varies by jurisdiction. However, a more important learning environment is the world, the space around us. From the instance of our birth, we are introduced to a three-dimensional world with spatial relationships between objects at different scales. Despite a rich learning opportunity, people have varying levels of geographic knowledge as we take in, process, and make decisions about spatial data. This research direction investigates the appropriate age and environment for geographic learning.

i) Is there a vital age at which geography needs to be explicitly instructed before the rate of absorption or understanding is compromised? Does spatial knowledge decrease or increase after a certain age?

ii) Once identified, do novices, intermediates, and experts require different learning environments or materials? What form might these take? How does each expertise level maintain (experts) or advance (novices and intermediates) in their spatial thinking abilities?

iii) Is it possible to recognize meaningful learning in-situ? If so, how can it be measured?

ii) Which geospatial concepts develop naturally and which ones need explicit instruction?

CHAPTER 7: TEACHING IMPLICATIONS IN GEOGRAPHY AND GIS

This chapter takes on a practical approach, focusing on three broad themes related to teaching implications. The first section summarizes general teaching implications grounded in observations. The second component examines the future of GIS online, blending learning. The final section suggests guided pencil and paper exercises to develop spatial thinking skills.

7.1 Overview of observed teaching implications

Nine teaching implications result from close observation of students' problem-solving processes and their reflections.

1. ***The GIS problem is best tailored to students' age and life stage.*** GIS problems can encourage students to integrate material from class with an understanding of their surroundings if the GIS exercise is reflective of their experiences appropriate to their age, stage of development, and life experiences.

Grade 9 students have little experience looking for rental housing, so the GIS problem becomes over-simplified or over-complicated in their minds. Personal subjectivity affects the final solution. For example, students choose housing locations that fulfill the required criteria but also suit their personal needs. As well, familiarity with a study area is a source of secondary information which adds richness to their approach. In general, students are interested in the problem-based exercise because they either have some personal experience or knowledge with the question. Hart and Berzok (1982) also recognize the need to investigate cognition of geographic space in a familiar setting with tasks that are meaningful to participants.

2. ***Novice students benefit from more structure, and even step-by-step instructions to solve the GIS problem.*** Novices benefit from step-by-step instructions because they are easier to

understand but it does not help students understand the problem-solving process. The GIS handbook, however, is helpful as a reminder of relevant GIS operations while participants navigate and problem solve on their own; it is particularly helpful for those who cannot keep pace with the class or those who want to learn by self.

3. ***Problem solvers benefit when adequate attention is given to data exploration***. The dataset should be thoroughly discussed so that students understand the properties of the data and the information they might therein derive.

4. ***Basic GIS concepts and visualization tactics are an important component of GIS use.*** Basic knowledge and familiarity with tools such as turning off/on layers, adding layers, changing properties, and reordering the table of contents are important to ease the visualization process. These are important for visualization effects and especially so if students primarily use visualization as a problem-solving tactic.

5. ***Students benefit from introductory exercises to integrate the conceptual knowledge of geography with the operations of the GIS***. An explicit link between relevant geographic concepts and GIS problem should be made at the start. The learning outcome is that students can relate theory (geographic concepts) with an application (GIS tool).

6. ***Explicit problem-solving method should be introduced to students.*** Specifically, students should differentiate between relevant and irrelevant data. In addition, close reading of the problem will reduce assumptions being made. A suggested problem-solving strategy should be explained in class:

i) Read problem carefully,

ii) Identify relevant information and which layers to display,

iii) Identify the geographic concepts and skills that are required,

iv) Form strategy and decide the sequence of GIS operations to apply,

v) Use information to arrive at an answer(s),

vi) Read problem statement over again, and

vii) Confirm solution satisfies all criteria.

*7. **Flow chart supports thinking processes***

The usefulness of a flow chart is that it forces the students to think through the steps of problem solving, select specific GIS operations to apply, and inspect the sequence of steps to predict possible outcomes. If the result is incorrect or unexpected, this is an opportunity for reflection and modification to the process. Thus, a flow chart becomes a method to monitor one's spatial thinking and its application in a problem-solving context makes it an education tool. It also acts as a 'button-break' such that students push buttons mindfully rather than become a buttonologist.

*8. **Feedback and usefulness of GIS operation handbook***

Feedback is information provided by an agent such as a teacher or parent regarding one's performance or understanding (Hattie and Timperley 2007). An important component of learning is the instantaneous feedback received in context, in contrast, delayed or poor feedback slows or impairs learning (Ericsson and Smith 1991; Azevedo and Bernard 1995) . Feedback can take the form of feed up (where am I going), feedback (how am I going), and feed forward (where to next) (Hattie and Timperley 2007). Students who seek, respond, and integrate feedback into their problem-solving experience are more willing to test different GIS functions and are thus more successful.

Hattie and Timperley (2007) defined four levels of feedback: 1) feedback on task or product (e.g., outcome is correct or incorrect), 2) process used to create product (e.g., thinking process),

3) self-regulation (e.g., student knows key features and is encouraged to incorporate them), and 4) personal characteristic (e.g., you are a great student). The second and third feedback types are the most powerful to develop deep processing and mastery of skills where the first is useful to improve strategy processing or enhancing self-regulation. The least useful is comment on personal characteristics as this can lead to a fixed mindset. In the GIS task, a different form of feedback was provided, one of clarification of the GIS operations. Many of the questions were technical in nature eliciting type one feedback. It is suggested that in a classroom setting, students are prompted about their thinking process throughout so that type two and three feedback can be provided.

9. Application of geospatial scale

The teaching and general application(s) of the geospatial scale is far reaching. An example is for diagnostic (beginning of school term), to formative (middle of school term), to conclusive (end of school term) evaluation. The results provide benchmarks for comparison with subsequent years' performance as well as to inform how and which part of the curricula may need reform. Another application is to correlate one's performance on the geospatial scale with other activities such as pattern recognition. Finally, application of the geospatial scale to other disciplines requiring spatial thinking (e.g., visual arts, mathematics, and science) is an interdisciplinary education to strengthen this ability.

7.2 Blended problem-based learning (PBL)

In this section, a brief discussion of GIS application outside of the traditional classroom (face-to-face) is considered for several reasons. First, GIS taught online may become a trend in the future because of improved technology and institutional innovations. Second, it is interesting to extend the findings of this study to a different setting, also known as blended learning, which is a combination of traditional classroom and online teaching.

Rapid technological evolution in the last few decades has changed the image of blended learning from the early days of an instructor-led training to e-learning. These new tools in turn provide distance education students with an alternative platform to traditional learning, the ability to work independently, at a self chosen time and place (Dibiase 2000). Although the concept of distance education is deeply rooted in technological dissemination of knowledge and is thus not new, the technology that is available for learning, such as asynchronous (simulations, web-based courses) and synchronous forms (live video, webcasting) (Bersin 2004) have evolved.

In a survey, Wright and Dibiase (2005) find that GIS is prominent in the classroom but it is not well entrenched as a distance education course. For example, within the geography community, distance education is debated. To some, it is felt that geographic education online contradicts the idea of 'space', as learning is remote and impersonal (Dibiase 2000). Other educators support distance learning at the university level and think it is a timely change (Cornford and Pollock 2003), particularly that of teaching GIS online, as it is a revenue source for the department. The marriage of GIS with online and blended education has prompted questions such as the meaning of online pedagogy, the use of technology in teaching and learning, as well as the relationship between current pedagogy with future modifications (Savin-Baden 2006).

GIS courses have increasingly been offered outside the traditional classroom by way of online media, subscribing to both an online and blended teaching pedagogy. GIS leading companies (e.g., E.S.R.I) and teaching institutions alike (Birkbeck College, University of London; Kingston University, UK) embrace distance education to reach a wider audience. A small literature about online GIS education exists, focusing on either the development of an online GIS education programme (Carver et al. 2004; Baker 2005; Johnson and Boyd 2005; Miller et al. 2006) and the student learning experience (Ramirez 1996; Keiper 1999; Morehead 1999; Purcell et al. 2006; Clark et al. 2007). However, there is a paucity of research on how to integrate the geospatial knowledge and thinking into the online curriculum.

In any GIS class, three components are significant to explore (Table 5.4), 1) geospatial knowledge, 2) problem-solving approach, and 3) mastery of GIS. Geospatial knowledge and problem solving are two areas that require guidance. It is suggested that explicit geospatial concepts are taught, using examples of GIS operations to illustrate. For example, 'buffer' can be introduced by its application in flood protection then applied to its potential analysis in GIS. The second component is problem-solving styles which can be examined by exploring GIS case studies. Students should be further encouraged to document their thinking process by using a flow chart. Finally, comfort with GIS is developed through guided exercises and practise.

Students tend to expect prescribed and perfect outcomes from a step-by-step outline. An alternative support material is a GIS handbook from which students can freely strategize or apply any operations they deem useful. In this process, they learn to think critically, independently (at home or in class), develop ownership of their solution(s), and consciously apply geospatial concepts. In an online class, a GIS handbook can be part of a class effort where students have permission to add to as well as modify current material similar to an online wikipedia.

Mishra and Koehler (2006) developed a teaching framework, Technological Pedagogical Content Knowledge (TPCK), that examines the components of technology education. The framework is applied to the development of guided GIS exercises; geospatial knowledge satisfies the content knowledge, problem-solving is the GIS pedagogy, and the mastery of GIS functions is the technological piece. Based on the TPCK working model, ten guided exercises to promote geospatial development are introduced in section 7.3. These can be used in class or served over the web synchronously or asynchronously.

7.3 Guided pencil and paper exercises

This study proposes an initiative to developing spatial thinking, in the form of ten pencil and paper games which can also be posted online for blended classes. The purpose is to help students explore isolated geospatial concepts and those that are integral to GIS operations. Teachers can include these non-technological activities into geography and related subject areas (e.g., science, social studies) without learning complicated software. The overall goal is that with repetition, practise, and experimenting with a range of low to high technology exercises (NRC 2006) this will enhance students' knowledge of geospatial concepts, develop comfort with GIS, and move students away from button-pushing to active thinking. The specific objectives are adapted from van Hiele (1986), to encourage:

1. Exploration of geography and GIS,
2. Discussions that integrate relevant and correct language use,
3. Application of spatial relations to various activities, with various outcomes, and
4. Reflection on personal learning and actions by integrating the concepts, relations, and rules.

These spatial thinking games are diverse so to hook students' interest and increase in difficulty levels to pose a sense of challenge to the students. They are created in sequence following Bloom's model, through practise, develop students' knowledge, comprehension, application, analysis, synthesis, and evaluation skills. The games are inspired by Bruner's (1963) spiral curriculum concept; to introduce spatial thinking and GIS skills at an early stage, repeatedly taught at later stages, and to vary in difficulty so students begin with simple tools before advancing to higher level GIS use. The repetition factor encourages students to relearn and integrate basic foundations in different settings. Hence, the transition from one level to the next is guided by a teaching-learning program (van Hiele 1986) and stages of development from cognitive to associative to autonomous skill acquisition (Fitts 1964). This is based on the assumption that all students can improve along the novice-expert continuum, wherever their current status, if they are provided with a sequence of guided exercises and supportive learning environment and materials.

Following the suggestion of Livingston and Borko (2002), the activities are organized in sequence and increase in difficulty for each expertise levels. Damon (1984) applies the theories of Piaget and Inhelder (1971) as well as Vygotsky (1978) to assert that students who are provided with cognitively appropriate tasks develop such skills as idea formulation, argumentation, and verification to develop base geospatial knowledge. Through practise, students will learn to select relevant information and how to apply them in problem solving. For example, some exercises should be solvable by simple to intermediate tools, others by intermediate and advanced tools and others that can only be solved with advanced tools. This assures that students progressively learn to differentiate the tools and its sequence of use.

Group learning is emphasized in these games as a collaborative atmosphere supports dialog and an exchange of ideas. The literature suggests that intermediate students learn better in homogeneous groups (same ability) where novices benefit from heterogeneous groups (mixed ability). Experts perform as well in both types of arrangements (Webb 1991; Lou et al. 2001; Saleh et al. 2005; Saleh et al. 2007).

In each game, a student is assigned the role of 'host' who leads the exercise and provides immediate feedback for all correct and incorrect answers. Role assignment is critical to reduce inequality in student participation and provides structured learning that is motivational to intermediates (Saleh et al. 2007).

These exercises can either be part of weekly homework, pre-lab preparation or part of the laboratory exercise. To promote student improvement different tiers of problems are developed, 'leisure,' 'intermediate,' and 'advance.' It must be stressed that common GIS tools or operations should be taught together as this reinforces a structured way to organize the large number of possible GIS operations. For example, if the upcoming lab draws upon the visualization tools (zoom, measure, pan, identify, select) only these common tools should be introduced. The ten games are described and demonstrated below.

A. Developing geospatial jargon (Bloom level: Knowledge)

Goal: A series of exercises introduce spatial relations jargon and prepositions which form mental representations of objects, patterns, locations, and events (Olson and Bialystok 1983).

Instructional preparation: Give students a brief explanation of geography terminology and their importance to creating spatial relations.

Olson and Bialystok (1983) suggest that prepositions paired with different frames of reference (ego, observer, object, and environment) derive higher order geospatial jargon. Another dimension, prepositions of place (point, surface and enclosed space) (Englishclub.com 2009), is integrated.

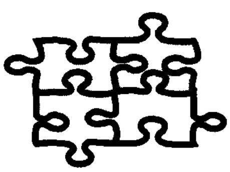
Game preparation: Cue cards (for small groups) or transparency/projector (for large groups) can be used. Each card shows a diagram with various interactions between people, objects or people and objects. Two objects are shown at the leisure level increasing in number and complexity at the advanced level.

Leisure level (Prepositions of place introduced): Students may work in pairs or in a small group. A diagram of the objects is shown to student(s). The student has three options: i) to provide an answer, ii) to ask one question which narrows the answer (these questions can only elicit 'yes' or 'no' response from host) or iii) to pass. A list of prepositions is included from which students may select from.

Example 1: **At** for a **point**

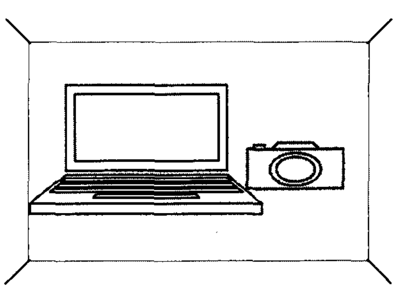
Possible answer: the tree is *at* the end of the road

Example 2: **In** for an **enclosed space**



Possible answer: the red piece fits *in* the puzzle

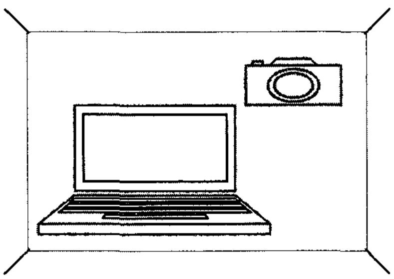
Example 3: **On** for a **surface**



Possible answer: The computer is *on* the table

Intermediate level (Prepositions based on three dimensional Euclidean space): The instructions are the same as for Leisure level above. Prepositions which relate to relationships in three dimensions, three orthogonal axes (Olson and Bialystok 1983), are introduced. Some examples include front and back, top and bottom, left and right, above and under.

Example



Possible answers:

- The camera is *to the right of* the computer
- The computer is *on top* of the table
- The table is *under* the camera and computer

Advance level (Prepositions in different frames of reference): At the advanced level, a proposition is defined by which frame of reference the object is placed in. These frames of reference include ego, observer, object, and environment. A combination of leisure and intermediate exercises are applied to the advanced level.

Example 1: Ego-related spatial preposition (ego = me)

The computer is *in front* of *me*

Example 2: Observer-related spatial preposition (object = fruit stand)

The coffee shop is *to the right* of the fruit stand owner

Example 3: Object- related spatial preposition (observer = person watching from outside)

The sun is rotating around Earth

Example 4: Environment- related spatial preposition (environment = volcano)

The earthquake is north of the volcano

B. Operation identification (Bloom level: Knowledge)

Goal: Students are introduced to the nomenclature and purpose of each GIS operation.

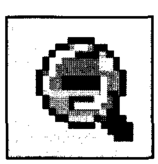
Instructional preparation: students are given an overview of the GIS software that organizes operations by general functions.

Game preparation: This can be accomplished with cue cards (for small groups) or transparency/projector (for large groups), the operation diagram printed on one side and the answer on the other side. Sets of cards are developed for different components of GIS operations ranging from basic GIS tools (e.g., zoom, measure tool) to GIS operations (e.g., spatial analysis).

Leisure level: Students may work in pairs or in a small group. A diagram of the GIS function is shown to student(s). The student has three options: i) to provide an answer, ii) to ask one question which narrows the answer (these questions can only elicit 'yes' or 'no' response from host) or iii) to pass.

Advance level: At this level, the student is allowed to i) provide an answer or ii) pass. However, at this level the exercise is timed. For every cue card that has been passed or incorrectly answered, an additional 10 seconds is added on to the total time.

Example

	**Zoom out**
Front	*Back*

Scoring: The student with the quickest time, on the most number of questions, wins. Another method is to declare the winner with the most number of correct answers.

C. Geographic and GIS concepts and vocabulary (Bloom level: Knowledge)

Goal: The goal of this exercise is to develop and strengthen geographic and GIS concepts and vocabulary.

Instructional preparation: Students are given a review on the function(s) and purpose of GIS operations whether through the previous game or lecture style.

Game preparation: Produce on separate cue cards a range of one-word geographic and GIS concepts and vocabulary.

Leisure level: Students will work in pairs with a list of concepts or vocabulary. One student selects a term and provides a clue to the second student. Based on the clue Student A guesses the answer. Student B is allowed to provide a maximum of three clues, each at separate times, before moving on to a new concept or vocabulary. If Student A has no confidence on a term, s/he can pass. In this game, both players benefit; Student B must know the term well to provide clues while Student A must know the term well to guess from the clues.

An alternative way to play this game is to encourage questions rather than giving out clues. In a pair, Student B chooses a concept or vocabulary. Student A can ask questions that can only be answered with 'yes' or 'no', limited to a reasonable number of questions. Begin with simple, primitive concepts or terms. There is a limit of 5 clues or questions to be asked.

Advance level: Same rules apply although the word(s) bank increases in difficulty. Three clues are allowed to be given and a time limit is applied.

Scoring: The student with the quickest time, on the most number of questions, wins. Another method is to declare the winner with the most number of correct answers.

D. Operation finder (Bloom level: Comprehension)

Goal: This game encourages students to identify GIS operations based on diagrams shown. Students are shown the diagram of a feature before a GIS operation was applied and a post-application diagram.

Instructional preparation: Students are given a review on the function and purpose of GIS functions whether through the previous game, in lecture or through an exploratory lab.

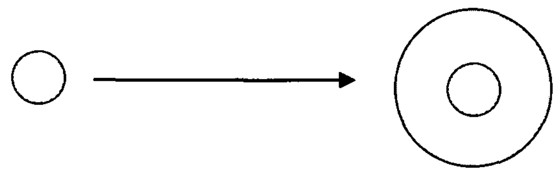
Game preparation: This can be accomplished with cue cards (for small groups) or transparency/projector (for large groups). The pre- and post- diagrams are printed side by side, clearly labelled. Sets of cards/transparencies are developed for different components of GIS operations ranging from basic GIS tools (e.g., zoom in, measure tool) to advance GIS operations (e.g., spatial analysis, network analysis).

Leisure level: Students may work in pairs or in a small group. Two features are displayed; one in its original form and the second after a GIS operation has been applied to the feature. The student will be asked to answer one of the following questions: i) name the operation that resulted in this solution, ii) the purpose of the operation or iii) to provide a realistic situation when this operation can be applied. Some examples of operations include buffer, intersection, and erase.

Intermediate level: Completion time and number of correct answers will be monitored. For every cue card that has been passed or incorrectly answered, an additional 10 seconds is added on to the total time.

Advance level: The start or end result of an operation is provided, along with the GIS operation. The student is asked to draw the pre- or post- GIS diagram. For every cue card that has been passed or incorrectly answered, an additional 10 seconds is added on to the total time.

Example



Scoring: The student with the quickest time, on the most number of questions, wins. Another method is to declare the winner with the most number of correct answers.

E. Group the operations (Bloom level: Comprehension/Analysis)

Goal: The goal of this exercise is to test students' ability to make connections between GIS operations. The student will be presented with two different lists of operations and asked to explain the common theme between each list. The student is then asked to place a given GIS operation into one of the two lists and to explain the reasoning.

Instructional preparation: Students are given a review on the function and purpose of GIS functions whether through the previous games, in lecture or through an exploratory lab.

Game preparation: Two lists of GIS operations are prepared, displaying the name and diagram. This can be shown on the overhead projector or as a hardcopy.

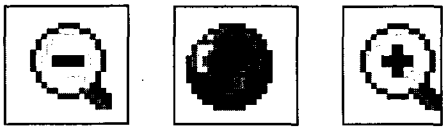
Leisure level: For this level, only one GIS operation is presented for placement.

Intermediate level: At this level, three or four operations are provided. The student is asked to select the three most relevant operations into the appropriate lists. For every incorrectly answered question, an additional 10 seconds is added on to the total time.

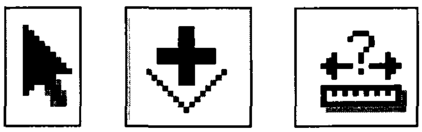
Advance level: At this level, the student is asked to design a GIS operation, explain its function and to place in the appropriate list. The final task is to search whether the software has this function and to compare the similarities/differences.

Example

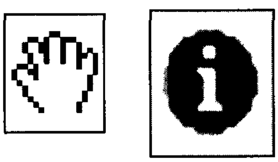
List A - These tools change the view of a map:



List B - These tools do not change the view of a map:



These tools belong to which list?



Scoring: For the basic and intermediate levels, the student with the quickest time, on the most number of questions, wins. Another method is to declare the winner with the most number of correct answers. For the advanced level, optional marks for creativity can be assigned.

F. Distinguish me! (Bloom level: Comprehension/Analysis)

Goal: The goal is to test students' ability to select the correct GIS operation. The student is to select the best option, from a choice of two similar GIS operations, to resolve a problem.

Instructional preparation: Students are given a review on the function and purpose of GIS functions whether through the previous games, in lecture or through an exploratory lab.

Game preparation: The diagram of two similar GIS tools or functions are printed on a transparency, a letter size page or shown with the projector.

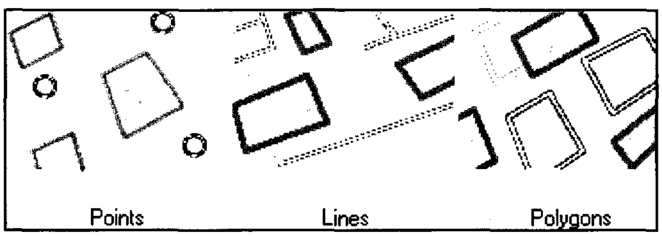
Leisure level: For this level, two very similar GIS tools/operations are presented and the student is asked to select the best option to reach the proposed solution. An example may be 'union' and 'intersection'.

Example

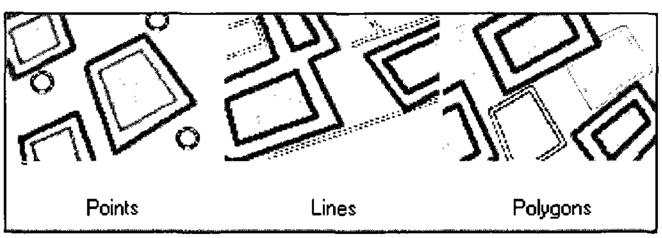
A farmer wishes to locate areas where his crops lie in a water source. Which tools should she select?

Tools to select from:

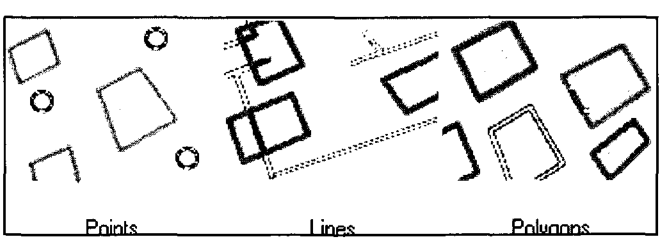
i) Intersection:



ii) Within a distance of



iii) Are completely within



Advance level: At this level, three or more operations are provided. The student is asked to arrange the GIS operations in the correct sequence to arrive at a specified solution (at least 1 tool or operation provided is incorrect). For every incorrectly answered question, an additional 10 seconds is added on to the total time.

Example: A Blue Jays fan arrives in Toronto for a baseball game. She wants to search for all parking available within a distance of 750 m from the Roger's Centre (where the baseball game is being played).

Using spatial query, which spatial relationship should she use to identify the spatial relationship between parking lots and Roger's centre?

Scoring: The student with the quickest time, on the most number of questions, wins. Another method is to declare the winner with the most number of correct answers.

G. Predict outcome (Bloom level: Application/Analysis)

Goal: This activity encourages students to develop six different skills 1) visualizing datasets, 2) creating datasets, 3) analyzing datasets, 4) thinking through how datasets produce a solution, 5) hypothesizing about research questions, and 6) inquiring about datasets. The student predicts the outcome(s) of a GIS analysis and proposes a possible research question.

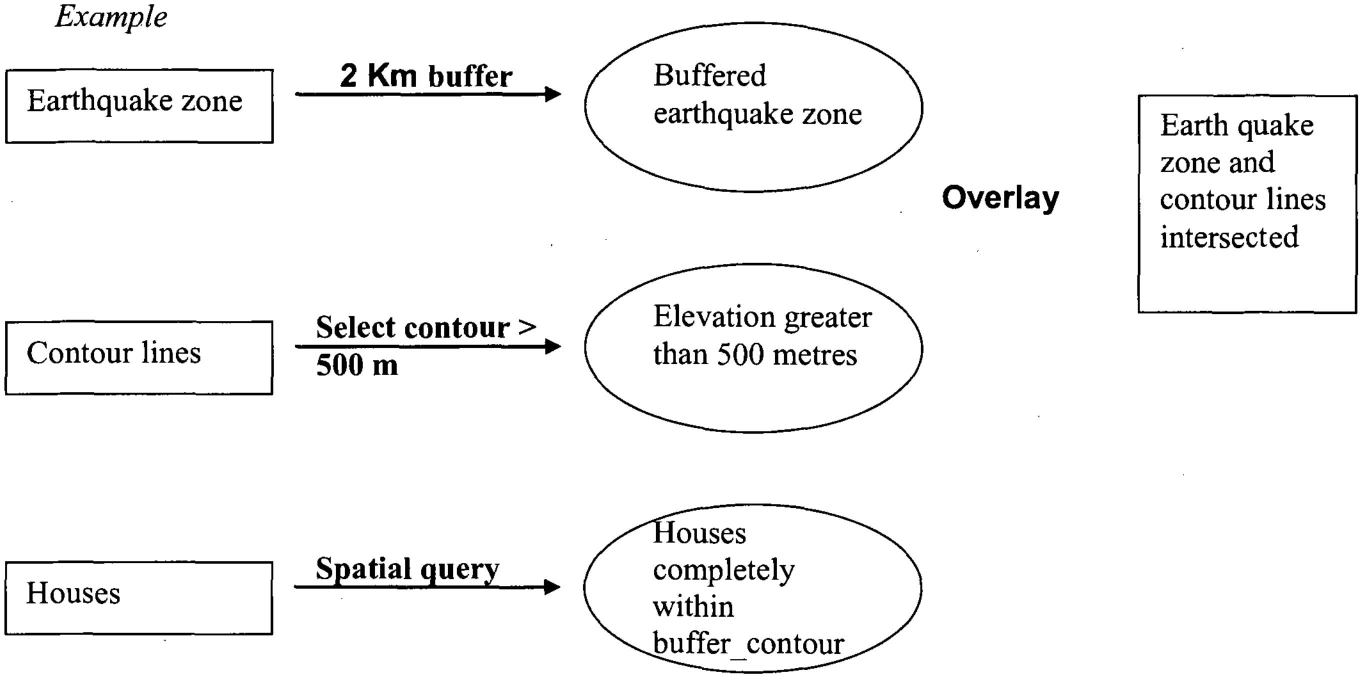
Instructional preparation: Students are given a review on the function and purpose of GIS functions whether through the previous games, in lecture or through an exploratory lab.

Game preparation: Produce scenarios that are new to the student as well as those that have been reviewed in class. The GIS tools/operations can be displayed in a flow chart.

Leisure level: Begin with 2 operations that are in the same category. It is optional to illustrate the problem with diagrams or simply with a flow chart.

Advance level: Begin with 3 operations and gradually increase this to 5 or 6, varying difficulty by choosing operations that fall into the same or different categories. For every incorrectly answered question, an additional 10 seconds is added on to the total time.

Example



Scoring: For the basic level, the student with the quickest time, on the most number of questions, wins. Another method is to declare the winner with the most number of correct answers. For the advanced level, creative marks can be rewarded.

H. Problem solving rethought (Bloom level: Synthesis/Evaluation)

Goal: In this exercise, a full solution will be given. Students will be asked where and how the solution can be improved such as the use of different operations, sequence of operations applied or the fewest number of steps to reduce redundancy. This will encourage students to arrive at alternative ways to problem solve.

Instructional preparation: Students are given a review on the function and purpose of GIS operations whether through the previous game or lecture style.

Game preparation: Produce scenarios that are new to the student as well as those that have been reviewed in class. The GIS tools or operations as well as the solution can be displayed in a flow chart.

Leisure level: Begin with 3-4 operations that are in the same category.

Advance level: Begin with 4 operations and gradually increase this to 5 or 6, varying difficulty by choosing operations that fall into the same or different categories.

Scoring: The student with the quickest time and correct analysis wins. Another method is to select most the most creative solution.

I. From reality to digital (Bloom level: Synthesis/Evaluation)

Goal: Student will select a news event, such as an earthquake, to transform into a GIS data collection and analysis project. Based on the event, students are asked to pose a relevant inquiry question and work towards a solution. This includes data needed to answer as well as an optimal analysis procedure to reach a solution.

Instructional preparation: Students are given a review on the function and purpose of GIS operations whether through previous games, lecture or discussion.

Game preparation: Select newspaper stories that are interesting to students and relevant to previous topics discussed.

Leisure level: Begin with a selection of short and simple stories and obvious solutions to build confidence and practice. Group size should be limited to a maximum of three students.

Advance level: Include optional detail and complex stories with multiple correct solutions to promote critical thinking and group discussion. Group size should be limited to two students.

J. Piece by piece (Bloom level: Synthesis/Evaluation) *

Goal: In this exercise, a full solution to a problem will be given such that the students see in chronological order only one part of the problem at a time. Students are asked to discuss and predict, based on the given problem, what follows next and why. This will encourage hypothesis creation, deductive reasoning skills, discussion, and appropriate application of given data.

Instructional preparation: Students are given a review on the function and purpose of GIS operations, whether through the previous game or lecture style. As well, a variety of GIS application examples are reviewed in class or provided for reading.

Game preparation: Produce a scenario that utilizes various GIS operations told as a story, including background information, problem that needs to be resolved, and the GIS functions used.

Leisure level: Begin with a simple story that draws on a small number of GIS operations. Group size should be limited to a maximum of three students.

Advance level: Develop a detailed and complex story that draws on a variety of GIS operations. Group size should be limited to two students.

*adapted from a teacher training session on June 25, 2008 at Branksome Hall, given by John Myers, Ph.d

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APPENDIX 1: Geospatial scale

Geospatial Thinking Scale

Niem Tu Huynh
Ph.D candidate in Geography and Environmental Studies
Wilfrid Laurier University
Waterloo-Laurier Graduate Program in Geography

If you or your child have any questions about this research at any time, you can contact me (Niem Tu Huynh) at (519) 884-0710 x.3778 or huyn1912@wlu.ca or my supervisor, Dr. Bob Sharpe, at (519) 884-0710 x.2684 or bsharpe@wlu.ca.

This project has been reviewed and approved by the Research Ethics Board at Wilfrid Laurier University (contact: Dr. Bill Marr, (519) 884-0710 x.2468, bmarr@wlu.ca) and the Research Committee of the Waterloo Region District School Board. Your child's teacher has agreed to allow this research to take place in his/her geography class.

Questionnaire

1. Gender: ☐ Female ☐ Male

2. Age:

3. Have you ever taken a Cartography, Geographic Information System (GIS) or Remote sensing course?

☐ Yes ☐ No

4. How often do you use Geographic Information System (GIS) such as Arcview or ArcMap at home or at school?

☐ Never ☐ A few times ☐ Frequently

Question 1

Task 1: A map will be shown to you for 20 seconds. You are asked to learn as many details as possible.

At the end of 20 seconds, draw and label as many locations as you remember on Figure 1 below.

Figure 1: Replication of locations

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Question 2

An infectious outbreak has been identified by the Health Department in the Region of Waterloo. The outbreak is identified by the 'X' symbol while residential areas are indicated as black circles.

Task 1: Please identify directly on Figure 2 the possible infection area if the disease can spread up to 300 Km from the outbreak.

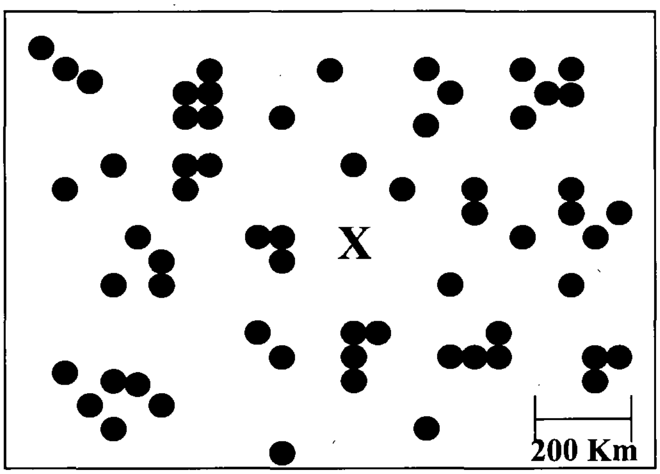


Figure 2: Infectious outbreak

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 2: Explain the term 'buffer' as used in geography.

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 3: Select a term below that best describes the relationship between increasing distance from the outbreak source and decreasing risk of infection:

a) Nearest Neighbour
b) Frame of reference
c) Spatial hierarchy
d) Distance Decay
d) Spatial organization

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Question 3

Answer the next three questions by referring to Figure 3 below.

Task 1: Which mountain has the steepest slope overall?

a) A b) B c) C d) D e) E

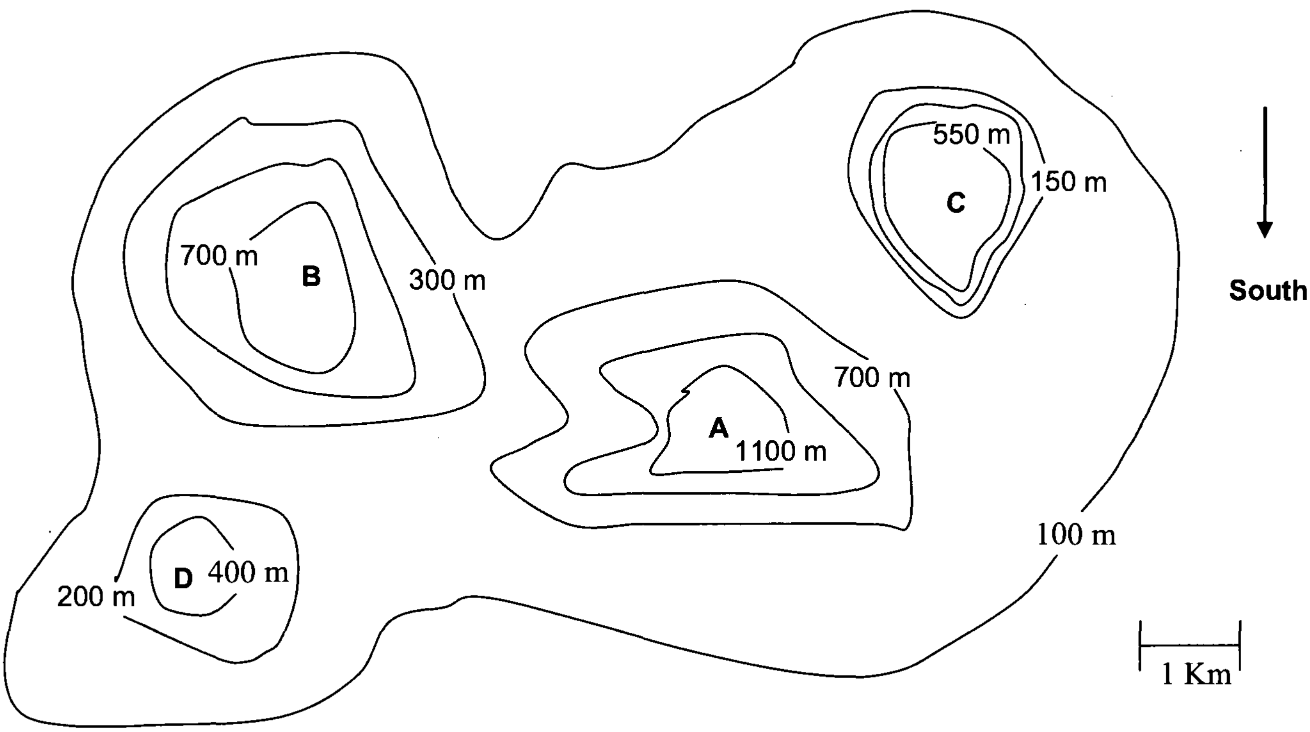


Figure 3: Mountains and Elevation

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 2: You are standing at the peak of mountain C looking south. Name in clockwise order the other mountain(s) you can see:

a) A, D, B   b) B, D, A   c) D, A, B   d) C, A, D   e) A, B

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 3: Circle *five (5)* term(s) that best describe the spatial relationship(s) between features A, B, C and D.

Above	Below	Distributed	Over
Along	Beside	Down	Parallel
Among	Bottom	Far	Patterned
Apart	Buffer	Inside	Peripheral
Area	Centre	Intersect	Proximal
Around	Classify	Isolated	Random
Arrangement	Clustered	Linked	Tangent
Aspect	Connected	Network	Top
Away	Contour	Next	Towards
Bearing	Coordinates	Node	Under
Behind	Direction	Outside	Up

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Question 4

Answer the next three questions by referring to Figure 4 below.

Task 1: You start at location 8 in the city map (Figure 4). You begin to travel north one street intersection, turn right one intersection, turn south four intersections and turn left one intersection. You will be closest to location:

a. 1
b. 2
c. 3
d. 4
e. 5

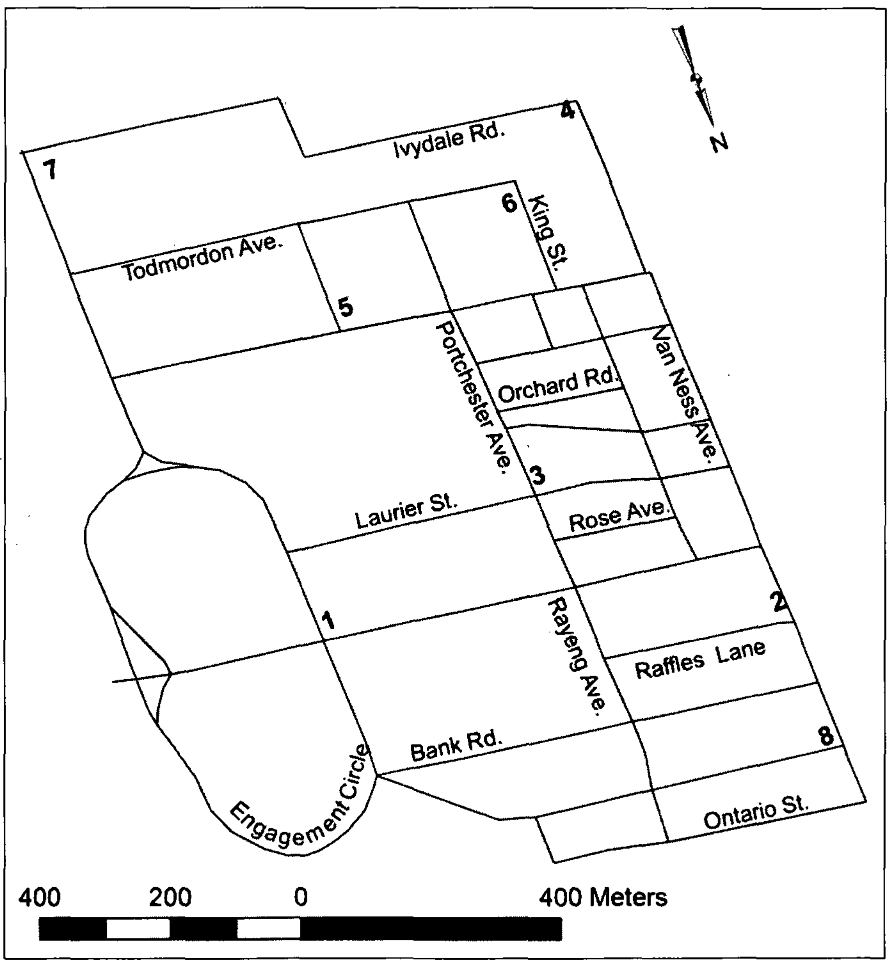


Figure 4: City Map

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 2: Estimate the TOTAL distance traveled in Task 1:

a) 1000 m
b) 2000 m
c) 3000 m
d) 4000 m
e) 5000 m

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 3:

You start at location 3 in the city map (Figure 4). You travel west one street intersection, south four intersections, east two intersections, south one intersection then east one intersection. You will be closest to location:

a. 1
b. 2
c. 3
d. 4
e. 5

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Question 5

Trees in the province of British Columbia, Canada have undergone severe attack by a type of beetle, the Mountain Pine beetle.

Figure 5 shows the regions of British Columbia that are being attacked by the Mountain Pine beetle.

Figure 6 shows the different types of Pine trees in the same area.

Task 1: Shade in Figure 6 the largest region infected by the Mountain Pine beetle.

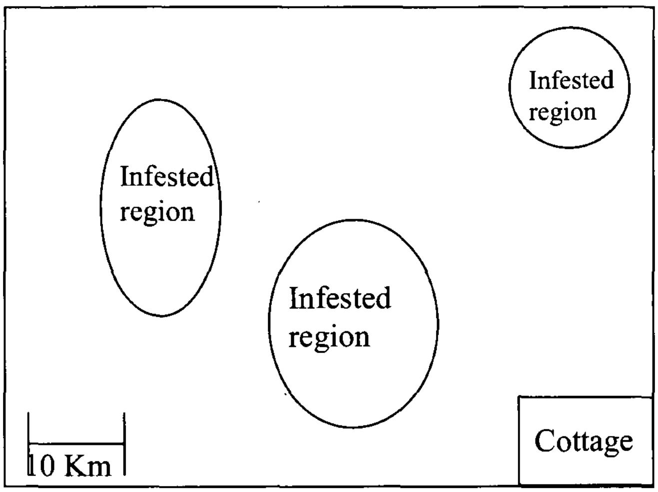


Figure 5: Regions of Beetle Infestation

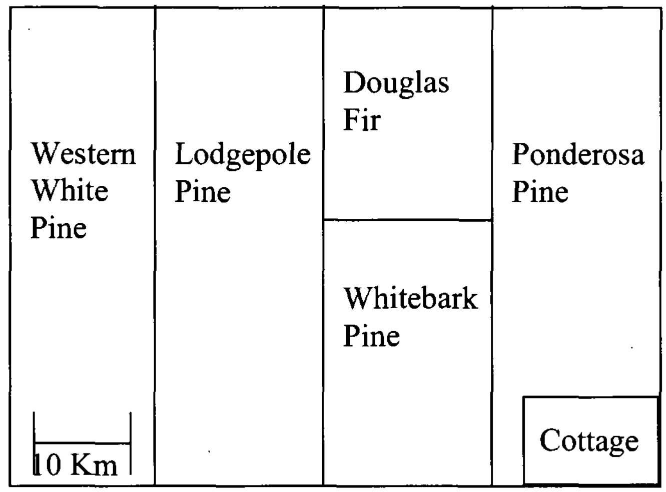


Figure 6: Areas of Pine Trees

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 2: Explain how you identified this area.

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 3: Estimate the TOTAL size of beetle infestation across the whole area:

a) 100 Km^2 b) 300 Km^2 c) 500 Km^2 d) 700 Km^2 e) 900 Km^2

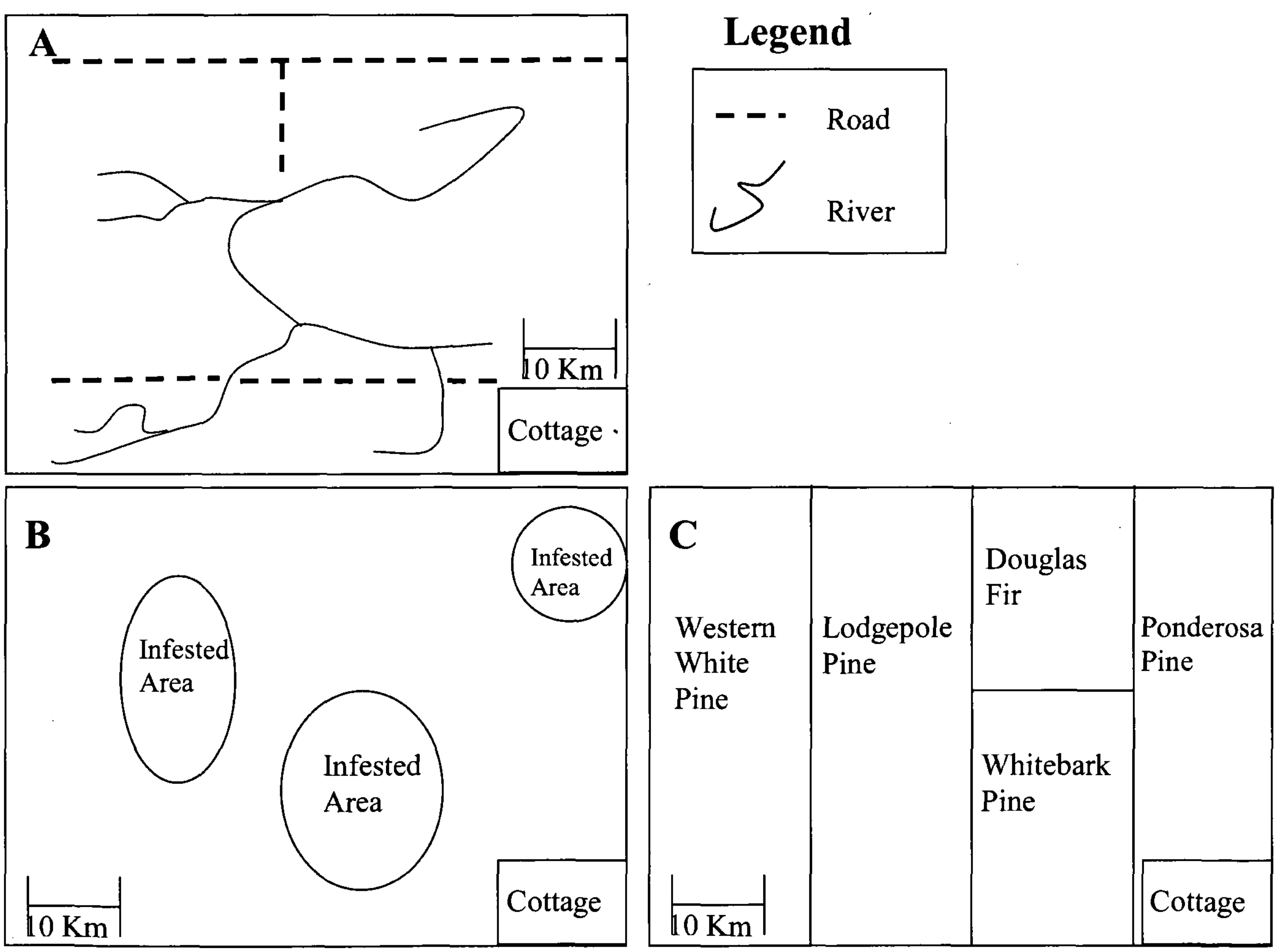
Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 4: On a summer's day, you are looking for a campsite on which to spend the evening. The campsite must have the following characteristics:

1. Within 3 Km of a road (Figure A)
2. Within 1 Km of a water source (Figure A)
3. At least 5 Km away from any infested region (Figure B)
4. At least 5 Km away from the tree type Whitebark Pine, as there is a fire warning for the duration of your camping trip (Figure C)

Circle the campsite (1, 2, 3, 4 or 5) in Figure 7 below that is most desirable based on the criteria outlined above.



Circle the campsite (1, 2, 3, 4 or 5) that is most desirable based on the criteria outlined above.

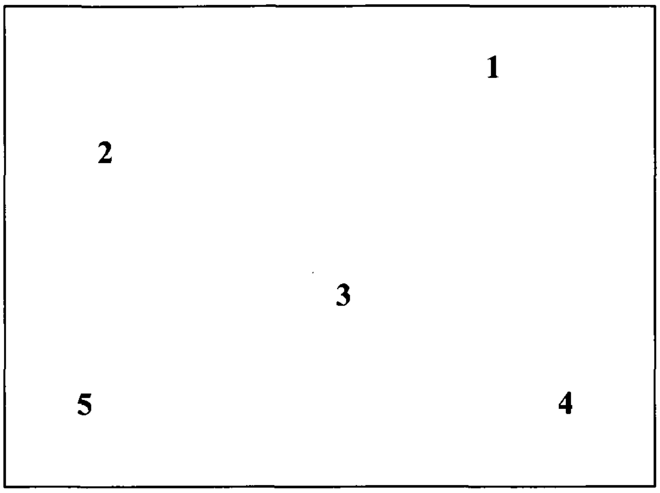


Figure 7: Possible camp sites

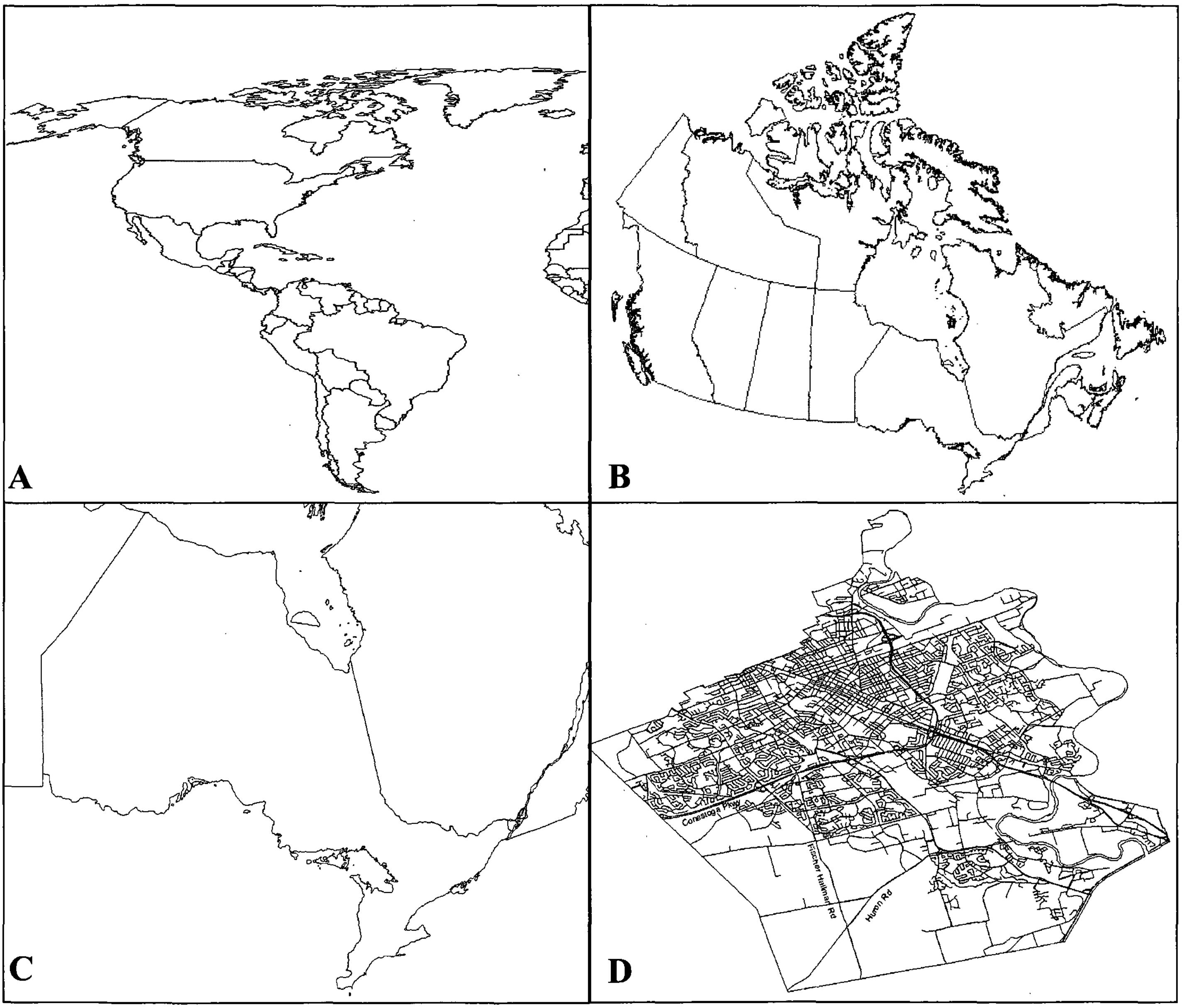
Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 5: In point form, please describe how you arrived at the answer above

Question 6

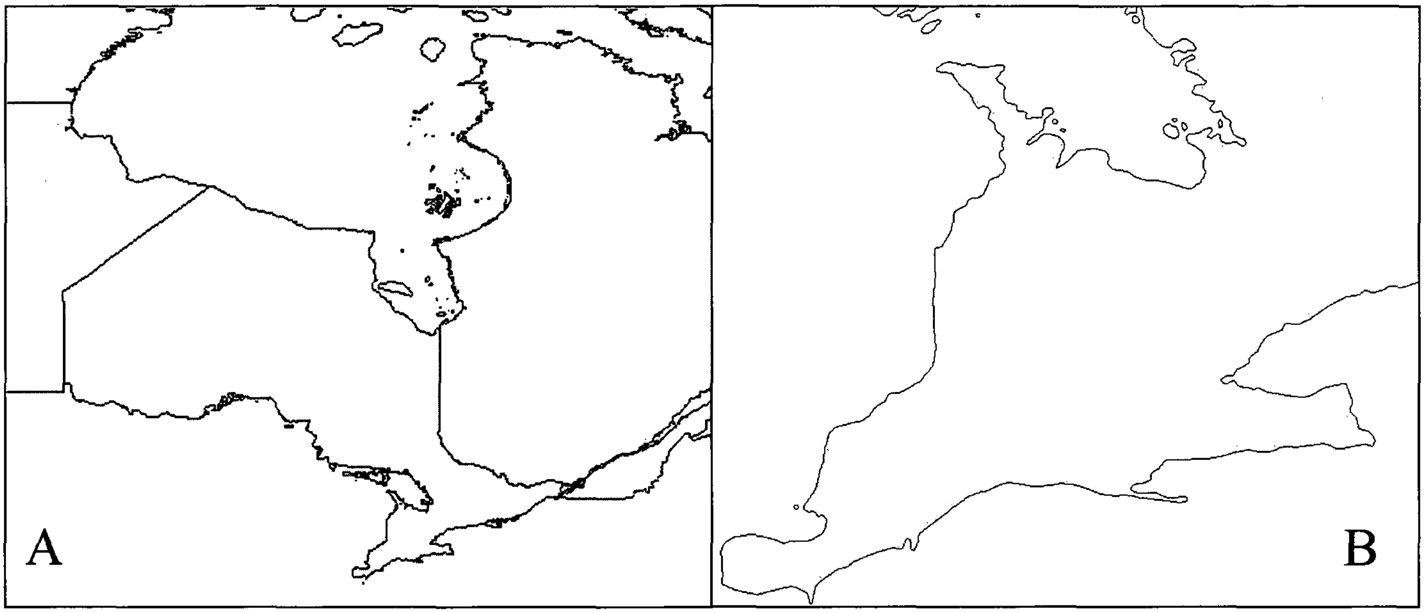
Task #1: Circle the diagram that represents a large-scale map:



Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task #2: Map A has a scale of 1: 20 000 000. Select a scale that would best describe Map B.



a) 1: 200

b) 1: 2 000

c) 1: 20 000

d) 1: 200 000

e) 1: 2 000 000

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Question 7

Task 1: The distribution of settlement areas in Kitchener, Ontario is displayed in Figure 8 below.

From the terms shown below, identify *five (5)* that best describe the spatial pattern of residences (Figure 8).

Above	Below	Distributed	Over
Along	Beside	Down	Parallel
Among	Bottom	Far	Patterned
Apart	Buffer	Inside	Peripheral
Area	Centre	Intersect	Proximal
Around	Classify	Isolated	Random
Arrangement	Clustered	Linked	Tangent
Aspect	Connected	Network	Top
Away	Contour	Next	Towards
Bearing	Coordinates	Node	Under
Behind	Direction	Outside	Up

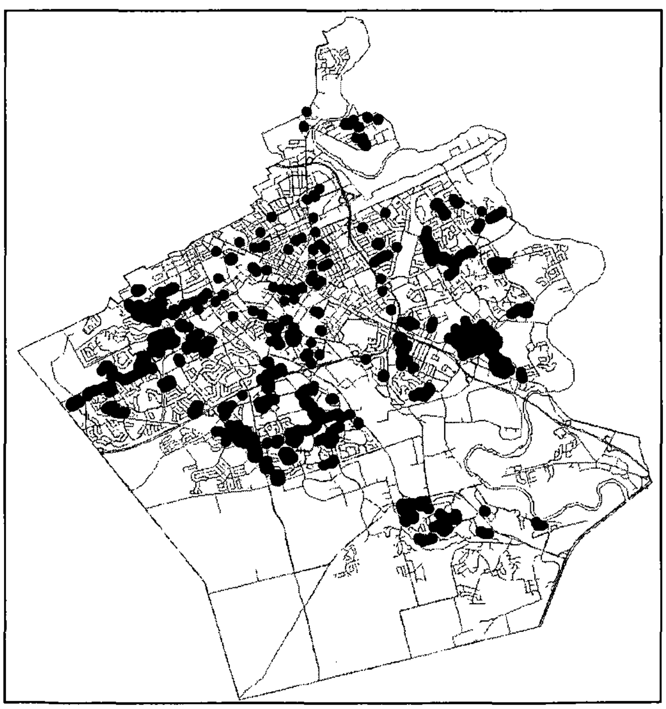


Figure 8: Settlement Areas

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Question 8

Real world objects can be represented in a computer by a point, a line (arc) and an area (polygon). Representative examples of these shapes are demonstrated below.

Examples

Point: used to define a particular location in space.		A point represents anything that occupies a fixed location (x, y) such as: a tree, a mining site etc.
Arc or line: used to define a length that is straight or curved, connected by points.		A line represents anything that occupies space with a length (but no width) such as: road, river etc.
Polygon: used to define a closed area formed by a line(s) and points.		A polygon represents an area such as: pond, city, country.

Based on the idea of point, line and polygon, answer the following questions.

Task 1: Figure 9a best represents this type of object:

a) Lakes b) Roads c) Houses d) Insects f) Neighbourhoods

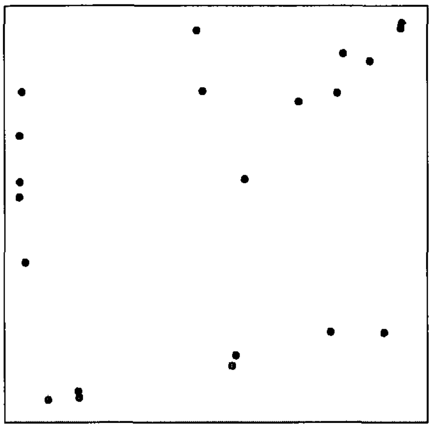


Figure 9a

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 2: Figure 9b best represents this type of object:

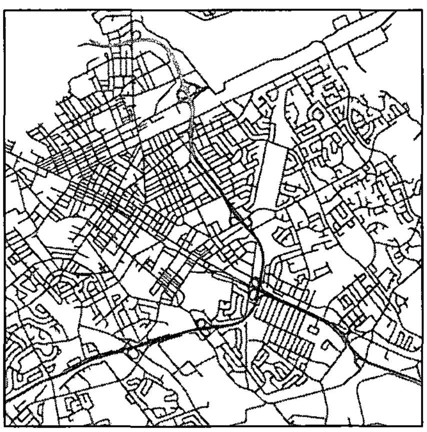


Figure 9b

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

a) Lakes b) Roads c) Houses d) Insects f) Neighbourhoods

Task 3: Figure 9c best represents this type of object:

Figure 9c

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

a) Lakes   b) Roads   c) Houses   d) Insects   e) Neighbourhoods

Answer the next three questions by referring to Figure 10A-E below.

Task 4: Identify the diagram that best represents schools () that are completely within a neighbourhood.

a) A b) B c) C d) D e) E

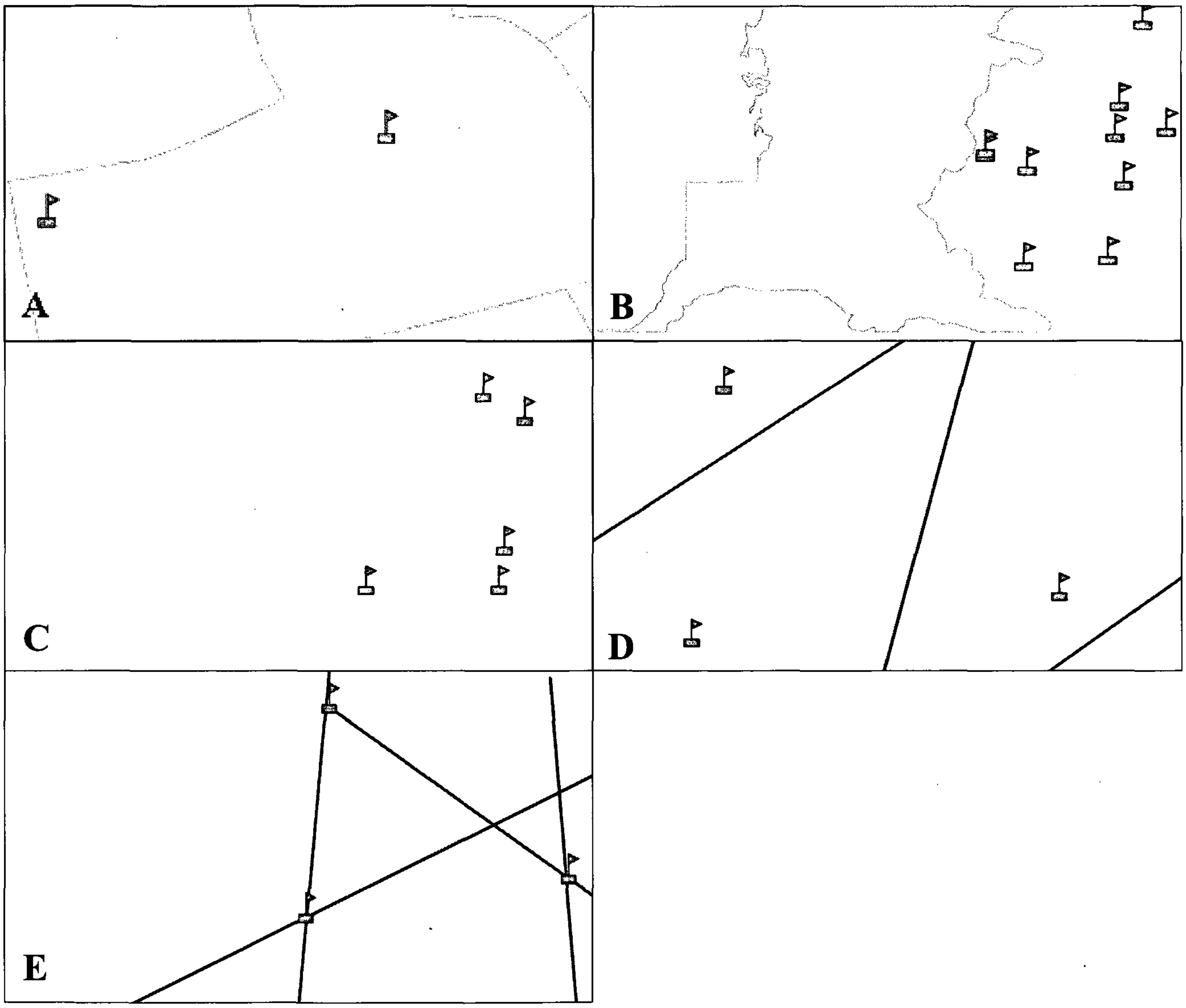


Figure 10A-E

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 5: Identify the diagram that best represents the intersection of roads and schools:

a) A b) B c) C d) D e) E

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 6: Identify the diagram that best represents schools which are within a distance of a park:

a) A b) B c) C d) D e) E

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 7: You are looking for campsites that are found:

1. **in a provincial park** ***and***
2. **close to lakes** ***and***
3. **close to wetlands**

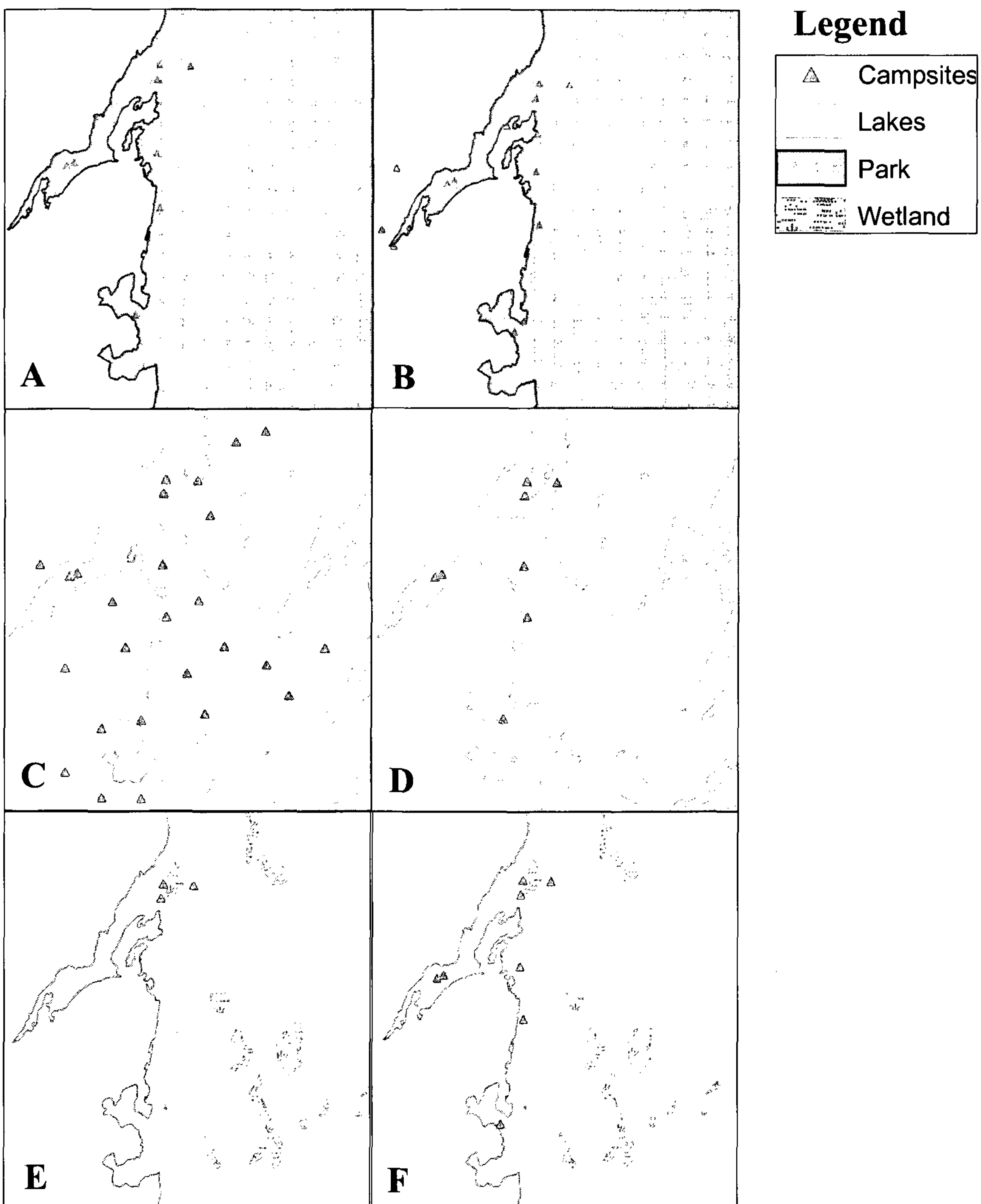
Select from each pair of diagrams the sequence that would best solve the task.

a) A, C, E b) B, C, F c) A, D, F d) A, D, E e) B, D, E

Pair 1

Pair 2

Pair 3



Degree of confidence in answer

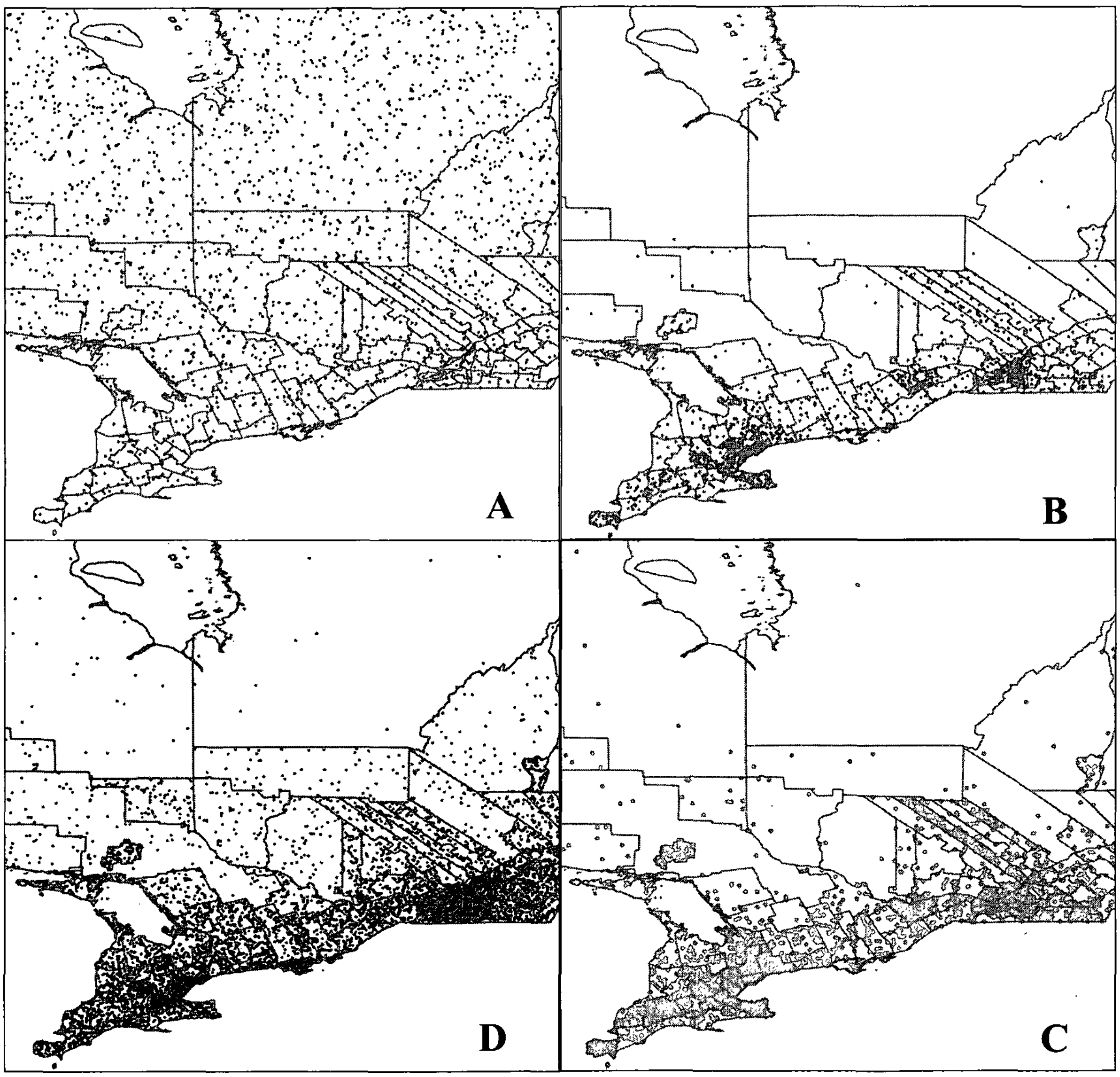
i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 8: In point form, please describe how you arrived at the answer in Task 7 above.

Question 9

Task 1:

Identify the two maps that have a strong positive spatial correlation (i.e. exhibit similar patterns).



a) A & B   b) D & B   c) C & B   d) D &C   e) A & C

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Question 10

Task 1:

Select the correct pair of latitude and longitude reading:

a) 100° 25' N, 160° 50' W   b) 72° 50' N, 65° 30' S   c) 17° 25' S, 200° 45' W

d) 23° 45' S, 61° 30' W   e) 158° 45' E, 125° 30' W

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 2:

The city of Kitchener is located at coordinates 43° 26' N, 80° 30' W. You travel directly south from Kitchener to Panama City. What latitude are you located at in Panama City?

a) parallel to 80° 30' W   b) perpendicular to 43° 26' N   c) parallel to 43° 26' N

d) 43° 26' N   e) 80° 30' W

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

Task 3:

Select the coordinate pair that best locates the 'City' in Figure 11 below.

a) 51° 50' E, 36° 10' N b) 36° 10' N, 51° 50' E c) 35° 0' N, 50° 0' E

d) 51° 50' W, 36° 10' S e) 36° 10' S, 51° 50' W

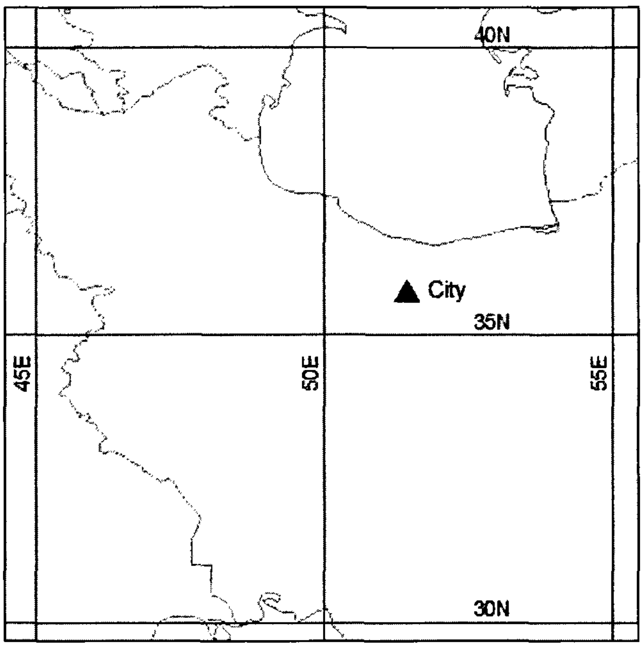


Figure 11

Degree of confidence in answer

i) Very sure
ii) Somewhat sure
iii) Not very sure
iv) Not sure at all

APPENDIX 2: Computer affection scale

Student name: ______________________ **Gender**: ______________

Age: ________________

This is not a test. There are no right or wrong answers. Please read carefully the questions below. Place an **'X'** in the box that best describes your opinion. Check only **ONE** box for each statement. Your answers will only be seen by the researchers.

Item	**Statement on attitude to computers**	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
1	I am comfortable using a computer	☐	☐	☐	☐	☐
2	Computer is something you have to use for school even though it is not enjoyable	☐	☐	☐	☐	☐
3	I like experimenting with new computer software	☐	☐	☐	☐	☐
4	While on a computer, I worry that I may do something wrong (e.g. push the wrong buttons, insert wrong commands) that will foul up the computer program	☐	☐	☐	☐	☐
5	When I have a problem with my computer, I use trial and error to try and fix the problem myself	☐	☐	☐	☐	☐
6	Computers make me nervous	☐	☐	☐	☐	☐
7	I like experimenting with new computer hardware	☐	☐	☐	☐	☐
8	I seek assistance when I need to fix a problem with my computer	☐	☐	☐	☐	☐

APPENDIX 2: Computer affection scale

This is not a test. There are no right or wrong answers. Please read carefully the questions below. Place an **'X'** in the box that best describes your opinion. Check only **ONE** box for each statement. Your answers will only be seen by the researchers.

Item	**Statement on attitude to computers**	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
9	I wish I had more chances to use computers in school	☐	☐	☐	☐	☐
10	I find computers fun to use	☐	☐	☐	☐	☐
11	I have a growing appreciation of computers through understanding its values, applications and processes	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐
12	When I get new software, I prefer to have someone else install it on my computer	☐	☐	☐	☐	☐
13	I like computers because it presents me with a way to organize, present and produce work	☐	☐	☐	☐	☐
14	I think computers help improve my ability to do good work in school	☐	☐	☐	☐	☐

APPENDIX 3: Geography affection scale

Student name: ______________________ **Gender**: ______________

Age: _________________

This is not a test. There are no right or wrong answers. Please read carefully the questions below. Place an '**X**' in the box that best describes your opinion. Check only **ONE** box for each statement. Your answers will only be seen by the researchers.

Item	**Statement on attitude to geography**	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
1	I feel geography is an important part of the school curriculum	☐	☐	☐	☐	☐
2	Geography thrills me and I like it better than any other subject	☐	☐	☐	☐	☐
3	Geography work is fun	☐	☐	☐	☐	☐
4	I can apply the geography we learn at school	☐	☐	☐	☐	☐
5	The wide application of geography gives me feelings of accomplishment	☐	☐	☐	☐	☐
6	I like geography because it helps me understand the world around me	☐	☐	☐	☐	☐
7	Looking at geographic data in different ways helps me to learn	☐	☐	☐	☐	☐
8	Using a map to study data helps me to learn	☐	☐	☐	☐	☐
9	Geography is an interesting subject	☐	☐	☐	☐	☐

APPENDIX 3: Geography affection scale

This is not a test. There are no right or wrong answers. Please read carefully the questions below. Place an **'X'** in the box that best describes your opinion. Check only **ONE** box for each statement. Your answers will only be seen by the researchers.

Item	**Statement on attitude to geography**	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
10	Explaining patterns in geographic data helps me to learn	☐	☐	☐	☐	☐
11	In geography, explaining why phenomena occur helps me to learn	☐	☐	☐	☐	☐
12	I like working on all types of geography problems	☐ ☐	☐ ☐	☐ ☐	☐ ☐	☐ ☐
13	I can analyze geographic data in many different ways	☐	☐	☐	☐	☐
14	I am capable of using a computer to display geographic data	☐	☐	☐	☐	☐
15	I am capable of asking questions to help focus my geographic investigation skills	☐	☐	☐	☐	☐
16	I can draw conclusions from geographic data	☐	☐	☐	☐	☐

APPENDIX 3: Geography affection scale

This is not a test. There are no right or wrong answers. Please read carefully the questions below. Place an **'X'** in the box that best describes your opinion. Check only **ONE** box for each statement. Your answers will only be seen by the researchers.

Item	**Statement on attitude to geography**	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
17	I am capable of using a map to analyze geographic data	☐	☐	☐	☐	☐
18	I am capable of asking new geographic questions from data that I have collected	☐	☐	☐	☐	☐
19	I can study data with the help of maps	☐	☐	☐	☐	☐
20	I like geography because it presents me with a challenge	☐	☐	☐	☐	☐
21	I have a growing appreciation of geography through understanding its values, applications and processes	☐	☐	☐	☐	☐

APPENDIX 4: Mathematics affection scale

Student name: ________________________ **Gender**: _______________

Age: __________________

This is not a test. There are no right or wrong answers. Please read carefully the questions below. Place an '**X**' in the box that best describes your opinion. Check only **ONE** box for each statement. Your answers will only be seen by the researchers.

Item	**Statement on attitude to Mathematics**	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
1	I feel mathematics is an important part of the school curriculum	☐	☐	☐	☐	☐
2	Mathematics is something you have to do in school even though it is not enjoyable	☐	☐	☐	☐	☐
3	Working with numbers is fun	☐	☐	☐	☐	☐
4	I do not like mathematics	☐	☐	☐	☐	☐
5	Mathematics thrills me and I like it better than any other subject	☐	☐	☐	☐	☐
6	I get no satisfaction from studying mathematics	☐	☐	☐	☐	☐
7	I like mathematics because the procedures are logical	☐	☐	☐	☐	☐
8	I am afraid of doing word problems	☐	☐	☐	☐	☐

APPENDIX 4: Mathematics affection scale

This is not a test. There are no right or wrong answers. Please read carefully the questions below. Place an **'X'** in the box that best describes your opinion. Check only **ONE** box for each statement. Your answers will only be seen by the researchers.

Item	**Statement on attitude to Mathematics**	**Strongly agree**	**Agree**	**Neither agree nor disagree**	**Disagree**	**Strongly disagree**
9	I like working on most types of mathematics problems	☐	☐	☐	☐	☐
10	I detest mathematics and avoid using it when possible	☐	☐	☐	☐	☐
11	I have a growing appreciation of mathematics through understanding its values, applications and processes	☐	☐	☐	☐	☐
12	I am completely indifferent to mathematics	☐	☐	☐	☐	☐
13	I like mathematics because it presents me with a challenge	☐	☐	☐	☐	☐
14	I like mathematics but I like other subjects just as well	☐	☐	☐	☐	☐
15	The completion and proof of an accurate mathematical answer give me satisfaction and feelings of accomplishment	☐	☐	☐	☐	☐